Energy Infrastructure Plan North Sea

Work Stream 3
Construction Forms of Energy Hubs

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Construction Forms of Energy Hubs

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Executive summary

The Dutch government has the ambition to realise a total offshore wind generation capacity of 21 GW in 2030, 50 GW in 2040 and 70 GW in 2050. To facilitate the transfer to shore of additional capacity potentially required between 2030 and 2040, the Dutch Government is exploring possibilities for the construction of an offshore energy hub, particularly in area 6 and 7 of the North Sea, known as the EIPN project Initial roll-out of infrastructure in search areas 6 and 7 is targeted from 2032.

The scope of work for Workstream 3 on construction forms of Energy Hubs includes providing the basis on which a decision can be made by government on the construction form of the energy hub. This report includes the full techno-economic evaluation of the energy hub concepts and a multi-criteria decision analysis as a method to guide government in selecting between the concepts. This report is an appendix to the overall advisory report made in collaboration with Deloitte, Norton Rose Fullbright and Common Futures.

Following engagement with and input of worksttream members (EZK, IenW, Gasunie, TenneT and EBN) – a decision funnelling process has been developed, by Mott MacDonald, based on the following key questions**:**

- Key Question 1 – Should a large island or multiple islands be constructed to support the area 6 and 7 energy hub including hydrogen production and HVDC equipment?
- Key Question 2 – Should the energy hub be facilitated by platforms or a combination of an island and platforms?
- Key Question 3 – Should hydrogen compression be centralised to a single location or decentralised throughout the search areas?
- Key Question 4 – Should centralised compression be located on platforms or an island?

Answering these key questions provides arguments which can guide the Dutch Government in decision making. Once these key questions are answered and the Dutch Government has made a decision, an energy hub concept can be developed by a selected contractor with ongoing input from government, HNO/TSO, developers, and other stakeholders. The role of the Dutch Government in the final development of the energy hub will be different depending on the energy hub design. There will be a number of go/no-go moments between the elaboration of the plan and the actual realization. urther design decisions to be made as the project progresses include:

- Selection of the hydrogen production concept (See Section 7).
- Selection of island design if selected (see Section 6.1.2).
- Selection of platform substructure (see Section 6.1.3).

Project Context

In this report, an energy hub in search area 6/7 is elaborated. The government will decide on the designation of this area in 2025. The aim is to indicate how many GW will fit into the area and which sub-area can be developed first. The available space is estimated at 22-28 GW. In this study we use the assumption of 24 GW. The areas are assumed to be parcelled up into wind blocks of approximately 2 GW wind generation capacity.

In the discussion with workstream 3 members, it was discussed that an energy hub concept of 24 GW with a 50:50 build out of HVDC capacity and offshore hydrogen production can be adopted for this study. This approach aims for the optimal ratio for a grid integrated hydrogen production hub, assuming that by the early 2030’s offshore wind generation meets a significant percentage of demand for onshore renewable electricity and therefore offshore hydrogen production will prevent curtailment during periods of high wind speed and contribute to meeting the Dutch Government's green hydrogen production targets for domestic use and regional international export. It is acknowledged that this roll-out of offshore hydrogen production capacity may be difficult to achieve and all constraints to this timeline should be identified and mitigated as far as possible. Should the overall energy hub capacity or the ratio of power export to hydrogen production vary this will not fundamentally change the decisions to be made to define the energy hub. This uncertainty does favour a more modular and scalable solution, which is already taken into consideration in the choises of the energy hubs construction form.

Concept Evaluation

To define the energy hub concept and guide government in decision making, a two-step concept evaluation process is selected:

Evaluation 1 – selection of energy hub infrastructure

Evaluation 1 defines the supporting infrastructure for the energy hub and compares the following concepts:

- Island based concept: All infrastructure including hydrogen production is installed on two large artificial islands.
- Platform based concept: All infrastructure is installed on platforms, with hydrogen production on either dedicated 500 MW platforms or local to the WTGs.
- Hybrid concept: A combination of platforms and one island.
  - The platforms will be installed first allowing longer to construct the island.

Depending on the infrastructure solution selected further decisions need be taken leading to the concepts assessed in Evaluation 2.

Evaluation 2 – Compression location selection

- Should compression be centralized or decentralized?

If centralized compression is desired, should it be placed on an island with 6 GW of HVDC equipment, on an island with hydrogen production and HVDC equipment or on platforms? If decentralized, it is assumed that this will be built on platforms due to the limited surface area required.These additional questions lead to the following concepts that will be evaluated in evaluation 2:

- Concept 1 - Two 12 GW artificial islands supporting all infrastructure (equivalent to the island concept in evaluation 1).
- Concept 2a – Platform-based concept with centralized compression on platforms (equivalent to the platform concept in evaluation 1).
- Concept 2b – Platform-based concept with decentralized compression on platforms).
- Concept 3 - Hybrid concept, with centralized compression and 6 GW HVDC installed on an island, 6 GW HVDC on platforms and 12 GW hydrogen production on platforms.

Illustrative layouts for each of the concepts are shown in section 6.4. These layouts indicate how each concept could be developed within areas 6 and 7 but do not represent an actual energy hub or the planned spatial layout. They are included for ease of visualisation and interpretation of what the different options may look like when discussing the evaluation of the differences.

The concepts in Evaluation 1 and 2 were evaluated using a multi-criteria decision analysis using the following criteria:

- Safety & Security
- Environment
- Economics
- Realisation & technical feasibility
- Operability & maintainability
- Future proofing

Results: Evaluation 1

The analysis carefully considered whether there are any hard constraints to the selection of either islands or platforms with a focus on the known challenges of large island construction in water depths up to 50m. The conclusion was that both islands and platforms are technically feasible and therefore their relative merits need to be assessed to determine the optimal concept. Overall, the analysis resulted in the platform concept being the preferred option based on the following arguments:

The analysis suggests that selecting only islands would make it very challenging to meet the target date for initial roll-out of direct power export and hydrogen production by 2032. An idealised schedule for island construction which considers no technical or other constraints to development achieves island-based first power export and hydrogen production in 2034 but given the novelty of island construction in the 50m water depths in areas 6 and 7 there is significant risk of this schedule slipping.The total installed capacity for offshore wind and the ratio between the landing of electricity and hydrogen is still uncertain.This is due to multiple factors which could impact the energy hub design such as changes in onshore demand, developments in technology, energy imports and blue hydrogen production. Given the uncertainties, the ability of a concept to adapt to changing conditions is key. Once an island has been designed then its area is fixed and whilst there is flexibility to alter the infrastructure constructed on it, its location cannot be changed, and neither can its size be increased easily. Platform concepts are inherently more flexible with modular designs that can be rolled-out in line with potential changing project requirements over time and adapted to changing hub design both in terms of concept and location. Overall platform-based concepts are considered significantly more adaptable than island-based concepts.

The environmental evaluation is based on an assessment of the CO_2 footprint, using Life Cycle Assessment (LCA) [1], and the potential impacts of hydrogen production (and associated waste streams) on the local ecology. The ecological impact of the construction is investigated separately by IenW, other environmental impacts are not included in the analysis. The LCA results indicate that the construction of an island has a significantly higher CO_2 footprint than the platform concept. This is mainly caused by the large amounts of sand and stone needed to develop the island. The ecological impact of hydrogen production is expected to be higher for the island concepts due to more concentrated disposal of waste streams. The impact of the waste streams is expected to be minimal due to the nature of the composition (mainly brine) and available mitigation measures. Moreover, the impact can easily be mitigated. Due to the impact of hydrogen production on both greenhouse gas emissions and local ecology, platforms can potentially be significantly more beneficial than islands from an environmental standpoint.

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[1] The Life Cycle Assessment (LCA) was conducted using a “cradle-to-practical completion” approach because it is anticipated that CO2 emissions during the utilisation phase will be minimum. Additionally, the decommissioning process is expected to occur around 2080, with no anticipated CO2 emissions during that phase.

For each of the concepts, cost estimates have been developed based on assumed configurations obtained through the NSWPH program. These CAPEX costs are estimated at 70.5 billion for islands and 75.5 billion for platforms for the entire 24 GW concepts excluding HVDC equipment. Due to the limited documents available in this phase (concept and feasibility studies), the cost estimates have a relatively high degree of uncertainty in the estimates (+/- 50% class 4/5 AACE estimate). Therefore, it is not possible to make a choice based on CAPEX at thismoment. Further elaboration of both concepts into a class 3/4 will give some improvement (+/- 30%), but this will require a significant amount of time and investment. Nor will this provide any certainty that a choice can be made based on CAPEX after these additional studies. Furthermore, the island concepts require greater upfront investments than platform-based concepts.

Because an energy hubs with island-only option does not seem to be feasible to achieving the intended timeline, a hybrid concept is a possible alternative. In this concept, the energy infrastructure will be installed on platforms between 2030 and 2035 and further on an island between 2035 and 2040. This provides potential benefits such as lower complexity and higher safety assurance in utilisation and maintenance. Also, an island has a longer expected lifespan than platforms. However, there remain significant risks in terms of construction complexity of islands in great water depths, material requirements, safety during construction, CO_2 footprint, delays, modularity, and costs for parallel development. In this analysis, all the pros and cons of a hybrid concept and platforms were considered, and a slight preference for the energy hubs in the form of platforms.

Results: Evaluation 2

Once the infrastructure supporting the energy hub has been selected consideration should be given to the selection between centralised and decentralised compression and whether centralised compression should be on an island.

The evaluation has shown that the platform concept with central compression (concept 2a) is preferred. Overall, the analysis has favoured centralized compression over decentralized compression, but the differences are limited. This preference is mainly due to the advantages in ease of use, scalability, time schedule and environmental impact. Chapters 6 and 8 of this report provide a full explanation of the differences between centralized and decentralized compression concepts.

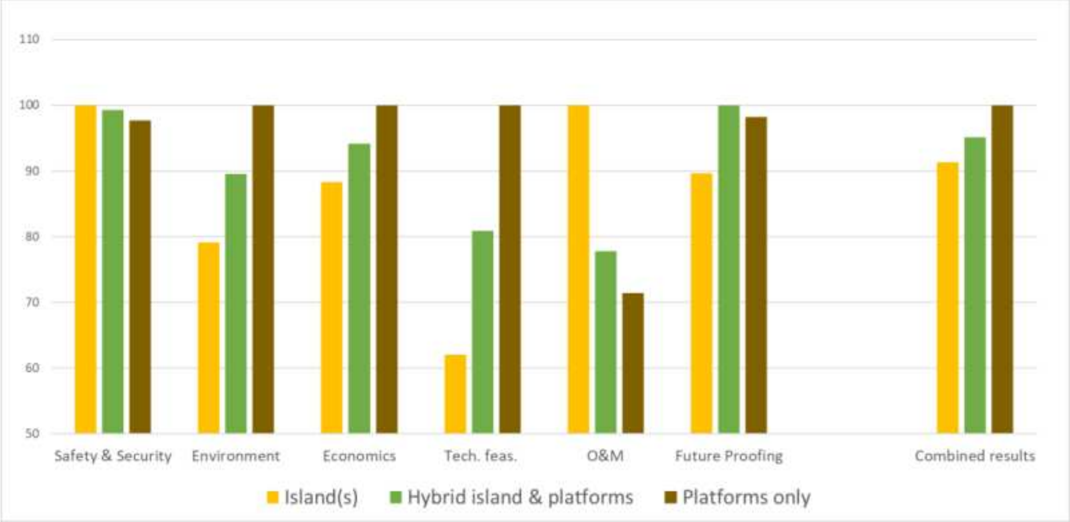
The selection of an island for centralized compression would probably only be made if there are technical limitations in the installation of compressors on platforms. The main concern is the impact of compressor vibrations on platforms. The work of the NSWPH program suggests that these risks can be mitigated, but further research is needed to confirm feasibility. These studies are planned by Gasunie and are expected to be completed by the end of 2024. Given the challenges of island building, several smaller decentralized compression platforms could be chosen as alternatives.

Results Summary

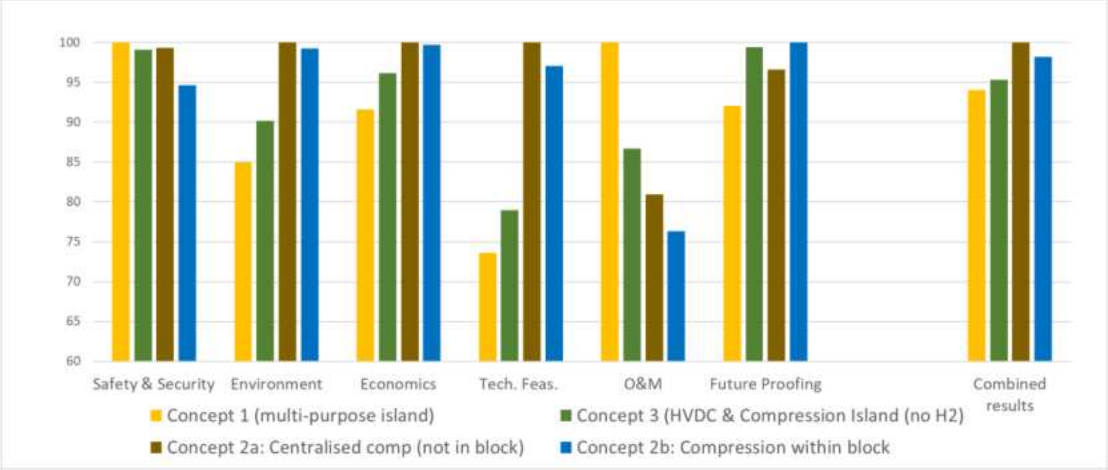
Due to the large number of considerations, with many conflicting advantages and disadvantages a systematic approach was adopted to rank the options being compared and aggregate the cumulative contributions to support the selection of a preferred option.

The relative ranking in preferences for the two evaluations is presented in the following charts in which the data has been represented on the basis that the highest values are most preferable. The data has also been normalised to 100 to standardise the visualisation of relative differences.

Evaluation 1: Normalised results evaluation 1, infrastructure of the energy hub



Evaluation 2: Normalised results evaluation 2, compression location



Both evaluations indicate that energy hubs on central compression platforms are preferable compared to island and hybrid concepts.

Decision Making Process

The selection of energy hub concept is a decision for government and this report is intended to provide the background information and analysis to support the decision-making process. Overall based on the assessment of workstream 3 platform-based concepts are favoured over islands in large part due to greater risks in island construction, greater need for pre-investment to realise island construction and due to the greater adaptability and lower environmental impact of platform-based concepts.

Furthermore, a comparison was made of decentralized and central compression. Of all the concepts that have been evaluated, the preferred option is concept 2a, an energy hub on platforms with central compression which contains the following components:

- High Voltage Direct Current Conversion (HVDC) on platforms
- Electrolysis on platforms (+/- 2 per 2 GW plot) and/or in hydrogen wind turbines

- Compression on centrally located platforms.

Within the (electrolysis) platform concepts, there is a choice between electrolysis platforms and hydrogen turbines. The choice between these two concepts can be made in consultation between the developer and the government and is not a choice that needs to be made at this time. It is expected that part of the electrolysis in area 6/7 will take place on platforms and part on hydrogen turbines. The development of hydrogen turbines to a high TRL will be taken up by market parties, in contrast to electrolysis platforms. Therefore, the advice for Dutch government is, to stimulate the development of these electrolysis platforms for search area 6 / 7, apart from Demo2.

The choice of the energy hubs construction form (platforms or islands) is a decision to be made by the Dutch government and this report is intended to provide background information and analysis to support the decision-making process.

Due to the time needed to develop either concept, it is advised to decide on the construction form of the energy hub and compression location in 2024. When it is decided that to not initiate of the development phase of an island (hybrid concept) in 2024, it will be implicitly decided to develop the entire area with platforms because the development of islands will then fall outside the realisation timeline. If it is desired to retain the different options, it is advised to start with the development phase of both island and platform concepts. This is essential for the development of areas 6 and 7 and the achievement of the NPE targets.

Managementsamenvatting

De Nederlandse regering heeft de ambitie voor een totale capaciteit van wind op zee van 21 GW in 2030, en ongeveer 50 GW in 2040 en 70 GW in 2050. Met het EIPN project onderzoekt de Nederlandse overheid de mogelijkheden voor energiehubs op zee om vooral in het zoekgebied 6 / 7 de extra capaciteit te faciliteren, die tussen 2030 en 2040 mogelijk wordt gerealiseerd. In 2032 is de eerste uitrol van infrastructuur in zoekgebieden 6 en 7 gepland.

Werkstroom 3 - Constructievorm van energiehubs omvat het leveren van de basis waarop de overheid een beslissing kan nemen over de constructievorm van de energiehub. Dit rapport omvat de volledige technisch-economische evaluatie van verschillende concepten voor de energiehub en een multi-criteria analyse om de overheid te begeleiden bij het maken van een keuze tussen de concepten. Dit rapport zal dienen als bijlage voor de overkoepelende adviesnotitie die zal worden ingediend in samenwerking met Deloitte, Norton Rose Fulbright en Common Futures.

Na overleg met en input van de belangrijkste werkstroomleden (EZK, IenW, Gasunie, TenneT en EBN) is door Mott MacDonald een afwegingskader ontwikkeld op basis van de volgende kernvragen**:**

- Kernvraag 1: Moet er één groot kunstmatig eiland of meerdere eilanden worden gebouwd ter ondersteuning van de energiehub in gebied 6/7, inclusief waterstofproductie en HVDC-apparatuur?
- Kernvraag2: Moet de energiehub worden gefaciliteerd door platforms of een combinatie van één eiland en platforms?
- Kernvraag 3: Moet waterstofcompressie worden gecentraliseerd op één locatie of gedecentraliseerd in de afzonderlijke kavels?
- Kernvraag 4: Moet gecentraliseerde compressie op platforms of op een eiland worden geplaatst?

De beantwoording van deze kernvragen levert argumenten voor het Rijk, op basis waarvan zij een beslissing kan nemen. Zodra deze belangrijke vragen zijn beantwoord en het Rijk hierover een beslissing heeft genomen, kan een hub concept worden ontwikkeld door een geselecteerde aannemer met voortdurende input van de overheid, HNO/TSO, ontwikkelaars en andere belanghebbenden. De rol van de overheid in de uiteindelijk te ontwikkelen energiehub zal verschillend zijn per constructievorm. Tussen de planuitwerking en de daadwerkelijke realisatie zal nog een aantal go/no-go momenten plaatsvinden. Verdere ontwerpbeslissingen die genomen moeten worden naarmate het project vordert zijn onder andere:

- Selectie van het waterstofproductieconcept (zie hoofdstuk 7).
- Selectie van eilandontwerp indien geselecteerd (zie paragraaf 6.1.2).
- Keuze van de onderconstructie (zie paragraaf 6.1.3).

Projectcontext

In dit rapport wordt een hub in zoekgebied 6/7 uitgewerkt. Het kabinet zal over de aanwijzing van dit gebied beslissen in 2025. Het streven is daarbij aan te geven hoeveel GW in het gebied zal passen en welk deelgebied het eerst is te ontwikkelen. De beschikbare ruimte is geschat op 22-28 GW. In deze studie wordt uitgegaan van 24 GW. De gebieden worden verondersteld te worden verkaveld in windblokken van ongeveer 2 GW windopwekkingscapaciteit.

In bespreking met leden van Werkstroom 3 - Constructievorm van energiehubs is besproken dat voor deze studie een energiehub concept van 24 GW met een 50:50 opbouw van HVDC-capaciteit en offshore waterstofproductie kan worden aangenomen. Deze benadering richt zich op de optimale integratie van een net geïntegreerde hub met waterstofproductie. Hierbij wordt ervan uitgegaan dat offshore wind begin 2030 aan een aanzienlijk percentage van de hernieuwbare elektriciteitsvraag zal voldoen. Vanaf dan zullen er naar verwachting meer perioden met veel wind en zon zijn waarin de elektriciteitsproductie groter is dan de vraag. Offshore waterstofproductie zal dan nodig zijn als conversiemethode om piekbelastingen te vermijden. Dit zal bijdragen aan de doelstellingen van de Nederlandse overheid voor groene waterstofproductie voor binnenlands gebruik en regionale internationale export. Deze uitrol van offshore waterstofproductiecapaciteit kan lastig te realiseren zijn en alle bedreigingen voor de planning moeten onderzocht worden, om deze zoveel mogelijk te beperken. Mocht de totale capaciteit van de energiehub, of de verhouding tussen de export van elektronen en waterstof variëren, dan zal dit de beslissingen die genomen moeten worden om de energiehub te definiëren niet fundamenteel veranderen. De onzekerheid vraagt echter wel om een meer modulaire en schaalbare oplossing en dit is in acht genomen in de keuze voor een energiehub constructievorm.

Evaluatie en concepten

Om het concept van de energiehub te definiëren en de overheid te begeleiden bij de besluitvorming, is gekozen voor een conceptbeoordelingsproces in twee stappen:

Evaluatie 1 - Selectie van de constructievorm voor de energiehub

Evaluatie 1 definieert de constructievorm van de energiehub en vergelijkt de volgende concepten:

- Eilandconcept: Alle infrastructuur, inclusief waterstofproductie, wordt geïnstalleerd op twee kunstmatige eilanden.
- Platformconcept: Alle infrastructuur wordt geïnstalleerd op platforms, met waterstofproductie op speciale 500 MW-platforms of op waterstofturbines.
- Hybride concept: Een combinatie van platforms en één eiland.
  - De platforms worden eerst geïnstalleerd, zodat er meer tijd is om het eiland aan te leggen.

Afhankelijk van de gekozen oplossing voor de hub zijn verdere beslissingen nodig over de concepten in de 2e evaluatie.

Evaluatie 2 - selectie van compressie locatie

- Moet compressie gecentraliseerd of gedecentraliseerd zijn?
- Indien gecentraliseerde compressie gewenst is, moet dit worden geplaatst op een eiland met 6 GW HVDC-apparatuur op een eiland, op een eiland met waterstofproductie en HVDC apparatuur of op platformen? Indien decentraal wordt er aangenomen dat dit zal worden gebouwd op platformen door het beperkte oppervlakte wat benodigd is.

Deze aanvullende vragen leiden tot de volgende concepten die geëvalueerd worden in evaluatie 2:

- Concept 1 - Twee 12 GW kunstmatige eilanden die alle infrastructuur ondersteunen (gelijkwaardig aan het eilandconcept in evaluatie 1).
- Concept 2a – Platform gebaseerd concept met gecentraliseerde compressie op platforms (gelijkwaardig aan het platformconcept in evaluatie 1).
- Concept 2b – Platform gebaseerd concept met gedecentraliseerde compressie op platforms).
- Concept 3 - Hybride concept, met gecentraliseerde compressie en 6 GW HVDC geïnstalleerd op een eiland, 6 GW HVDC op platforms en 12 GW waterstofproductie op platforms.

Illustratieve lay-outs voor elk van de concepten worden getoond in paragraaf 6.4. Deze lay-outs geven aan hoe elk concept ontwikkeld zou kunnen worden binnen de gebieden 6 / 7, maar zijn geen weergave van een daadwerkelijke energiehub of de geplande ruimtelijke indeling. Ze zijn opgenomen om het visualiseren en interpreteren van hoe de verschillende opties eruit kunnen zien te vergemakkelijken bij het bespreken van de evaluatie van de verschillen.

De concepten worden in evaluatie 1 en 2 geëvalueerd met behulp van een analyse op basis van meerdere criteria:

- Veiligheid
- Milieu
- Economie
- Realisatie & technische haalbaarheid
- Gebruik & onderhoud
- Toekomstbestendigheid

Resultaten: Evaluatie 1

In de analyse is zorgvuldig gekeken of er harde beperkingen zijn voor de keuze van eilanden of platforms, met de nadruk op de bekende uitdagingen van de bouw van grote eilanden in waterdieptes tot 50m. De conclusie is dat zowel eilanden als platforms haalbaar zijn en dat daarom hun relatieve voor- en nadelen moeten worden beoordeeld om het optimale concept te bepalen. In het algemeen leidt de analyse ertoe dat het platformconcept de voorkeursoptie is op basis van de volgende argumenten:

De analyse laat zien dat het selecteren van alleen eilanden het moeilijk zou maken om de streefdatum voor de eerste uitrol van directe export van energie en waterstofproductie in 2032 te halen. Een ideaal schema voor het bouwen van eilanden, waarbij geen rekening wordt gehouden met technische of andere beperkingen voor de ontwikkeling, bereikt de eerste export van energie en de productie van waterstof op basis van eilanden in 2034. Gezien de noviteit van het bouwen van eilanden in 50 meter waterdiepte in gebieden 6 / 7 zijn er aanzienlijke risico's op vertragingen.

De totaal geïnstalleerde capaciteit wind op zee en verhouding tussen het aanlanden van elektriciteit of waterstof is nog onzeker. Dit komt door meerdere factoren die van invloed kunnen zijn op het ontwerp van de energiehub. Dit kan zijn de fluctuatie in de vraag voor energie op het land, ontwikkelingen in de techniek, energie-import en blauwe waterstofproductie. Gezien de onzekerheden is het belangrijk dat een concept zich kan aanpassen aan veranderende omstandigheden. Hoewel er enige flexibiliteit is om de op het eiland aangelegde infrastructuur te wijzigen, is dit gelimiteerd doordat er specifieke locaties vooraf zijn aangewezen voor kabels en pijpleidingen. Verder staat de locatie en de omvang van een eiland vast en kan dit niet gewijzigd worden. Platformconcepten zijn flexibeler met modulaire ontwerpen die kunnen worden uitgerold in lijn met mogelijk veranderende projecteisen, zowel qua concept als qua locatie. Over het algemeen worden platformconcepten beschouwd als aanzienlijk flexibeler dan eilandconcepten.

De milieu-evaluatie is gebaseerd op een beoordeling van de CO_2 voetafdruk met behulp van levenscyclusanalyse (LCA)[2] en de mogelijke effecten van waterstofproductie (en bijbehorende afvalstromen) op de lokale ecologie. De ecologie impact van de bouw wordt separaat door IenW onderzocht en overige milieu impact is niet opgenomen in de analyse. De LCA-resultaten geven aan dat de bouw van een eiland een aanzienlijk hogere CO_2 voetafdruk heeft dan het platformconcept. Dit wordt voornamelijk veroorzaakt door de grote hoeveelheden zand en steen die nodig zijn voor het eiland. De ecologische impact door waterstofproductie is naar verwachting

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[2] De LCA is uitgevoerd met een "cradle to practical completion" benadering omdat verwacht wordt dat de CO_2 uitstoot tijdens de gebruiksfase minimaal zal zijn. Ook zal de ontmanteling plaats vinden rond 2080 waarbij geen CO_2 uitstoot verwacht wordt.

hoger voor de eilandconcepten vanwege meer geconcentreerde afvoer van afvalstromen. De impact van de afvalstromen zal naar verwachting miniem zijn vanwege de aard van de samenstelling (voornamelijk pekel) en beschikbare mitigerende maatregelen. Bovendien kan de impact eenvoudig worden gemitigeerd. Vanwege de impact op zowel broeikasgasemissies als de lokale ecologie door waterstofproductie, kunnen platforms vanuit milieuoogpunt aanzienlijk gunstiger zijn dan eilanden.

Voor elk van de concepten zijn kostenramingen ontwikkeld op basis van veronderstelde configuraties die zijn verkregen via het NSWPH-programma. Deze CAPEX kosten zijn geschat op 70,5 miljard voor eilanden en 75,5 miljard voor platforms voor de gehele 24 GW concepten exclusief HVDC apparatuur. Door de gelimiteerde beschikbare documenten in deze fase (concept- en haalbaarheidsstudies) hebben de kostenramingen een relatief hoge mate van onzekerheid in de schattingen (+/- 50% klasse 4/5 AACE schatting). Daarom kan er op dit moment geen keuze gemaakt worden op basis van CAPEX. Het verder uitwerken van beide concepten tot een klasse 3/4 zal enige verbetering geven (+/- 30%), maar dit zal een significante hoeveelheid tijd & investering vereisen. Ook zal dit geen zekerheid geven dat na deze additionele studies wel een keuze gemaakt kan worden op basis van CAPEX. De eilandconcepten vragen om grotere voorinvesteringen dan concepten op basis van platforms.

Omdat een energiehub met alleen eilanden niet haalbaar lijkt te zijn voor het behalen van de beoogde tijdlijn is een hybride concept een mogelijk alternatief. In dit concept zal in de periode 2030 tot 2035 de energie infrastructuur op platforms worden geïnstalleerd en tussen 2035 tot 2040 op één eiland. Dit geeft mogelijke voordelen zoals een lagere complexiteit en hogere veiligheidswaarborging in gebruik en onderhoud. Ook heeft een eiland een langere verwachte levensduur dan platforms. Er blijven echter aanzienlijke risico's op gebied van bouwcomplexiteit van eilanden in grote waterdiepte, materiaalbehoefte, veiligheid tijdens bouw, CO_2 voetafdruk, vertragingen, modulariteit en kosten voor parallelle ontwikkeling. In deze analyse zijn alle voor en nadelen van een hybride concept en platforms overwogen en is er een lichte voorkeur gevonden voor een concept met platforms.

Resultaten: Evaluatie 2

Zodra de constructievorm van de energiehub is geselecteerd, is de volgende stap het kiezen tussen gecentraliseerde en gedecentraliseerde compressie en/of gecentraliseerde compressie op een eiland.

Uit de evaluatie is gebleken dat de voorkeur ligt bij het platform concept met centrale compressie (concept 2a). Over het geheel genomen heeft de analyse gecentraliseerde compressie verkozen boven gedecentraliseerde compressie, maar de verschillen zijn beperkt. Deze voorkeur komt voornamelijk door de voordelen in gebruiksgemak, de schaalbaarheid, het tijdsschema en de milieu-impact. In de hoofdstukken 6 en 8 wordt een volledige uitleg van de verschillen tussen gecentraliseerde en gedecentraliseerde compressieconcepten gegeven.

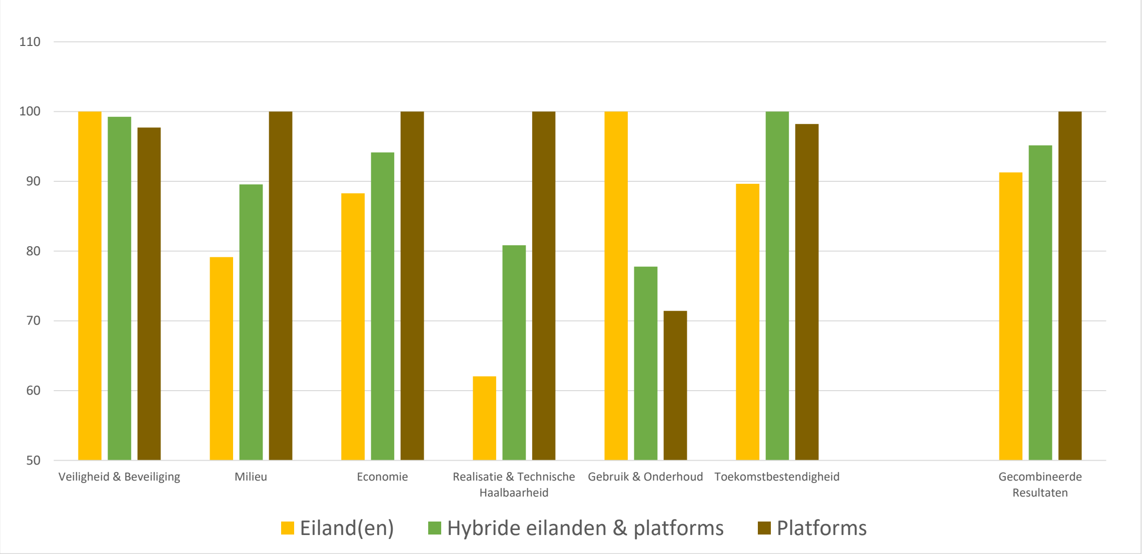
De keuze van een eiland voor gecentraliseerde compressie zou waarschijnlijk alleen worden gemaakt als er technische beperkingen zijn in de installatie van compressoren op platforms. De belangrijkste zorg is de impact van compressortrillingen op platforms. Het werk van het NSWPH-programma suggereert dat deze risico's kunnen worden beperkt, maar verder onderzoek is nodig om de haalbaarheid te bevestigen. Deze studies zijn gepland door Gasunie en zullen naar verwachting eind 2024 afgerond zijn. Gezien de uitdagingen van het bouwen van eilanden zouden meerdere kleinere decentrale compressieplatforms als alternatief kunnen worden gekozen.

Samenvatting resultaten

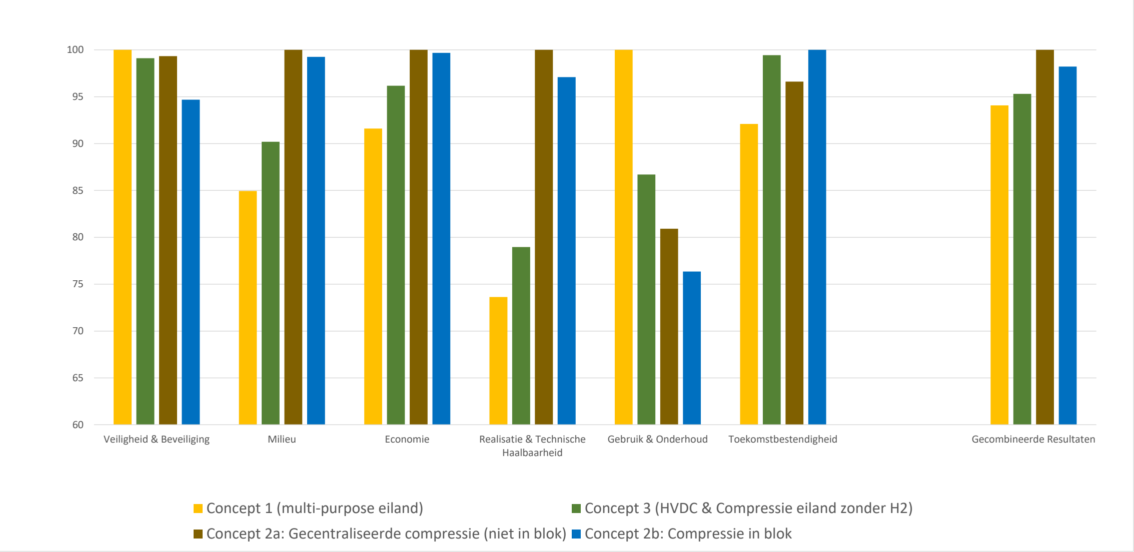
Vanwege het grote aantal overwegingen, met veel tegenstrijdige voor- en nadelen, is een systematische aanpak gekozen om de opties te rangschikken en de bijdragen samen te voegen voor de selectie van een voorkeursoptie.

De relatieve rangorde in voorkeuren voor de twee evaluaties wordt weergegeven in de volgende grafieken, waarin de gegevens zijn weergegeven op basis van het feit dat de hoogste waarde de voorkeur heeft. De gegevens zijn ook genormaliseerd naar 100 om de weergave van de relatieve verschillen te standaardiseren.

Evaluatie 1: Genormaliseerde resultaten evaluatie 1, constructievorm voor de energiehub



Evaluatie 2: Genormaliseerde resultaten evaluatie 2, compressie locatie



Beide evaluaties geven aan dat energiehubs op platforms met centrale compressie de voorkeur heeft in vergelijking met eiland- en hybride concepten.

Besluitvormingsproces

In het algemeen wordt door Mott MacDonald op basis van de beoordeling van Werkstroom 3 - Constructievorm van energiehubs de voorkeur gegeven aan energiehubs op platform concepten boven eilanden. Dit vanwege de grotere risico's bij de doorlooptijd van het ontwikkelen van een eiland in relatie tot de gestelde doelen, de grotere behoefte aan voorinvesteringen om de bouw van eilanden te realiseren en vanwege het grotere aanpassingsvermogen en de lagere milieueffecten van energiehubs op platform. Verder is een vergelijking gemaakt van decentrale en centrale compressie. Van alle concepten die geëvalueerd zijn ligt de voorkeur bij concept 2a, een energiehub op platformen met centrale compressie met de volgende onderdelen:

- Hoogspanningsgelijkstroom conversie (HVDC) op platformen
- Elektrolyse op platformen (+/- 2 per kavel van 2 GW) en / of in waterstofwindturbines
- Compressie op centraal geplaatste platformen.

Binnen de (elektrolyse) platform concepten is er een keuze tussen elektrolyse platformen en waterstofturbines. De keuze tussen deze twee concepten kan gemaakt worden in overleg tussen de ontwikkelaar en de overheid en is geen keuze die op dit moment gemaakt dient te worden. Naar verwachting zal een deel van de elektrolyse in gebied 6/7 op platforms plaats vinden en een deel op waterstofturbines. De ontwikkeling van waterstofturbines tot een hoog TRL zal door marktpartijen opgepakt worden, in tegenstelling tot de elektrolyse platformen. Het advies is daarom ook om los van Demo2 ook de ontwikkeling van deze elektrolyseplatforms voor zoekgebied 6 / 7 te stimuleren vanuit de overheid.

De keuze voor de constructievorm van de energiehub (platforms of eilanden) is een beslissing van de Nederlandse overheid en dit rapport is bedoeld om achtergrondinformatie en analyses te verschaffen ter ondersteuning van het besluitvormingsproces.

Vanwege de tijd die nodig is om een van beide concepten te ontwikkelen, wordt er geadviseerd om in 2024 een besluit te nemen over de energiehub constructievorm en compressie locatie. Indien er in 2024 niet gekozen wordt voor de initiatie van de ontwikkelingsfase van een eiland (hybride concept), wordt er impliciet gekozen om het gehele gebied met platformen te ontwikkelen omdat ontwikkelen van eilanden dan buiten de realisatietijdlijn zal vallen. Mocht het gewenst zijn om de optieruimte te behouden wordt geadviseerd om te starten met de ontwikkelingsfase van zowel een eiland als de platform concepten. Dit is van essentieel belang voor de ontwikkeling van gebieden 6 en 7 en het behalen van de NPE-streefdoelen.

1 Introduction & Scoping

Mott MacDonald (“MML”) has been subcontracted by Deloitte Financial Advisory B.V. (“Deloitte”) to contribute to Workstreams 2 and 3 of a European tender dated 18 January 2023 to provide advice for the Energy Infrastructure Plan for the North Sea up to 2050 (“EIPN”). The Dutch government Ministry of Economic Affairs and Climate (“EZK” or “Client”) is seeking to provide the Dutch government, future Hydrogen Network Operators (HNOs), Transmission System Operators (“TSOs”) and market parties with a guiding vision of what the future development and growth of the energy system in the North Sea may look like after 2030. This EIPN vision is focussed on the infrastructure needed for the continued rollout of offshore wind power between 2030 and 2050, the potential for offshore hydrogen production and scenarios for the reuse of existing gas infrastructure for hydrogen transportation to the mainland, the development of the interconnected electricity and hydrogen transmission infrastructure to both the Dutch mainland and other surrounding North Sea countries (and potentially to a network of offshore energy hubs). Consideration should be given to the phasing and timing of interrelated infrastructure over this time horizon. Furthermore, the EIPN is expected to provide insight into the necessary decision-making for this development plan taking role allocation, market organisation and legal instruments needs into account.

The EIPN study follows on from previous work done in 2022 by EZK to explore the development of energy hubs at sea, possible locations for them and the most suitable forms of construction. This work included contributions from the Ministry of Infrastructure and Water Management (“IenW”), which is responsible for spatial planning in the Dutch North Sea, TenneT and Gasunie. The results and insights from this work have been made available to us and are listed as reference documents in Section 1.3.

Similarly, the results from the various studies conducted under the umbrella of the North Sea Wind Power Hub (NSWPH), some of which MML was a participant of, have also been included.

Consideration is also given to related policy and planning work being developed by other initiatives including:

- The foreseen designation of new wind energy areas in the Partial Review of the North Sea Program 2022-2027 (commenced early 2023).
- Finding new landfall locations in the Program Connections Wind Energy At Sea 2031-2040 (pVAWOZ, commenced early 2023); in addition a second project has been commenced (PAWOZ) linked to landing wind in Eemshaven and therefore crossing the Wadden Sea, a UNESCO world heritage site.
- The National Energy System Plan (expected to be published at the end of June 2023).
- Concurrent assessment work by TenneT, Gasunie and EBN on the impact that an 'NL Energy hub' may have on their businesses.

The overall scope of the EIPN study is divided into the following four Workstreams:

- **Workstream 1** focuses on the strategic vision for the continued growth of the energy system in the North Sea after 2030 to 2050,
- **Workstream 2** supports the research into and decision-making process for whether to reuse current offshore gas infrastructure for an offshore hydrogen network.
- **Workstream 3** calls for the development of a decision-making framework to support the design concept selection (or 'proof of concept') of the first large-scale energy hub in search area 6 and 7 while taking safety, ecological and environmental factors into account.

- **Workstream 4** provides advice on the development of a market regulation framework to support the various components of the North Sea infrastructure development plan.

1.1 Scope of Work

This report is exclusively focused on Workstream 3. The scope of work is further defined in the tender document to include:

- The development of a decision-making funnelling process to facilitate the selection of a construction form of an energy hub. The Contractor analyses and synthesises relevant data to inform an assessment framework to facilitate the decision-making process.
- The Client has provided a rough-draft conceptual assessment framework based on public interests to help select a construction basis of a large-scale energy hub (ref. 4). The Contractor is required to finalise this assessment framework, based on its own proposals and in consultation with the Client and relevant stakeholders (making use of working groups and consultation sessions).
- The Contractor is also required to take safety and environmental factors into account by collecting relevant information related to:
  - Consideration will be given to the safety considerations related to working conditions and general safety requirements related to the handling and management of hydrogen during production, storage and transport on or near the energy hub. The Client anticipates that these considerations will have an impact on the selection of different construction forms (viz. platforms, artificial island, etc.). Safety aspects related to cybersecurity, sabotage vulnerability, etc., are excluded from our study as these will be addressed in parallel by the relevant state parties within the existing consultation structures for this purpose.
  - The Contractor is required to take the environmental impact of materials of construction of different construction forms into account by considering life cycle analysis (LCA) techniques.
  - The Contractor will incorporate the results of a quick-scan ecological impact assessment (“EcIA”) to be undertaken by an independent third-party on behalf of IenW during the first quarter of 2023. The Contractor is also expected to identify the potential ecological impact of hydrogen production, storage and transport at sea (including the waste flows from desalination) and incorporate this into its advice on the decision-making framework. As this assessment will now not be completed until the end of 2023 it will not be incorporated into workstream 3.

The client would like to have a ‘concrete design’ or 'proof of concept' of a first large-scale energy hub (LSEH) planned for construction in search area 6 and 7. By ‘proof on concept’ the Client would like an understanding of the technical design of an energy hub as well as a corresponding description of the division of roles between TSO, the Hydrogen Network Operator (“HNO”) and relevant market parties. The Client is looking for an integrated synthesis of how the stakeholders and policy instruments work together to enable a functional conceptual solution that can be supported by further elaboration of technical and regulatory matters with the view to ‘eventually commission the construction of energy hubs and the manufacturing of the equipment required for them’. We will describe our understanding of a typical Project Development Life Cycle (PDLC) based on best practice in the engineering industry and what steps would need to be in place to enable the specification of details for manufacturing and commissioning.

1.2 Scope Exclusions

We will not be developing a conceptual engineering proposal representing a ‘concrete design’ or 'proof of concept'. In our opinion, this is not possible yet, given the maturity of the design details. In Section 2.15.1 we described what we consider to be best practice related to the PDLC, in which we explain the level of engineering detailed required at each stage of a project’s development. We will, however, develop a concept proposal taking the limited amount of design information that is currently available into account. The development of this concept proposal will take multi-criteria decision-making considerations (in addition to any engineering data) into account.

To avoid potential confusion, our definition of these terms are as follows:

Concept proposal means: a proposal with sufficient scope definition to start a formal FEL-1 stage pre-feasibility study (for FEL stage definitions see Section 2.15.1).

Concept design or proof of concept means: a well-scoped design incorporating initial technical, financial and legal feasibility assessments that is ready to proceed to a FEL-3 stage FEED study in order to prepare a request for proposal (RFP) for an engineering, procurement and construction (EPC) contract.

We will not be creating an ecological impact assessment for the Hydrogen production and management infrastructure but will contribute relevant inputs into the parallel process to build on the EcIA quick scan, understood to be managed by IenW.

1.3 Document Reference List

Table 1.1 presents the sources of data that have been referenced in compiling this report.

Table 1.1: Summary of Workstream 3 Documentation

Ref #	Title	Description	Author(s)
1	Quickscan nieuwe zoekgebieden WOZ na 2030	The Netherlands Enterprise Agency has asked Deltares for a quick scan of potential wind farm search areas. This memo provides an overview of existing data to characterise the areas by bathymetry, morphodynamics, geology and hydrodynamics. A summary of the main characteristics of the seven wind farm search areas is provided.	Deltares
2	North Sea Summit II – Gas TSOs Declaration	In their joint statement on the North Sea Energy Cooperation (NSEC) and the NSEC-UK Memorandum of Understanding on offshore renewable energy cooperation, the NSEC member countries and the UK recognise their historic opportunity to accelerate the delivery of regional offshore renewable energy and are setting a framework for greater cooperation. TSOs Joint statement fully supporting the ambition stated by the participating countries of the North Sea Conference.	TSOs of Belgium (fluxys), Denmark, France, Germany, Ireland (Gas Networks Ireland), Norway, Netherlands, Denmark (Energinet) and the UK (national gas)
3	NL Energy Hub – Voorverkenning – Hoofboodschappen	NL Energy Hub Main Messages: Consolidation of key messages regarding the usefulness and necessity of (NL) Energy Hubs.	TenneT, Gasunie
4	Afwegingskader constructievormen	Proposed assessment framework between platforms and offshore islands	TenneT, Gasunie
5	Esbjerg declaration for prime ministers	Joint declaration to develop the North Sea as a Green Power Plant of Europe, an offshore renewable energy system connecting Belgium, Denmark, Germany and the Netherlands and possibly other North Sea partners,	Prime Ministers of Denmark and Belgium

Ref #	Title	Description	Author(s)
		including the members of the North Seas Energy Cooperation (NSEC)	
6	NL Energiehub – Voorverkenning naar nut en noodzaak van energiehubs op de Nederlandse Noordzee (2023)	Preliminary exploration into the usefulness and necessity of energy hubs on the Dutch North Sea.	TenneT, Gasunie
7	NSE-202-2022-1.1 Energy Hubs and Transport Infrastructure v2	Study is first attempt to design offshore energy system integration hubs in the Dutch Sector of the North Sea. Energy hubs as designed in this study (Hubs West, East and North) together contribute towards achieving approximately 34GW of Dutch offshore wind installed capacity by 2050. Offshore power to hydrogen platforms and islands as the building blocks to scale the installed wind capacity to 70GW by 2050 are conceptually described. Identification of North Sea Energy Hubs where system integration projects could be materialised and advanced. This includes system integration technologies strategically connecting infrastructures and services of electricity, hydrogen, natural gas, and CO_2. A fit for purpose strategy plan per hub and short-term development plan has been developed.	North Sea Energy (TNO, NEC and others). Project carried out with a subsidy from the Dutch Ministry of Economic Affairs and Climate
8	NSE-2020-2022-2.1 Standardisation	National, European, and international standards are pivotal for the offshore energy system. Standardisation is an important tool to cover aspects on safety, interoperability, and life-cycle analysis. The standardisation research question for NSE 4 is: What standardisation is still needed to govern multi-use offshore energy structures	Prepared by NEN and others, Checked by Rijks Universiteit Groningen (RUG) and TNO and Approved by TNO
9	NSE-2020-2022-3 Safety Integrity Reliability of offshore hydrogen production installations	Provides the work performed in the 3rd work package: Safety, Reliability, and Integrity: Further evaluation of safety concerns highlighted in previous phase (NSE3) HAZID. Highlights key points related to asset integrity and asset safety of key components of the hydrogen generation systems. Applies the gained knowledge in design iterations together with the platform design teamwork package 1 (WP1)	Prepare by TNO, Bureau Veritas and Total Energies, Checked by NEN and TNO and Approved by TNO.
10	NSE-2020-2022-4.1 Exploration study on ecological values in relation to North Sea energy system	The main aim of the report is to gain a better understanding of relevant ecological information of species and ecosystems in the North Sea to support decision-making for energy hub selection and choices between decommissioning, re-use or abandonment.	Prepared by Royal Haskoning DHV, Bureau Veritas and Total Energies and Checked by RoyalHaskoningDHV
11	NSE-2020-2022-4.2 Carbon footprint of offshore structures	Aim of the report is to quantify and compare the carbon footprint of offshore structures available for hydrogen production (4GW) and other energy hub functions. The following structures were included: jacket platform, sand island and hybrid island built of a sand island and floaters.	Prepared by TNO and Bureau Veritas and Total Energies, checked by NEC and Royal Haskoning DHV and Approved by TNO
12	NSWPH CBA 1.6 Final draft 22-12-2022	The study focusses on providing perspectives on the socio-economic impact from specific configurations of offshore hubs and spokes. The impact is estimated as the difference in total system costs. The evaluation of system costs includes impact on system dispatch, import of hydrogen, investments in electricity and hydrogen trade	NSWPH programme

Ref #	Title	Description	Author(s)
		capacities and investments in other flexibility measures (batteries, hydrogen turbines, electrolysers).	
13	Offshore Wind – Nodes 2050	Schematic indicating European offshore wind generation potential	ONDP
14	Ordeningsvragen energiehubs	Description of the market organisation associated with offshore wind energy	Not provided
15	IP2022 Netopland 12-9-2022	Investment plan Grid at sea 2022-31 describes TenneT's investments necessary over the next 10 years to open offshore wind farms as included in the Offshore Wind Energy Development Framework.	TenneT
16	IP2022 Netopzee 12-9-2022	Investment Plan Grid on Land 2022-2031 describes the need for investments in the network for the next 10 years	TenneT
17	Het elektriciteitsnet van de duurzame toekomst begint vandaag	Introduction to Target Grid includes key considerations in shaping the first version of the 2045 electricity grid – energy future in 2045 is shaped by the desire of Europe to be the first carbon neutral continent: the high-voltage grid at sea, on land with hubs and power highways between countries required to make the energy system and industry more sustainable.	TenneT
18	Memo mijnbouwactiviteiten	Memo indicating mining activities in wind search areas 6 and 7.	EBN
19	Technical Feasibility Report 424532-N-RP-0006	Main conclusions reached during the concept development phase, including key design decisions and associated design information for 4GW P2G Onshore and Offshore (Platforms) concept designs. A technical comparison is also provided between the two concepts.	NSWPH
20	Concept Design Report Offshore Structures 424532-N-RP-0007	Concept design report for the structural elements (topsides and substructure) of the offshore hydrogen production development.	NSWPH
21	Technical Feasibility Report 424532-N-RP-0009	Main conclusions reached during the concept development phase, including key design decisions and associated design information for 4GW P2G Offshore (Caisson Island) concept design. A technical comparison is also provided between the two offshore (platforms vs caisson island) concepts.	NSWPH
22	Technical Feasibility Report 424532-N-RP-0011	Main conclusions reached during the concept development phase, including key design decisions and associated design information for 5.34GW P2G Hydrogen Turbines concept design.	NSWPH
23	Infrastructure energy outlook	Together with TenneT, Gasunie has investigated how the dutch energy system will continue to function properly in the future. Existing electricity- and gas infrastructure in NL and DE are crucial to reach the Paris climate goals. (https://www.gasunie.nl/expertise/energiesysteem/infrastructure-outlook-2050)	Gasunie
24	Uitgangspuntennotitie	The context of pVAWOZ is provided in this document. It provides the building blocks and key points for the tracing and locations of transformer- and converter stations, landing stations for hydrogen and electrolysers.	pVAWOZ
25	Windpark "Ten noorden van de waddeneilanden" moet in 2031 offshore waterstof produceren	Article describing the development of the windpark and electrolysis planned for 'Ten Noorden van de Waddeneilanden" wind search area in the dutch North Sea. (https://energeia.nl/energeia-artikel/40106102/windpark-ten-noorden-van-de-waddeneilanden-moet-in-2031-offshore-waterstof-produceren)	Sluijters, S.; Energeia

Ref #	Title	Description	Author(s)
26	Werkstroom 1 adviesnotitie		
27	Het energiesysteem van de toekomst: de II3050-scenario's	The Dutch electricity net operators present four scenarios for the energy system in 2050. The four scenarios are: decentral initiatives (DEC), national leadership (NAT), european integration (EUR) and international trade (INT). (https://open.overheid.nl/documenten/ronl-7219ac2558977a6050ac4db764d2ddebb156df32/pdf)	Netbeheer Nederland
28	Programma Noordzee 2022-2027	The aim of the program is to find the right societal balance in the spatial development of the North Sea. (https://www.noordzeeloket.nl/beleid/programma-noordzee-2022-2027/)	Rijksoverheid
29	Kamerbrief over aanvullende routekaart windenergie op zee 2030	Letter from the minister of EZK, providing insights in the vision of the government on hydrogen policy.	Jetten, R.A.A.; EZK
30	Dutch offshore Wind Guide	Guide to Dutch offshore wind policy, technologies and innovations. (https://www.rvo.nl/sites/default/files/2021/10/Dutch%20Offshore%20Wind%20Guide%202022.pdf)	RVO
31	Gasunie Onderzoekt waterstofnetwerk op Noordzee	Article which describes the aim of Gasunie to develop an offshore hydrogen network. (https://www.gasunie.nl/nieuws/gasunie-onderzoekt-waterstofnetwerk-op-noordzee)	Gasunie
32	Porthos en Aramis: de grootste CCS-projecten in Nederland	Article describing the two largest CCS projects in the Netherlands; Porthos and Aramis. The goal is to transport CO_2 from the port of Rotterdam to empty gas fields in the North Sea. (https://www.onsaardgas.nl/porthos-aramis/)	Onsaardags.nl
33	History of EBN	Article describing the history of Energie Beheer Nederland (EBN) (https://www.ebn.nl/en/about-ebn/history/)	EBN
34	Danish Government Postpones Tender for North Sea Energy Island, Current Concept Found to be Too Expensive	Article describing the postponement of the tender for the Danish energy island. The current concept for the island was too expensive, according to the Danish Government. (https://www.offshorewind.biz/2023/06/28/danish-government-postpones-tender-for-north-sea-energy-island-current-concept-found-to-be-too-expensive/)	Buljan, A., offshorewind.biz
35	Princess Elisabeth Island	Webpage describing the development of the Princess Elisabeth Island in the Belgian North Sea, connecting wind farms with the mainland and neighbouring countries. (https://www.elia.be/en/infrastructure-and-projects/infrastructure-projects/princess-elisabeth-island)	Elia Group
36	Offshore hydrogen transportation through re-used natural gas pipeline on the North Sea	Article on the granted Certificate of fitness for the transport of green hydrogen through existing pipelines at sea from Bureau Veritas Inspectie & Certificering. (https://noordgastransport.nl/offshore-hydrogen-transportation-through-re-used-natural-gas-pipeline-on-the-north-sea/)	Noordgastransport (NGT)
37	EIPN werkstroom 2		
38	18R-97: Cost Estimate Classification	Guidelines for applying the general principles of estimate classification to project cost estimates.	AACE inc.

Ref #	Title	Description	Author(s)
	System - As Applied in Engineering, Procurement, and Construction for the Process Industries	(https://www.costengineering.eu)	
39	Additional Offshore Wind Energy Roadmap 2030	Letter from the minister of EZK, describing which new wind farm zones will be subject to development and when. Furthermore, it describes the awarding of the construction contract of the offshore grid to TenneT. (https://english.rvo.nl/sites/default/files/2022/07/WOZ-210622022062-Letter-Additional-Offshore-Wind%20Energy-Roadmap-2030.pdf)	Jetten, R.A.A.; EZK
40	The 2GW Program	Article describing a new standardized platform with a new certified cable system and a higher transmission capacity, capable of transporting 2GW of power. (https://www.TenneT.eu/about-TenneT/innovations/2gw-program)	TenneT
41	Digital tools for life-cycle assessment	PhD project on a parametric and machine learning-based approach to implement life-cycle assessment in the early design stages. (https://www.udk-berlin.de/studium/architektur/fachgebiete/konstruktives-entwerfen-und-tragwerksplanung/forschung/a-holistic-and-parametric-approach-for-lca-in-the-early-design-stages/)	Universität der Künste Berlin
42	Life cycle assessment of onshore and offshore wind energy – from theory to application	Article from 2016, published in Applied Energy, on the life cycle assessment of onshore and offshore wind energy. (DOI: 10.1016/j.apenergy.2016.07.058)	Bonou et al.
43	Life cycle assessment of hydrogen from proton exchange membrane waterelectrolysis in future energy systems	Article from 2019, published in Applied Energy, on the life cycle assessment of hydrogen from proton exchange membrane waterelectrolysis in future energy systems. (DOI:10.1016/j.apenergy.2019.01.001)	Bareiβ et al.
44	HVDC Circuit Breakers	Webpage describing the basics of HVDC circuit breakers (https://www.entsoe.eu/Technopedia/techsheets/hvdc-circuit-breakers)	entsoe
45	Enrichment Session with Bureau Veritas	Minutes of the Meeting	Mott MacDonald and Bureau Veritas
46	Enrichment Session with IenW	Minutes of the Meeting	Deloitte, Mott MacDonald, IenW
47	Workshop with Gasunie and TenneT	Minutes of the Meeting	Deloitte, Mott MacDonald, Gasunie and TenneT
48	Enrichment Session with EZK and RVO	Minutes of the Meeting	Deloitte, Mott MacDonald, EZK, RVO
49	Enrichment Session with TNO - North Sea Energy	Minutes of the Meeting	Deloitte, Mott MacDonald, TNO
50	Knowledge sharing session - Action Agenda	Minutes of the Meeting	Deloitte, Mott MacDonald, Common Futures, Norton Rose Fulbright

Ref #	Title	Description	Author(s)
51	WS 3 workshop	Minutes of the Meeting	Mott MacDonald, EZK, Deloitte, EBN, TenneT, IenW, Deloitte, Gasunie
52	WS 3 workshop	Minutes of the Meeting	Mott MacDonald, EZK, Deloitte, EBN, TenneT, IenW, Deloitte, Gasunie
53	WS 3 workshop	Minutes of the Meeting	Mott MacDonald, EZK, Deloitte, EBN, TenneT, IenW, Deloitte, Gasunie
54	WS 3 workshop	Minutes of the Meeting	Mott MacDonald, EZK, Deloitte, EBN, TenneT, IenW, Deloitte, Gasunie
55	SSEN Transmission gets to work on HVDC Switching Station in Caithness	Article describing the start of the construction of the HVDC switching station in Caithness. (https://www.ssen-transmission.co.uk/news/news--views/2020/11/ssen-transmission-gets-to-work-on-hvdc-switching-station-in-caithness/#:~:text=%E2%80%9CThe%20Caithness%20Switching%20station%20is%20a%20key%20component,in%20facilitating%20the%20transition%20to%20net%20zero%20emissions.)	Scottish & Southern Electricity Networks
56	Haalbaarheidsstudie offshore ondergrondse waterstofopslag	Feasibility study for offshore underground hydrogen storage from 2022	TNO and EBN

1.4 List of Abbreviations and Acronyms

Abbreviation	Description
AACE	American Association of Cost Engineering
AC	Alternating Current
AIS	Air-Insulated Substation
ASL	Above mean Sea Level
BEP	Best Efficiency Point
BFD	Block Flow Diagram
BoP	Balance of Plant
CBA	Cost Benefit Analysis
CC(U)S	Carbon Capture (Utilization) and Storage
DC	Direct Current
DE	Germany
DP	Design Pressure
DK	Denmark
DMNC	Deloitte, Mott MacDonald, Norton Rose Fulbright and Common Futures
EBN	Energie Beheer Nederland
EcIA/EIA	Ecological Impact Assessment
EDI	ElectroDeIonisation
EIA	Environmental Impact Assessments
EIPN	Energy Infrastructure Plan North Sea 2050
EOL	End of Life
EPC contract	Engineering, Procurement and Construction contract
EZK/MEAC	Ministry of Economic Affairs and Climate
FEED	Front End Engineering Design
FEL	Front-End Loading
FID	Final Investment Decision
GBF	Gravity Base Foundation
GHG	Greenhouse Gas
GIS	Gas-Insulated Substation
GW	Gigawatt
GW WTG	Wind turbine generation equivalent (i.e. ignoring losses)
HAZID	Hazard Identification Study
HAZOP	Hazard and Operability study
HNO	Hydrogen Network Operator
HP	High Pressure
HV	High Voltage
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
H_2	Hydrogen
IA	Inter-Array
ICCP	Induced Current Corrosion Protection
IDON	Interdepartmental Directors Consultation North Sea
IGBT	Insulated-Gate Bipolar Transistor
IenW / MIWM	Ministry of Infrastructure and Water Management

Abbreviation	Description
KNMI	Royal Netherland Meteorological Institute
LCA	Life Cycle Analysis
LCOH	Levelised Cost Of Hydrogen
LP	Low Pressure
LSEH	Large-Scale Energy Hub
LV	Low Voltage
MAOP	Maximum Allowable Operating Pressure
MCDA	Multi Criteria Decision Analysis
MED	Multi-Effect Distillation
MML	Mott Macdonald BV
MTO	Material Take-Offs
MW	Megawatt
NAT	National Leadership / Nationaal Leiderschap
NGO	Non-Governmental Organization
NGT	Noordgastransport B.V.
NL	Netherlands
NOGAT	Northern Offshore Gas Transport B.V.
NPE	National Plan Energysystems / Nationaal Plan Energiesysteem
NSE	North Sea Energy
NSWPH	North Sea Wind Power Hub
OEM	Original Equipment Manufacturer
OHL	Overhead Line
OP	Operating Pressure
O_2	Oxygen
O&G	Oil & Gas
O&M	Operation & Maintenance
PAWOZ-Eemshaven	Programma Aansluiting Wind Op Zee (ligt bij Eemshaven)
PDLC	Project Development Life Cycle
PN	Programma Noordzee
RAM	Reliability, Availability Maintainability
RVO	Netherlands Enterprise Agency / Rijksdienst Voor Ondernemend Nederland
PEM	Proton Electrolyte Membrane
PSA	Pressure Swing Adsorption
PtG	Power to Gas
pVAWOZ	Programma Verkenning Aanlanding Wind Op Zee
P&ID	Piping and Instrumentation Diagrams
RfP	Request for Proposal
RO	Reverse Osmosis
SOL	Start of Life
SEA	Strategic Environmental Assessment
SDE++	Stimulering Duurzame Energieproductie en Klimaattransitie
SIL	Safety Integration Level
SIMOPS	Simultaneous Operations
SLPE	Sea and Land Project Engineering Ltd

Abbreviation	Description
SodM	Staatstoezicht op de Mijnen
STATCOM	Static Compensator
SVC	Static Var Compensator
SWRO	Sea Water Reverse Osmosis
TEG	Tetraethylene Glycol
TNO	Nederlandse Organisatie voor Toegepast-Natuurwetenschappelijk Onderzoek
TNW	Ten Noorden van de Waddeneilanden
TRL	Technology Readiness Level
TSA	Temperature Swing Adsorption
TSO	Transmission System Operators
TWh	Tera Watt hour
UPS	Uninterruptible Power Supply
WTG	Wind Turbine Generator
XXL	eXtra-eXtra Large

2 Project Context

In the transition towards a sustainable energy mix there is a need for sustainable energy sources. The Netherlands is located at the shore of the North Sea, which contains great potential for offshore wind energy generation. Currently 4.5 GW of offshore wind capacity is installed, and the Dutch government is targeting a total of 21 GW of offshore wind capacity by 2030, 50 GW by 2040 and 70 GW by 2050. At peak production it is expected that the national energy supply will exceed demand. This leads to curtailment in energy which is not preferred. To prevent curtailment, the energy needs to be stored or be used in other forms. Expected is that in 2050 around 25-40 % of the Dutch energy will be in the form of Hydrogen (ref. 23). There can be economic and environmental benefits to converting energy into hydrogen offshore instead of onshore.

Additionally, these offshore facilities can be connected via cables or pipelines to neighbouring countries. These interconnections can again improve the flexibility of the energy system and prevent necessary curtailment or energy shortages. Preferably, these connections are located at specific locations in the North-Sea creating so-called offshore energy hubs. Neighbouring countries such as the United Kingdom, Denmark, Belgium and Denmark are exploring similar concepts. In the North Sea Wind Power Hub (NSWPH) programme and the North Sea Energy (NSE) studies possibilities for interconnections and energy hub concepts have been explored. This research showed that the most likely energy hub forms are the construction of an energy island or multiple platforms.

The Dutch governmental institutions that are working on the rollout of wind energy and the energy hubs on the North Sea are the Ministry of Economic Affairs and Climate (EZK) and the Ministry of Infrastructure and Water Management (IenW). Together with the Dutch TSO's Gasunie, TenneT and EBN, EZK and IenW are starting on the path to determine the technical feasibility of these energy hubs. In 2022, these organisations have worked on initial research into the most likely scenarios through setting up the Energy Infrastructure Plan North Sea (EIPN) project. The EIPN project should give more understanding of the energy hub concepts and offshore energy infrastructure and create a framework to facilitate their rollout for first operation in the early 2030's.

The EIPN projects consists of four different subtopics (Workstreams):

- Workstream 1: Strategic vision
- Workstream 2: Repurposing of existing gas infrastructure
- **Workstream 3: Offshore energy hub**
- Workstream 4: Market regulation

The Dutch ministries have worked together with the other Dutch ministries on the Nationaal Plan Energiesystem (NPE) and Programma Noordzee (PN). These policies are giving guidance to the energy system of the future and in which areas these energy hubs and wind farms can be constructed. In Figure 2.1 the wind search areas are presented, and subsequently the relevant wind farm search areas with expected energy hubs functions will be described.

Figure 2.1: Illustrative windfarm search areas Dutch North Sea area* (ref. 24).

*Wind area locations are indicative and could be outdated, it is understood that these are subject to continuous changes as the exact location is under development and still needs to be confirmed.

2.1 Demonstration Projects

100 MW pilot

The first large scale offshore hydrogen project on the North Sea is demonstration project 1. This project is expected to have a hydrogen production capacity of max. 100 MW and should be operational around the year 2027. The hydrogen production facility will be placed on a platform and will be located at the windfarm “Hollandse Kust”.

500 MW demonstration

The second large scale offshore hydrogen project is demonstration project 2. This project is expected to have a hydrogen production capacity of 500 MW and should be operational around the year 2031. The hydrogen production facility will be placed on a platform and will be connected to a 700 MW wind farm which is named “Ten Noorden van de Waddeneilanden” (TNW)(ref. 25). This area is 56 km north of the Netherlands and is approximately 120 km from shore. Demo 2 will potentially be a grid-integrated facility by connecting to the near HVDC system in location “Doordewind”. This will allow it to either transport energy to shore via power or hydrogen and can thus function as an energy hub. This should create a more flexible and robust energy system. To bring hydrogen ashore the facility should be connected to an offshore pipeline. Which pipeline can be used is discussed in EIPN Workstream 2.

As far as possible, lessons from these pilot and demonstration projects should be integrated into the design of the energy hub for search areas 6 and 7 but this will be challenging as based on the required schedule the design of the area 6 and 7 islands or platforms will need to be completed before the demo projects are commissioned. However, there will be earlier learnings, for example from engagement with the supply chain and from design development which can be incorporated.

Gasunie will develop a pre-FEED design for the 500MW demonstration platform based on the conceptual design of a 500MW hydrogen production platform completed as part of the NSWPH programme.

2.2 Search Areas 6 and 7

The largest share of the new installed wind energy capacities is expected to be installed in search areas 6 and 7. The area is located around 150 km from the nearest landing point (Den Helder, Uithuizen) and has and has an area of more than 3,000 km^2. In the search areas approximately 22-28 GW of wind energy can be installed, and this will be installed mainly in the timeframe of 2031-2040. The first energy hub with power and hydrogen transport capacities is expected to be installed in this area. The water depth is 45-55 meters, which is deeper than the other wind areas, but still shallow enough for the construction of the foundations for wind turbines, platforms or a potential island.

2.3 Works Stream 1 Summary

Inputs that are required before a decision can be made about the construction form of the energy hub have been developed in EIPN Workstream 1 (ref. 26). The goal of Workstream 1 is to set out the strategy vision on the future energy system in the North Sea approaching 2050. Important outputs for this study are the energy hub location, energy capacity, interconnection capacities, rollout in time and the ratio between power export and hydrogen production.

Workstream 1 started by investigating the demand for sustainable energy. This was done with a literature study comparing different scenarios. The literature study showed that the scenarios described by Gasunie and TenneT in II3050 were most in line with the goal of the government (ref 27). Specifically, the scenario for Nationaal Leiderschap (NAT). This scenario showed the following values for national demand:

- 2030: 600 ‑ 642 TWh
- 2040: 535 TWh
- 2050: 566 TWh

Furthermore, the following interconnection capacities are expected:

- 2030: 12.8 GW
- 2040: 14.8 GW
- 2050: 18.8 GW

Countries considered for connection include:

- Denmark which aims to develop into an electricity exporter; wind power currently meets 53 % if domestic demand and is expected to expand by 9-14GW taking this to between 100 and 160 % of domestic demand. Denmark also has an active programme for the production of green hydrogen.
- Germany which is a major net importer of electricity. Domestic demand is expected to reach 150-175TWh/year in 2037 and 190-220TWh/year in 2045. Germany is also a net importer of hydrogen.
- Belgium which is a net importer of electricity and hydrogen in part due to its low potential for offshore wind. Belgium has an ambition to become a transit country and a hub for hydrogen.
- The UK where Scotland is expected to be a future exporter of electricity and hydrogen. Scotwind expects to add 27.6GW of offshore wind over the next 10 years for export to England and continental Europe.
- Norway which is a net electricity exporter and has big ambitions for 30GW of offshore wind by 2040. Norway could become a net exporter of hydrogen with initial focus on blue hydrogen.

Interconnection can use either electricity or hydrogen. The assumption from workstream 1 is that initial interconnectivity will be predominantly electrical.

The Netherlands is currently planning a total of 4 GW of electrolyser capacity by 2030 and 8 GW by 2032. The largest share of these capacities is to be installed on land. Overtime offshore electrolysis is required as it comes with economic and environmental benefits and land area is limited in The Netherlands. The NPE states an increase from 21 GW of offshore wind capacity in 2030 to 50 GW in 2040. A share of this capacity will be converted offshore into hydrogen in the energy hub. In the II3050 NAT scenario, around 10 GW of the 29 GW is expected to be converted into hydrogen. The Target Grid study executed by TenneT also confirms that this ratio would be likely. Furthermore, in this document it was discussed that in 2040 around 38 GW of electricity can be transported to shore, with a buildout rate of 2 GW a year between 2030 and 2040. This results in a total residual of 12 GW that needs to be transported to shore by either increasing the buildout rate of TenneT's HVDC capacity or offshore hydrogen production. On this basis it was estimated that between 2031-2040 the HVDC rollout is 2 GW/year and the offshore H_2 rollout is 1 GW/year.

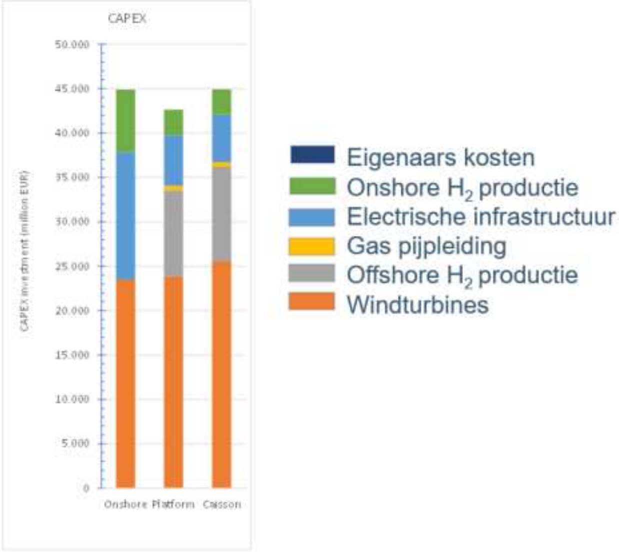
The majority of the wind production is assumed to be constructed in search areas 6 and 7, which has a potential capacity of around 20-28 GW. The energy hub to be installed will also be in this area. The energy hub should also facilitate electrical interconnections to the United Kingdom, Denmark and Norway. The wind area's Noorderwiek (hub west) and Doordewind (hub east) can be used for additional capacity and will also be used as a location for electric-only interconnections. The interconnections in those locations don't affect the energy hub in search areas 6 and 7. After 2040 the rollout of offshore wind energy is expected to take place in zone 9/10, but this has not been confirmed yet and is out of scope for this study.

2.3.1 Interfacing Workstream 1 with Workstream 3

Workstream 1's projections for the roll-out of offshore wind generation are based on the required schedule as defined by the Dutch Government. The split between export as direct power via the HVDC system and offshore hydrogen production is influenced by TenneT's capacity to roll out HVDC systems, assumed to be maximum a standardised 2 GW system per year and a maximum of 38GW of electrical landing in 2040. The estimated roll-out of hydrogen production – 8 GW by 2032 – is based on government projections and includes offshore hydrogen production and onshore. Due to the immaturity of offshore hydrogen production, there is concern that it will not be available in line with the required schedule.

The selection of offshore hydrogen production in preference to onshore needs to consider the entire cost of developing each option. The significantly higher cost of bringing energy ashore as electrons versus atoms – a 2 GW HVDC system can cost approximately €10 billion compared to a €500 million subsea pipeline which can transport the equivalent of 10 GW as hydrogen – needs to be balanced against the additional infrastructure in the form of islands or platforms required to support offshore hydrogen production. Once all these costs are considered the overall costs of onshore and offshore hydrogen production are comparable as indicated by the costs estimates.

Figure 2.2: CapEx estimate NSWPH (ref. 4).



The optimal capacity of onshore hydrogen production would be based on energy recovery when offshore wind power transmitted to shore exceeds onshore demand. Due to the high cost of subsea HVDC cables, the quantity of power transmitted ashore should balance offshore generation with the average base load onshore demand to minimise periods when power transmitted to shore is constrained by limitations in onshore demand. Beyond this point further expansion of wind generation capacity should be accompanied by a combination of power export to shore and offshore hydrogen production.

The optimal date for first hydrogen production both onshore and offshore is determined by the balance between renewable electricity production offshore and onshore demand. Power should be brought ashore until approximately 70 % of the expected average base load demand is met and then onshore hydrogen production installed to reduce/optimise curtailment during periods of base load generation offshore but reduced demand onshore. Here the economics clearly favour onshore production as the capacity to bring power ashore already exists via the installed HVDC cables, although this must be balanced against constraints on onshore construction including land availability, permitting and public acceptance. As offshore wind generation is further rolled out, if the economics favour offshore hydrogen production, this should be stepped out at approximately a one-to-one ratio with HVDC transmission capacity to maximise energy recovery by avoiding curtailment at close to peak wind speeds. To allow for this optimal grid integrated approach to offshore hydrogen production, Workstream 3 will design the energy hubs to allow for up to 50 % of offshore peak wind generation to be routed ashore as hydrogen. It is acknowledged that this roll out may not be practically possible, but the aim of this approach is to identify the optimal energy hub concept to support it and to encourage action to be taken to as far as possible remove constraints.

The date by which it is assumed that first offshore hydrogen production is desirable is the early 2030s in line with assumed initial wind generation within search areas 6 and 7 in 2032. This date is very challenging for a purely island-based solution, and there may be constraints, whether technical or regulatory, which prevent offshore hydrogen production to this timescale. The date is little less challenging for platform-based concepts due to the need to scale up offshore hydrogen production capacity considering the limitations in the equipment supply market. In fact, delivery of any energy hub concept to the required timeline will be a major achievement, although the identified risks are greater for island-based concepts.

Workstream 1 acknowledged these constraints on hydrogen production limiting roll-out to 9GW in the 2030's without specifying a specific date for the first offshore hydrogen production infrastructure to be commissioned. Large scale roll-out of offshore hydrogen production may commence later due to technical constraints, potentially starting in 2035, but this should then be incorporated into the energy hub by leaving blocks undeveloped rather than be a reason to adjust the ratio of power export to offshore hydrogen production from what would otherwise be optimal.

Delaying offshore hydrogen production, if required, should not necessarily influence the ultimate ratio of direct power export to offshore production and consideration should be given to rolling out wind generation in other search areas to allow offshore hydrogen production to be retrofitted to search areas 6 and 7. This approach would need to ensure there would not be long term constrained power. In line with the assumptions of TenneT a portion of the search area 6 and 7 wind blocks should be delayed to allow both the WTGs and associated offshore hydrogen production infrastructure to be installed when it is ready.

2.4 Definition of an Energy Hub

An energy hub is a construction form at sea, that accommodates the electrical and process equipment required to perform at least two of the following functions:

- Collecting electricity from wind farms and transform into required voltage for long-distance transport.
- Connecting neighbouring countries and energy hubs by either cables or hydrogen pipelines.
- Converting electricity into other energy carriers.
- Compressing hydrogen from platforms or hydrogen turbines to a sufficient pressure to transport it to shore or neighbouring countries or energy hubs.

The energy hub can be in one location or can be a combination of multiple platforms across a specific area fulfilling the required functions. By fulfilling these functions an energy hub creates benefits to the future energy system because:

- Collecting energy before transporting it to land is most likely cheaper due to economies of scale and better utilisation of cables.
- Connecting energy hubs among themselves and with different countries creates a flexible and robust energy system with increased market integration and security of supply.
- Increasing export area promotes efficient use of electricity.
- Being able to convert energy carriers can improve the integration of large amounts of energy into the energy system. In addition, these energy carriers can also offer storage and transportation advantages.
- Depending on the type of energy hub (e.g. island) an energy hub may perform additional ancillary functions that provide benefits to the energy system, the offshore wind industry or other users in the North Sea.
- Transport of hydrogen to land is done by a public grid operator except in the case of an existing or geographically defined grid. Here market fragmentation and inefficient competition with the public grid should be avoided.

The functions of energy hubs can evolve over time, from gathering functions to conversion functions. Energy hubs constructed until 2030, except for pilots and scaling up offshore electrolysis, mainly consist of electricity infrastructure. Here mainly the gathering function will be fulfilled before the connection function becomes increasingly prominent. This is expected to be combined with significant onshore electrolysis capacities. Connections through interconnection with Germany, Denmark, Norway, Belgium and the United Kingdom are currently being investigated.

After 2030 the hub functions are expected to increase as technology develops and matures. These energy hubs are therefore expected to not only collect and transport electricity but also include the conversion function with electrolysis taking place not just onshore but also offshore. The energy hub considered in search areas 6 and 7 is therefore expected to have all of the above-mentioned functionalities.

2.5 Role of the Government

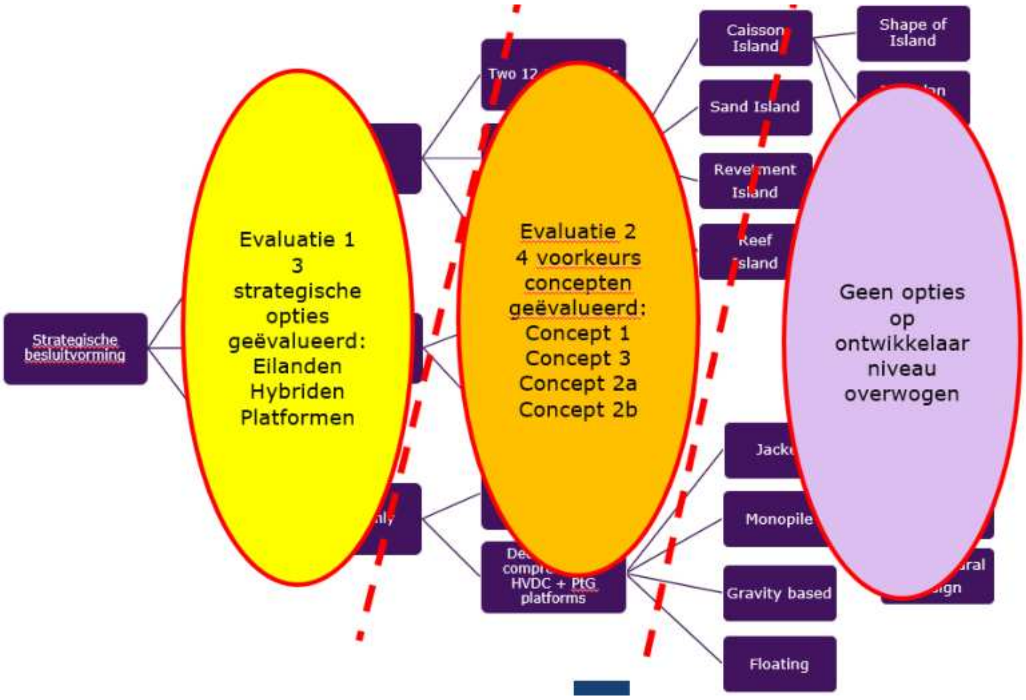
The Dutch government is taking an active role in the development of offshore hydrogen production and infrastructure. A similar approach is taken for the development of offshore wind, as explained in the Dutch offshore wind guide of 2022. The role that the government assigned to itself is a coordinating role, thereby safeguarding timing and coherence between all offshore activities. Moreover, the government aims to accelerate the development of offshore hydrogen by developing frameworks and creating clarity.

The Governance model defines the roles and responsibilities for various components of an energy hub across the life cycle. In the governance model responsibilities must be designated, both for electricity and hydrogen, in the areas of system planning, development and ownership and the operation of assets. The Governance model can go roughly in two ways:

- Centralised, with much of the responsibilities lying with central governments or grid operators. This is the current governance model for offshore wind in the Netherlands.
- Decentralised with wind farm developers being largely responsible.

The balance between these two approaches will dictate the decision that should be part of the Workstream 3 decision making framework. The selection of the key decisions within Workstream 3 and the funnelling process design are selected considering the decisions that the government needs to take as illustrated in Figure 2.3.

Figure 2.3: Decision Funnelling Approach



Electrolysis and offshore wind energy generation is expected to be primarily a market activity. Studies show that the production cost of offshore hydrogen is about equal to that of onshore production of hydrogen from offshore windfarm energy. Nevertheless, the LCOH must be attractive enough for parties to capitalise on offshore hydrogen production. Furthermore, hydrogen production offshore is meant to make a robust energy system. In the first years it might be favoured to transport energy to shore in the form of electricity, as power demand is sufficient, and curtailment is not needed. The load hours of the electrolysers will be lower in the first years and make the project less profitable.

The role of the government here is to subsidise offshore hydrogen to offset differences between production costs and market value, as was done in the SDE++, set purchase obligations for industry for offshore hydrogen, and investigate mitigation options before electrolyser curtailment. Already in effect are the purchase obligations of renewable fuels of non-biological origin, starting in 2026, and the subsidising of production and use of green hydrogen in refineries.

The government has appointed TenneT as the designated TSO for the offshore grid who are thus responsible for coordinated planning, development and management of the offshore grid. This offshore grid consists of the platforms housing offshore substations, subsea and onshore export cables, onshore converter stations and connection to an existing onshore transmission system. For an initial hub, electrical interconnectors can be developed and managed by the TSO. Management of the entire electricity system becomes more complex if the management of individual offshore grids is left to private 3rd parties. A centralised organisation of the offshore grid results in community costs. Moreover, TenneT and its offshore activities will be described in Section 2.7.

The government has provisionally appointed Gasunie as the HNO although this is to be confirmed. The role of the HNO is to facilitate and supervise the construction of a hydrogen grid including storage. The HNO is in close contact with hydrogen producers and consumers. In principle offshore electrolysis is a commercial activity with a role for state parties only when the market does not pick this up. Gasunie will be involved in the development of the 500MW offshore demonstration platform. Furthermore, Gasunie is exploring the possibilities of operating centralised offshore compression platforms.

Lastly the government has commissioned a wide range of research projects to better understand all possibilities of energy generation in the North Sea. Together with the TSO and HNO the government has worked closely with others in projects such as NSWPH and EIPN. Furthermore, environmental studies and site selection studies are part of the government's activities.

Overall, it is desirable that the government, together with the TSO and HNO, continues to play a major role in the development of large scale industrial offshore hydrogen production and energy generation. Further research is required into the division of roles, to ensure public and private interests are safeguarded for both the platform and the island options. If an island will be constructed it can be expected that the government will be the owner of the island to prevent a commercial/private party to have a monopoly and control who can work on the island.

2.6 Ministry of Infrastructure and Water Management

The Dutch government is divided into different ministries each with different responsibilities. One of the two important ministries that are involved in the rollout of sustainable wind energy is IenW. One of the main involvements of the IenW is in the decision making for the spatial distribution of the Dutch sector of the North Sea. There is a lot of interest in the North Sea and only limited space available in the Dutch sector, see Figure 2.4. Activities such as fishery, oil & gas, excavation, aviation, and military are already taking up a large area. Adding 70 GW of wind energy, hydrogen production and potential subsurface storage of hydrogen and CO_2 is therefore very challenging. In Programme North Sea (Programma Noordzee, PN) and the Partial Revision (Partiële Herziening, PH) of PN, two documents commissioned by IenW, the different stakeholders are considered and new wind areas have been investigated including the expected capacities (ref. 28).

As a part of the Strategic Environmental Assessment accompanying the Partial Revision of the North Sea Program in parallel to these decisions, IenW is studying the ecology in the North Sea area and the impact of the offshore activities. An ecology QuickScan has been initiated that should be finished by the end of Q4 2023. In this QuickScan IenW is working together with ecology experts, NGO's and national universities to map out the ecological status. Ecology is a major factor that will influence the decision on the location of the energy hub. Afterwards IenW will set up the required Environmental Impact Assessments (EIA) and Strategic Environmental Assessment (SEA) to be performed by an external consultant.

Figure 2.4: Map of the Dutch Sector of the North Sea* (ref. 28).

2.7 Ministry of Economic Affairs and Climate Policy

Another Dutch Ministry that is involved in offshore wind energy is the Ministry of Economic Affairs and Climate Policy (EZK). Where IenW has a focus on spatial distribution of the North Sea area, EZK will focus on the rollout of energy generation, conversion, storage and transport. For example, the Nationaal Plan Energysysteem (NPE) is part of the activities under EZK. This report describes the long-term roadmap towards the intended carbon-neutral energy system in 2050. Furthermore, EZK is in close contact with the industry to assist in the decarbonisation while maintaining an attractive business case by allowing for financial support. EZK takes site decisions so determines the location for wind farms and is responsible for the tendering of the wind farms.EZK is responsible for creating a robust and sustainable energy system in the future. Onshore, EZK is working on the rollout of sufficient quantities of sustainable energy in the form of solar, wind and also nuclear. As the demand and supply of sustainable energy sources is fluctuating over time EZK is also investigating the installation of sufficient quantities of adjustable power by repurposing natural gas power plants to hydrogen power plants. All these transitions are part of the NPE while in the meantime EZK is working on keeping sufficient quantities of natural gas and oil to overcome the transition period.

In the North Sea area, EZK is in close contact with the TSO, HNO, IenW and the industry. In consultation with these parties EZK has written the “Routekaart windenergie op zee 2030-2050” (ref. 29). In this report, the goals for offshore energy generation are set to 50 GW in 2040 and 70 GW in 2050. Furthermore, EZK is responsible for the tender process of the assigned wind farm areas to make sure these goals are met. To achieve the rollout, it is estimated that in the period of 2022-2026 at least 15 GW of wind areas have to be assigned to developers. This can be done by different methods as described in the law “Windenergie op zee”(ref. 30). Most likely the developer will bid for a specific wind area or the areas will be assigned via an auction. It has not been decided yet if the same strategy will be used for assigning the hydrogen production facility to the developers or if the HNO will also play a role in this. Furthermore, EZK is developing the framework under which Gasunie and TenneT will develop the energy infrastructure of search areas 6 and 7. Finally, the developers need agreements with the HNO or TSO for transporting the energy to the national electricity or hydrogen grid.

A coordinated and integrated energy system will provide benefits in terms of costs and security of energy supply. The Energy Infrastructure Plan North Sea study is contributing to the development of an integrated system. This study has been commissioned by the Netherlands Enterprise Agency (Rijksdienst voor Ondernemend Nederland, RVO) which is part of EZK. The learnings from this study will function as input to EZK to set up the final policy “EIPN”.

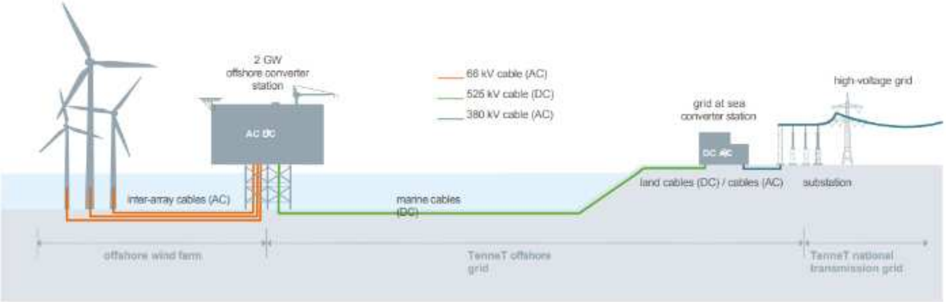
2.8 TenneT

TenneT have been appointed the TSO for the onshore and offshore Dutch grid. The offshore grid consists of separate sections connecting the wind energy areas to the national high-voltage grid on land. The standardised offshore grid will consist of platforms, electrical installations, export cables to land, land stations and connections to the national high-voltage grid. The build-out of the offshore grid from 2022-2031 will support only direct power export and will be supported by a combination of HVAC platforms for near shore wind farms and HVDC platforms for wind farms located further offshore. TenneT expect to invest between 8 and 9 billion euros in the construction of the offshore grid in the Netherlands over the next 10 years. Standardised platforms will have nominal capacities of:

- 700 MW for HVAC platforms.
- 2 GW for HVDC platforms.

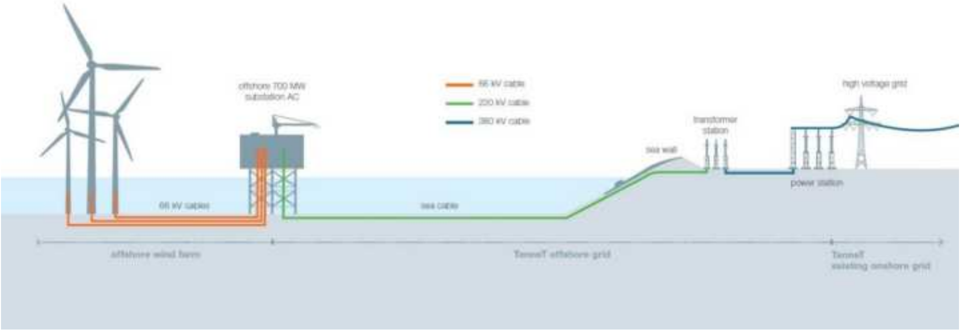
Due to their distance to shore, power export from search areas 6 and 7 will be via 2 GW HVDC platforms, see Figure 2.5. Due to their remote distance, the 2 GW HVDC platforms are assumed to require helicopter access with the associated exclusion zones. During the NSWPH programme the assumption was that compression and hydrogen production platforms would be supported by maintenance vessels without helipads thereby not requiring exclusion zones which could affect the spatial development of the wider wind farm. Consideration should be made in the future as to whether these platforms could be grouped together with some shared facilities. Power export to shore from the HVDC platforms will be via DC cables with a nominal voltage level of 525 kV. The system is expected to be configured as a bipole with dedicated metallic return (DMR) , meaning that the cable system will consist of two HVDC cables and a third cable acting as a metallic return cable.

Figure 2.5: Typical Arrangement of offshore HVDC System (ref. 16).



We understand that WTG array cables within the wind farm are not part of TenneT's system. However, HVAC interlinks and cables between offshore HVAC platforms are part of TenneT's network. The typical arrangement of a HVAC system is presented in Figure 2.6 below.

Figure 2.6: Typical Arrangement of offshore HVAC System



Source: TenneT TSO B.V

The onshore grid is known to need significant investment. The Dutch 380 kV grid is the backbone of the HV grid, comprising:

- National ring structure with connections to coastal locations where large-scale generating capacity is connected.
- Direct connections to Germany and Belgium.
- HVDC subsea interconnectors to Denmark, Great Britain and Norway.

There is also a smaller 220 kV grid located in the northern part of the Netherlands.

TenneT has seen a sharp increase in demand for connection and transmission capacity in the Netherlands over the last 3-4 years and expects to invest between 10 and 13.6 billion euros in the national HV grid. Further investment will be required to ensure the onshore grid is not a bottleneck to the transmission of power ashore from the offshore grid as offshore wind generation expands.

Just as with EZK and IenW, TenneT is also involved in the EIPN project. The role of TenneT in this study is providing the required information to the DMNC consortium. As TenneT is part of the NSWPH consortium, they have executed multiple studies on the potentials of offshore energy hubs. Furthermore, TenneT attends the organised meetings within Workstream 3 to assist in scoping the project and to advise in the funnelling process from an electrical point of view.

2.9 Gasunie

Gasunie are expected to be appointed as the HNO for the offshore grid. Gasunie is a 100 % state-owned company. In multiple ways, Gasunie is heavily involved in the development of Dutch hydrogen production and the Dutch hydrogen network, both onshore and offshore. Currently, the company is the TSO and owner of the natural gas network in the Netherlands and will serve the same role for the onshore hydrogen network, including storage and import of hydrogen. HyNetwork Services, a 100 % Gasunie owned company, is constructing a national hydrogen network, connecting five major industrial clusters. This is done by repurposing existing pipelines for hydrogen and building new pipelines. The aim is to finish the project by 2030. In a larger strategic vision, HyNetwork Services is exploring possibilities to develop an offshore hydrogen network, see 7. The envisioned pipeline, running from Den Helder to Eemshaven, would run pass the major wind farms on the North Sea, including search areas 6 and 7 and demonstration project 2 (see Section 2.1). This pipeline would enable one integrated solution for the transport of green hydrogen produced offshore.

The NSWPH consortium, an international consortium including Gasunie, performed a feasibility study on the hub-and-spoke configuration to land both electricity and hydrogen. Four categories were investigated: System integration, technical feasibility, cost & benefits, and regulatory & market design.

Gasunie has built up expertise in recent years, from their position within the NSWPH consortium, on offshore hydrogen production and transportation which has enabled them to provide valuable technical details for EIPN.

They will be responsible for the design of the hydrogen compression equipment but do not have the capability to do the design of hydrogen production which will potentially be the responsibility of the associated wind zone developers.

Figure 2.7: Illustrative Offshore Hydrogen Network of HyNetwork Services (ref. 31).

2.10 Energie Beheer Nederland

Energie Beheer Nederland (EBN) was established 50 years ago to realise oil and gas revenues on behalf of the Dutch State by investing together with the industry. In accordance with the Dutch Mining Act, EBN participates with a 40% share in the oil and gas exploration and production. EBN is also co-owner of many of the oil and gas infrastructures on the North Sea. Currently, EBN's activities focus on three key areas: the gas transition, the heat transition, and carbon capture and storage (CCS) and transport systems. EBN is involved in (future) industrial scale CCS projects offshore such as Porthos and Aramis (ref. 32).

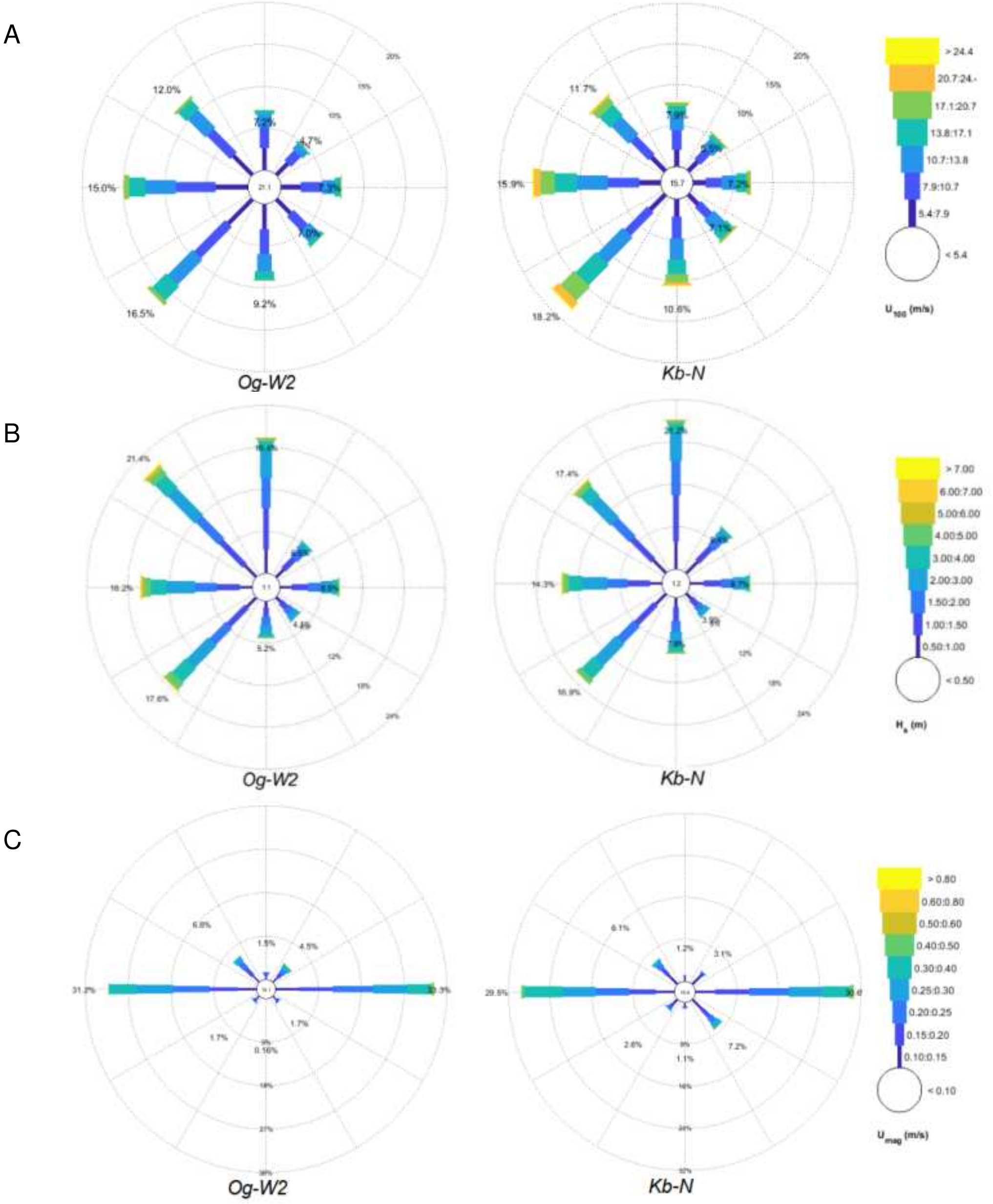
Based on EBN's knowledge of the Dutch subsurface and involvement in exploration EBN also explores technical options for hydrogen storage and production at sea. As co-owner of the Dutch offshore gas infrastructure EBN sees it as its responsibility to stimulate responsible reuse of pipelines and existing platforms and to use these assets, where possible, for acceleration of the energy transition.

As the focus of EBN is on onshore heat networks, CO_2 and H_2 storage & transport and oil & gas activities, the role of EBN in the WS3 is limited. However, EBN is involved in workstream 2 and it is expected that a potential energy hub might support equipment required for EBN's activities. The expection is that this would not influence the construction form of the energy hub. The involvement of EBN in workstream 3 is mainly in providing information about storage potentials in search areas 6 and 7 and overlapping oil & gas activities. EBN's participation in 200 oil and gas joint ventures, CCS projects and exploratory studies into hydrogen storage capacity gives access to public and confidential data. EBN is involved in the repurposing of the pipeline network offshore and therefore the focus of EBN is workstream 2.

2.11 Conditions in Search Areas 6 and 7

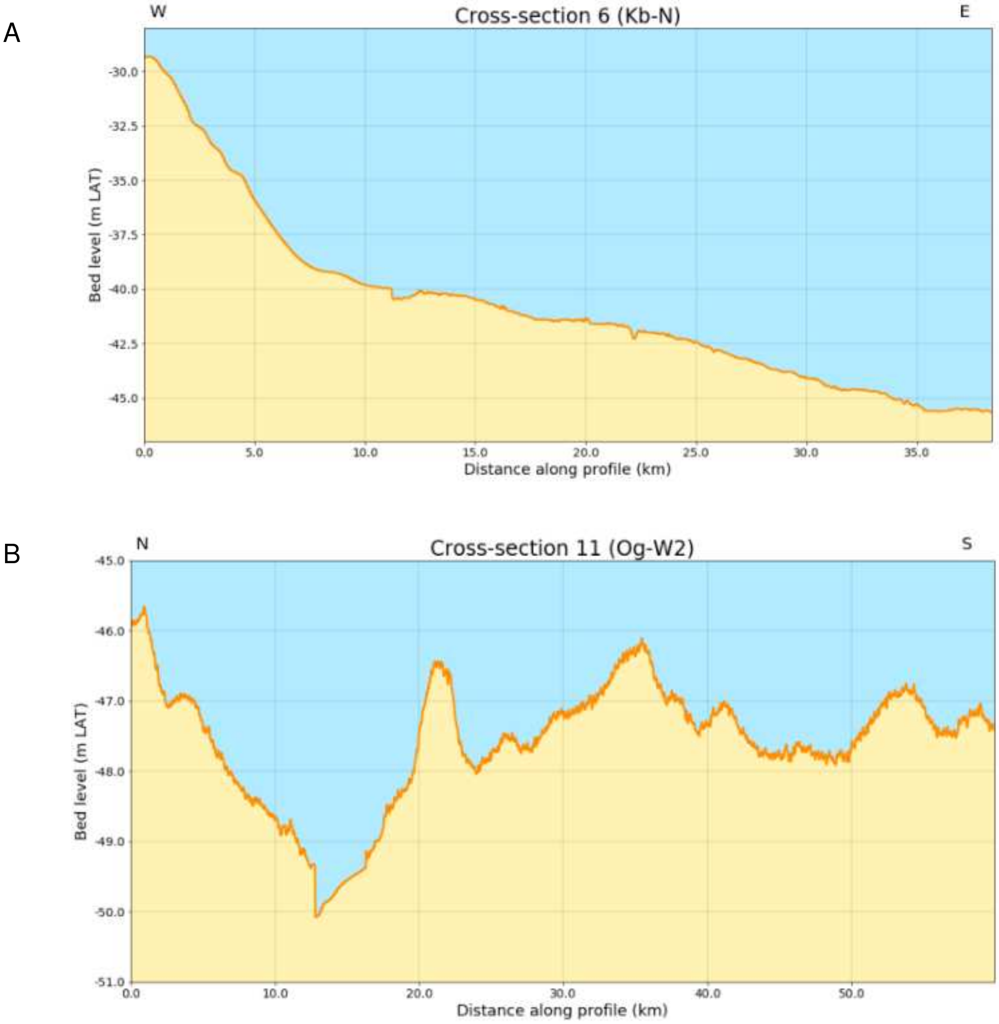
The feasibility of constructing an energy island or platform offshore is dependent on the offshore conditions. To make an estimation of the conditions in search areas 6 and 7 a study has been done by Deltares. From this study the results for North Sea areas OG-W2 and Kb-N were used since those areas are closest to search areas 6 and 7. The average wind speeds (8A), wave height and wave peak period (8B), and subsea current velocities (8C) are analysed. From this data, it is estimated that the wind speeds are >24 m/s dominantly from west / southwest direction. Wave peaks are dominantly coming from in between North to Southwest direction at a maximum height of 5m. Lastly, the report shows that the currents are dominantly from West to East at an average velocity of around 0.5 m/s. The impact of these conditions on construction forms will be discussed in section 2.10.1.

Figure 2.8: (A) Average wind speeds and directions of OG-W2 and Kb-N. (B) Wave peaks and directions of OG-W2 and Kb-N. (C) Depth average current velocity (ref. 1).



Furthermore, the report discusses the water depth profile of the two search areas. From the profiles of both areas from North to South (Figure 2.9A and B), it is estimated that the water depth for search area 6 is around 40-45 meters, for search area 7 the water depth is in between 46-50 meters. Furthermore, search area 6 gently slopes whereas in search area 7 the water depths fluctuate more.

Figure 2.9: (A) Water depth of Kb-N and (B) water depth of OG-W2A (ref. 1).



The last condition of search areas 6 and 7 that was measured are the sediment properties. Results of these measurements are presented in Table 2.1.

Table 2.1: Sediment properties of zones 6 and 7 (ref. 1).

Property	Value
Grain size of sediment	62.5-125 um
Mud/Silt mass percentage	10-60 %
Gravel mass percentage	0-2 %

2.11.1 Credibility of Island Construction in 50 m Water Depth

As part of the NSWPH programme a caisson island concept was developed considering water depths up to 35 m. For that depth the supply of rock core under the caissons was a limiting factor, affecting the construction programme. For 50 m depth of water the volume of rock core would need to be substantially increased, and, with no change to the design, supply would be considered to make the construction impracticable. However, it is considered that sand would be stable as a bed material at around 35 m depth and an alternative construction would be possible with a sand blanket on the bed bringing the formation of the rock core up to 35 m depth. Dredged sand is reasonably available in the area, but the source site would need to be considered in the environmental studies and this should be incorporated into energy hub location selection by IenW if islands are selected.

Construction of the island will take several years and therefore the partially constructed island will be exposed to storms over winter seasons. Some damage during these storms is expected or temporary protection could be provided and removed increasing material demand and extending the construction programme. There is a significant risk of delays during the island construction due to winter storms being more intense than allowed for.

Cable routes onto the island for the original NSWPH concept was via J tubes on platforms adjacent to the island. For the deeper water these platforms are more substantial structures but alternative routes through the rock core also become more difficult to construct and have consequences on cable capacity. Similar considerations apply to water intakes and discharges from the island. Based on the work of the NSWPH programme these platforms will be needed to bring the array cables onto the island even if their voltage is increased to 132kV or higher.

To mitigate safety risks and ensure reliability of production the weather downtime on the service berths needs to be low through the winter season. The NSWPH concept includes a short protective breakwater to the service berth. This may need to be longer to assure the reliability of supply. In the 50 m water depth this breakwater is a substantial construction but of the same size as the perimeter bund for the island so is, in context, a credible construction. In summary, it is considered technically feasible to construct an artificial island in zone 6 and 7.

2.11.2 Danish Energy Island Learnings

The Danish government has explored the possibilities of constructing an energy island in the North Sea. The island was to be constructed about 80 km off the Peninsula of Jutland. At this location the water depth is around 20-30 metres. The island would have facilitated 3 GW of electrical infrastructure in 2033 and then increased to 10 GW by 2040. It is understood that the tender for the energy island was postponed due to high construction costs. It is estimated that the construction costs for the state were around 6.7 billion (ref. 34). As the location for the Danish Energy Island is shallower and closer to shore, this raises questions to the cost of constructing an energy island in search areas 6 and 7.

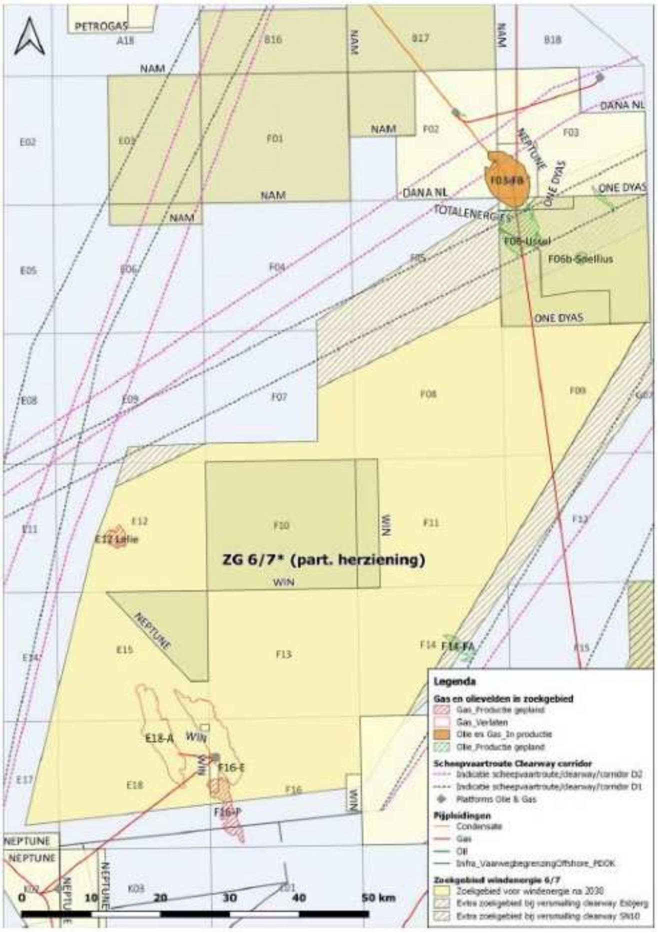
2.11.3 Belgium Energy Island Learnings

The Belgium government is also exploring the possibilities of an energy island. The island should be in the Princess Elisabeth zone. This area is subdivided into 3 wind farms lots with an expected total capacity between 3.15 GW and 3.5 GW. The expectation is that in Q4 2024 the energy island will be tendered and will be operational in 2028. The prospective location has an equal water depth to the location for the Danish Island and is located around 60-80 km from shore (ref. 35). The extensive studies executed for this energy hub will function as inputs for EIPN.

2.12 Sub-Surface Hydrogen Storage

The location of the energy hubs must enable future exploitation of offshore sub-surface hydrogen storage. Based on an initial screening by TNO and EBN in 2022 (ref 56) , an empty gas field and a salt structure with an estimated capacity of 35 salt caverns are theoretically available for storage in search areas 6 and 7 (10). The gas field in the area would be suited for short cyclic storage, with a storage capacity of about 1 bcm H_2, equal to 3,3 TWh. This field is technically and geologically quite complex, therefore this field is not likely to be the best candidate for underground hydrogen storage in a Dutch gas field. The salt caverns individually have a lower capacity (100-250 GWh) but can respond quicker to loading and unloading of the hydrogen facility. Also, storage of hydrogen in salt caverns need less purification but does need dehydration after storage. In both cases, the development will most probably start after 2030 and will take at least 10 years. Whilst there are no anticipated bottlenecks to hydrogen export to shore, it is envisioned that building enough storage capacity on land may be hard due to societal resistance and, in case of salt caverns, limited geological options, leading to the expectation that offshore hydrogen storage will be required in the future. Moreover, a pilot with hydrogen storage in an empty gas field will be required before 2030 to advance the technology readiness level (TRL), which is currently at TRL 4. Little concrete can currently be said about the location for pilots and projects at this stage, and all potential developments are continuously under development. In any case, the realisation of sub-surface hydrogen storage will not affect the design of the energy hubs as dedicated platforms are required for the storage.

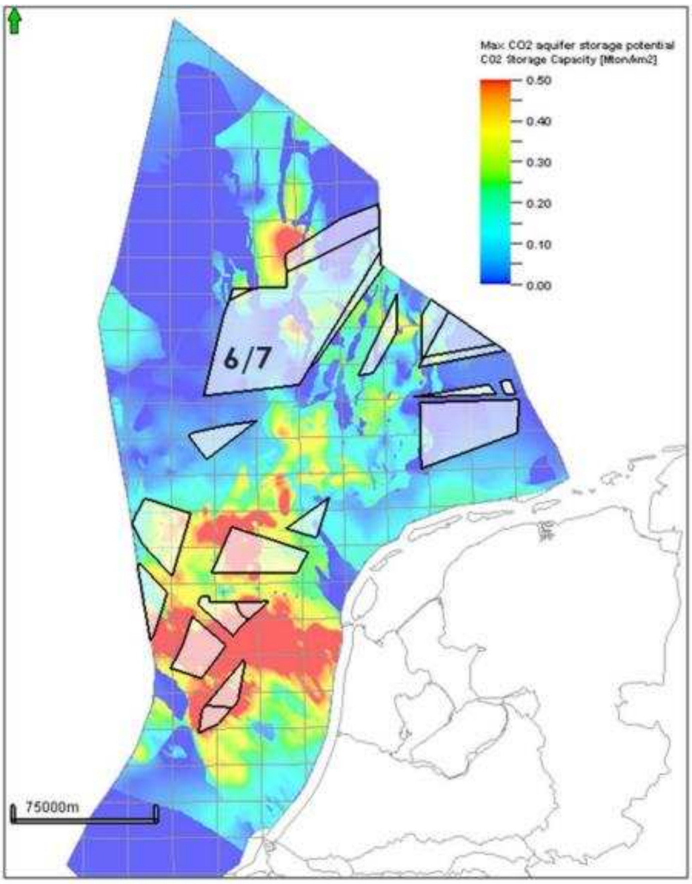
Figure 2.10: Location of possible hydrogen storage capacity projects in search area 6 and 7 (ref. 18).



2.13 CCUS Infrastructure

An initial screening by EBN (“EBN Memo Mijnbouwactiviteiten zoekgebied windenergie 6-7” (ref. 18)) revealed that CCUS potential in search areas 6 and 7 was limited. There are no empty gas fields available for CO_2 storage and CO_2 storage in aquifers still must be investigated further to fully determine their potential. The Rotliegend and Cretaceous layers have limited potential for CO_2 storage due to their limited thickness in search areas 6 and 7. The Trias layer in the core and western half of search areas 6 and 7 reveal greater potential for storage purposes. The highest potential for CCUS is north of search areas 6 and 7 (Figure 2.11). Interdependencies on gas infrastructure could arise when zone 2, just above search areas 6 and 7, is purposed for CCUS. Economic aspects, development concepts, and reuse or new build of infrastructure still must be investigated. The timelines of CCUS realisation in and above search areas 6 and 7 are unknown and it is expected that the development will not start before 2030. Furthermore, other projects such as Aramis and Porthos are currently in the development phase, and both have significant capacity at a shorter distance to shore (west of the Dutch shore) (ref. 32). 6 and 7Nevertheless, the energy hub should not block access to the subsurface storage areas. The decision between islands and platforms is not influenced by this but the development options for CCS in this area must be carefully followed by the various Ministries involved in the spatial planning of the North Sea before deciding between the installation of islands or platforms in this wind area.

Figure 2.1: Carbon storage potential in the Dutch Sector* (ref. 18).



*Wind area locations are indicative and could be outdated, it is understood that these are subject to continuous changes as the exact location is under development and still needs to be confirmed.

2.14 Existing Pipeline Infrastructure

Existing infrastructure might influence the decision between islands and platforms. EBN owns a significant share of the gas infrastructure, the organisation is also 40% shareholder of one of the pipelines “Nogat” that runs through search areas 6 and 7. Another major pipeline in the area is NGT. Both these pipelines can potentially be used for the transport of future hydrogen production in search areas 6 and 7 and for demonstration project two (Figure 2.12). In EIPN, Workstream 2 is exploring the feasibility of repurposing both pipelines. Furthermore, an overview of other infrastructure is giving in Table 2.2.

Figure 2.2: Subsea Natural Gas Pipelines in the Dutch Sector* (ref. 36).

*Wind area locations are indicative and could be outdated, it is understood that these are subject to continuous changes as the exact location is under development and still needs to be confirmed.

Table 2.2: Overview of existing and future infrastructure in search areas 6 and 7 (ref. 18).

Asset	Status
Platform E18-A	Has already been cleaned up by Wintershall Noordzee B.V. in 2019.
Platform F16-A	Permanently suspended and well decommissioning has started It is expected to be fully decommissioned by 2032. No legal obligation yet to clear associated pipelines so EBN’s assumption is that the pipeline between E18-A and F16-A will remain in place.
Cluster F3-FB	Cluster F3-FB (just outside the wind farm) will continue to produce oil from nearby blocks for many years.
NOGAT and NGT pipelines	Will transport gas from other North Sea O&G licenses for years to come. Potential repurposing is discussed in Workstream 2.
E15c	In case of success of the exploration well, EBN expects the installation of a processing platform at the edge of the E15c licence together with pipelines to connect to the NGT pipeline. This platform will still be in production when the first wind turbines are installed in Wind Farm 6 and 7.
Other	Economically successful E&P activities in the F06 and F10 blocks lead to the installation of one or more platforms/satellites and pipelines. Produced oil should be evacuated via platform F02-Hanze or F03-FB. Pipelines need to be installed for this purpose. Some of these activities could take place before 2032. The installation of wind turbines in these blocks might be difficult but could take place in good

Asset	Status
	coordination with the operators regarding the location of platforms and wind turbines and their timeline.

2.15 Oil & Gas Activities

The oil and gas activities in search areas 6 and 7 are in various stages of development (ref 18). Operational platforms and oil & gas pipelines are situated in or on the border of search areas 6 and 7. Furthermore, certain zones in search areas 6 and 7, i.e., E15-C (Figure 2.), are of interest for test drills and prospects, and stranded fields are present. It is necessary that permits for the wind sector in these licensed areas are granted carefully so that synergies are stimulated, and possible conflicts solved beforehand by the O&G and wind operators.

Table 2.3 and Figure 2.13 the current licensed areas for which various operators have plans for exploration and extraction through to 2050. A synergy between the energy hubs and oil & gas platforms could exist, as mentioned in the Offshore Energy Roadmap 2030 (ref. 39). The oil and gas platforms could draw the electricity required for the facilities present on oil and gas facilities from offshore wind farms. Besides the better usage of the offshore grid, this could reduce CO_2, NO_x, and particle emissions. No interdependencies are expected, except possible power supply to O&G platforms, and oil and gas activities are therefore not considered to be part of decision making. There is a potential spatial impact between wind energy and oil and gas due to exclusion zones for helicopter access and this needs to be considered in the spatial development of the energy hub.

Figure 2.3: Oil and Gas prospects in Search Areas 6 and 7 (ref. 18).

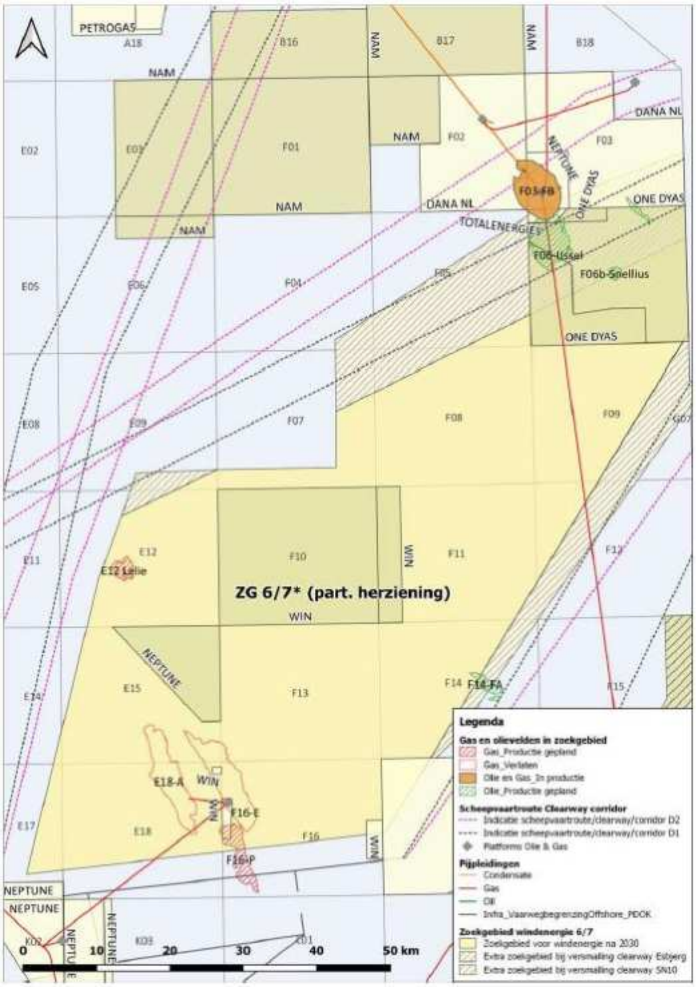


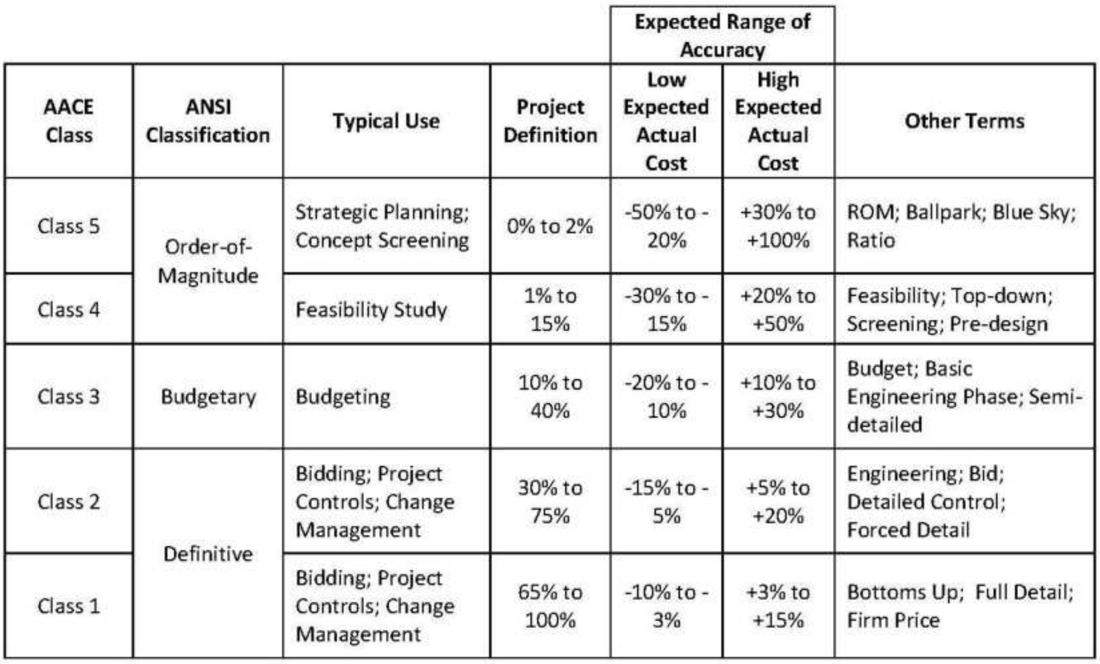
Table 2.3: Overview of status of mining permits in search areas 6 and 7, along with the name of the operator and the end date of the permit. WIVA = Winning licence application (ref. 18).

License	Type	Operator	End date	In wind energy search areas 6 and 7?
E15c	Exploration	Neptune	31-12-2023	Yes
F03b	Production	Neptune	21-12-2047	Extension North
F03c	Production	Dana	08-03-2026	Extension North
F06a	Production	Total Energies	21-12-2042	Yes
F06b	Exploration (WIVA requested)	ONED	-	Yes
F06C&D	Exploration (WIVA requested)	ONED	-	Yes
F10/F11a	Exploration	Wintershall North Sea	31-12-2023	Yes
F16a & F16b	Production	Wintershall North Sea	21-10-2032	Yes
F17	Production	Wintershall North Sea	25-06-2023	Yes

2.15.1 Project Development Life Cycle

The engineering industry has incorporated best practices over the years that have led to the evolution of a PDLC system (Table 2.4).

Table 2.4: AACE 18R-97 Cost estimate classification system (ref. 38).



				Expected Range of Accuracy		
AACE Class	ANSI Classification	Typical Use	Project Definition	Low Expected Actual Cost	High Expected Actual Cost	Other Terms
Class 5	Order-of-Magnitude	Strategic Planning; Concept Screening	0% to 2%	-50% to -20%	+30% to +100%	ROM; Ballpark; Blue Sky; Ratio
Class 4		Feasibility Study	1% to 15%	-30% to -15%	+20% to +50%	Feasibility; Top-down; Screening; Pre-design
Class 3	Budgetary	Budgeting	10% to 40%	-20% to -10%	+10% to +30%	Budget; Basic Engineering Phase; Semi-detailed
Class 2	Definitive	Bidding; Project Controls; Change Management	30% to 75%	-15% to -5%	+5% to +20%	Engineering; Bid; Detailed Control; Forced Detail
Class 1		Bidding; Project Controls; Change Management	65% to 100%	-10% to -3%	+3% to +15%	Bottoms Up; Full Detail; Firm Price

Each stage in the life cycle is elaborated below:

Concept / Feasibility (also known as FEL-1 stage)

The concept / feasibility stage is the first stage of screening of an infrastructure project, to establish whether the project is technically, legally, and commercially viable. Typical activities carried out at this stage include options studies, process descriptions, block flow diagrams, and preliminary mass and energy balances. Cost estimations may be defined to AACE 18R-97 Class 5.

Basic Engineering / Pre-FEED (also known as FEL-2 stage)

The basic engineering / pre-FEED phase aims to develop the concept further, to enable a better cost and schedule estimate to be evaluated. Typical activities carried out at this stage include process flow diagrams, equipment lists, preliminary sizing of major equipment, plot plan, and project schedule. Cost estimations may be defined to AACE 18R-97 Class 4 or 3.

FEED (also known as FEL-3 stage)

The FEED stage builds upon the basic engineering stage by carrying out a full design. Typical activities carried out at this stage include process datasheets, line sizing and line lists, piping and instrumentation diagrams (P&IDs), electrical equipment lists, utility balance, safety studies (e.g. HAZOP/SIL), detailed material take-offs (MTOs), a project execution plan, and updated schedule and cost estimation, to be defined to AACE 18R-97 Class 3 or 2.

Detailed Engineering

The detailed engineering stage develops the design up to full definition for construction, including approved for construction drawings, 3D models, lists (line, valve, tie-in, electrical load, instrument) selection of vendors, procedures (start-up, operating, shutdown, emergency shutdown), and other deliverables. Cost estimations may be revised to AACE 18R-97 Class 1.

Procurement

At the procurement stage, purchase orders are placed for the equipment required for the project. Purchase orders for long-lead items are placed as early as possible, and other materials are based on the MTOs.

Construction

At the construction stage, the physical works are carried out for the project. This includes civil site works, mechanical installation, piping integration, electrical installation, instrumentation and controls installation, testing, defect identification, commissioning, and performance testing.
Given our interpretation of the project development stage of maturity, we are of the opinion that the selection of a construction form for a LSEH is at the beginning of an FEL-1 stage of development. In order to get to a stage of development where it will be possible to procure equipment and begin construction, the project would need to be at the end of FEL-3 following the completion of a Front-End Engineering Design ("FEED") study that would enable relevant project sponsors to make a Final Investment Decision ("FID").

2.15.2 Conceptual Design Maturity

To better understand the maturity of the different hub-forms the provided documents were reviewed and combined with in-house knowledge and experience from the NSWPH programme. From this information it is understood that three different hub-forms concepts have been explored: artificial islands, platforms, and hydrogen turbines. Each of these hub-forms have different alternatives which are more or less developed, depending on the alternative. This section will shortly describe the hub-forms and the maturity of the variables.

Artificial Island

The first possibility for the construction of an energy hub is the construction of an artificial island. This can be done using different methods: caisson, sand, revetment, or reef. Which technique is suited best depends on multiple decisions such as, water depth, weather conditions and costs. Although artificial islands have been constructed globally it is not common practice. Only the caisson-island method has been studied by the NSWPH consortium at this point at a concept engineering level. The concept has been developed for a 10 GW island with 4 GW HVDC capacity and 6 GW hydrogen production.

Platforms

Another possibility is the use of platforms which are common practice in the oil & gas industry. Different substructures for platforms can be considered: jacket, XXL monopile, gravity-based structures and floating. The most commonly used platform in the North Sea is currently jacket structures. As the surface area of a platform is limited, the required equipment has to be split on multiple platforms. For example, from documentation it is known that a jacket structure is limited to 2 GW of HVDC power transformation or 500 MW of hydrogen production. The 2 GW platform is under development by TenneT and is currently at FEED / detailed engineering stage and the first platform should be operational. The 500 MW electrolyser platform will soon start with the basic engineering phase. For the other three substructures no engineering studies are known to exist.

Hydrogen turbines

A last possibility of creating a hydrogen hub is the use of grid integrated hydrogen wind turbines. This solution is a combined solution with platforms, as power transformation at a 2 GW HVDC system is still required and final compression needs to be done on a central platform. Wind turbine generators (WTGs) can also make use of different substructures such as floating, monopile and jacket. The most common used and studied substructure is the monopile. On the monopile a platform needs to be installed, lifting the electrolyser equipment. The monopile has limitations in terms of weight load and it is estimated that around 20 MW of electrolyser equipment can be installed on one WTG. The development of such a WTG is currently at concept engineering stage.

As indicated in this section there are several phases of project development all of which need to be completed to realise an offshore energy hub. Projects begin at conceptual design and proceed through FEED/Detailed Design to Construction. The energy hub concept that will be selected for search areas 6 and 7 is not exactly analogous to any of the designs developed so far which are all at the conceptual design phase. In order to progress the development of the energy hub first its concept must be selected, and the best available conceptual design adapted ready for progression to FEED.

3 Approach to Workstream 3

3.1 Defining the scope

The scope of work for Workstream 3 is included in the RfP for the overall EIPN programme and discussed in 1.1. The scope was further defined and will be discussed in this section.

Workstream 3 – Energy Hub Goals are to:

- Prepare an advisory note based on which a decision can be made on the construction form of the energy hub (artificial island, platform-based hub, floating structure or hub configuration based on hydrogen production at the wind turbines or a combination of these options).
- Ensure that the required information for each process step is available and complete in a timely manner.

The activities that are to be completed to achieve the goals are:

- Organising an internal kick-off meeting with the working group to determine goals and deliverables.
- Analysing information (and interacting with TenneT and Gasunie) on the content of the main categories of the decision-making framework.
- Analysing and finalising the decision-making framework with design principles (per tender clarifications main categories: ecology, environmental impact, safety, costs, system integration, supply security) during the intensive start-up phase of the project. Based on their own proposals and in close consultation with the client.
- Organising a meeting with directly involved parties in the pre-study by involving and providing opportunities to speak in working sessions of this Workstream (including TNO about the TNO North Sea Energy Programme).
- Collecting/generating additional information to fill the content of the decision-making framework. See below for a detailed breakdown of activities per main category from the decision-making framework:
  - Ecology: Analysis of a quick scan completed by IenW on the construction form, supplemented with their own analysis of the ecological impact of hydrogen production, storage, and transport at sea (including waste streams from desalination). This will now be completed by EZK generally and for the demonstration project. EZK will investigate areas 6 and 7.
  - Environmental impact: Life cycle analysis to display the consequences of material use.
  - Safety: Identifying the safety aspects of working conditions and external safety (particularly production, storage, and transport).
  - Costs: Analysing the key cost drivers (CapEx and OpEx) including the possibilities in the supply chain.
  - System integration: Based on the available research results, the main variables and their interdependencies will be identified. This provides the opportunity to evaluate scenarios for various optimisation criteria through a fixed methodology.
  - Supply security: For the various scenarios available in the research reports, the main drivers and the correlation with supply security will be determined.
  - Organising stakeholder consultations with a broader group of stakeholders (to be further defined).

  - Summarising the essence of the above analyses, stakeholder consultations, and their own analyses. This will be incorporated into a decision-making framework on which the decision-making process can be based.
  - Preparing an advisory note.
  - Throughout this process, the core team will be kept informed of the status and progress.

The end product of Workstream 3 shall be:

- A decision-making framework with design principles.
- An advisory note including:
  - A concrete design of a first large-scale energy hub in search areas 6 and 7.
  - Completed decision-making framework based on information obtained from preliminary studies, stakeholder consultations and our own analysis.

3.2 Interpretation and Application of Scope Requirements

We tailored our approach in line with the Workstream requirements as defined in the scope of work to both produce a funnelling process and to comparatively evaluate energy hub concepts to facilitate a decision on the hub design.

The challenge in developing a decision-making framework for an energy hub is initially to define the decisions to be made, the decision-making timeline and the context in which the decision is made. At no point can the decisions be made with perfect information available and understanding gaps in available information and their impact on the accuracy of contributing evidence is part of the evaluation.

The decision-making framework is developed considering:

- The key decisions to be made.
- The timeline for making those decisions.
- Who should be involved in making decisions and which decisions can be taken later.
- The criteria to be applied to each decision.
- The methodology for facilitating those political decisions to be made.

To gain the understanding required to develop the decision-making framework we first reviewed the suite of documents provided to Workstream 3 (Table 1.1). This understanding of the documents provided supported by our involvement throughout the North Sea Wind Power Hub (NSWPH) programme prepared us for our engagement with key stakeholders: EZK, IenW, TNO, Gasunie, TenneT and EBN. The NSWPH consortium comprising Gasunie, TenneT and Energinet of Denmark aim to develop the energy infrastructure for the integration of the large-scale offshore wind roll-out required to the meet the Paris Agreement climate targets. Acting as Technical Advisor, Mott MacDonald supported NSWPH in developing conceptual designs for the following grid-integrated power to gas concepts:

- Onshore power to gas.
- Offshore (platform-based) power to gas.
- Offshore (artificial island based) power to gas.
- Hydrogen production local to the WTGs.

3.3 Summary of Workstream 3 Documentation

The documents provided were useful in developing our understanding of the conditions within search areas 6 and 7. The “Quickscan nieuwe zoekgebieden WOZ na 2030” (Ref 1) provided an overview of existing data for all search areas including areas 6 and 7 to characterise the areas by bathymetry, morphodynamics, geology and hydrodynamics. This was complemented by the memo on mining activities in search areas 6 and 7 provided by (Ref 18). The conditions and infrastructure within search areas 6 and 7 is described in Section 2.10.

The role of the government in relation to the Hydrogen Network Operator (HNO), assumed to be Gasunie, and the Transmission Service Operator (TSO), TenneT, in relation to the energy hub in search areas 6 and 7 is described in Sections 2.4 to 2.8.

TenneT also provided "IP2022 Netopland 12-9-2022" (Ref 15) setting out their plans to develop the offshore grid and "IP2022 Netopzee 12-9-2022" (Ref 16) setting out their plans to invest in the onshore grid. These documents highlight the challenges in ensuring grid capacity to supply power from offshore to onshore consumers as described in Section 2.7.

The North Sea Energy (NSE) study reports (Ref 7-11) detail the work done in defining alternative energy hubs for the development of the Dutch Sector. The study is the first attempt to design offshore energy system integration hubs in the Dutch Sector of the North Sea. It aims to identify and assess opportunities for synergies between energy sectors offshore. The fourth phase of the programme focusses on identification of North Sea Energy Hubs where system integration and projects could be materialised: strategically connecting infrastructure and services of electricity, hydrogen, natural gas, and CO_2. The study considers integration with existing and future O&G infrastructure and with CCS. The assumption for Workstream 3 is that any integration with existing oil and gas facilities will be limited to potentially powering existing platforms which will not impact the energy hub design. CCS infrastructure in the Dutch Sector is being developed as part of the separate Porthos and Aramis projects. To avoid creating interdependencies between two such major infrastructure projects Workstream 3 assumes that the development of offshore wind including offshore hydrogen production is independent to CCS except in terms of spatial considerations.

The main aim of the study is to identify the potential locations for offshore system integration given the existing and planned offshore activities and to perform a first attempt designs of how these Energy Hubs can be developed in the future:

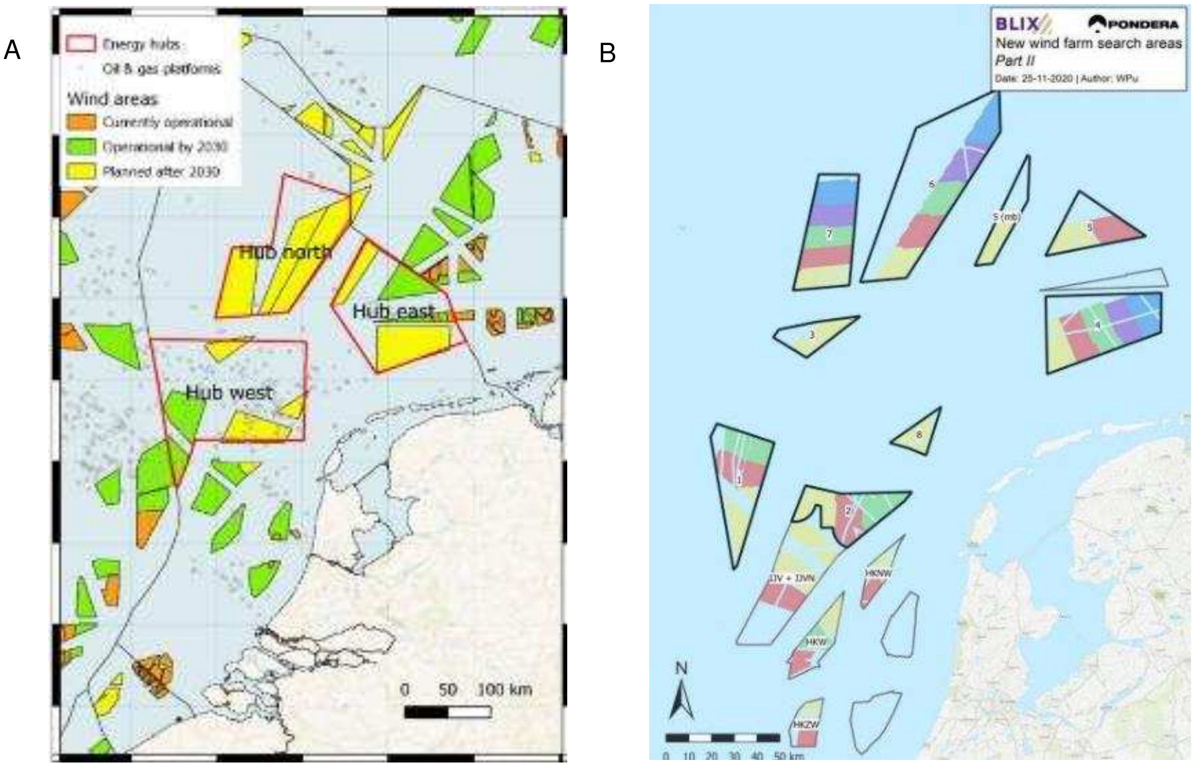
- What are the potential locations for Dutch Offshore Energy Hubs given the existing and planned offshore activities?
- What are the relevant building blocks and generic features that can be utilised in every hub to perform system integration?
- How does a first attempt design of the Dutch Offshore Energy Hubs look like and what investments are required to develop them?
- What are the main interdependencies in the required actions to develop Offshore Energy Hubs?

North Sea Energy Hubs are chosen based on several assessment criteria:

- Expected future offshore wind energy roll-out mainly between 2030-2040
- Availability of existing infrastructure
- Expected activities in the field of gas, electricity, hydrogen and CO_2
- Data availability
- Potential for international interconnection
- Ecological circumstances
- Landing and market opportunities

The study developed three energy hubs: Hub West, Hub East and Hub North with Hub North most closely located to search areas 6 and 7 (Figure 3.1).

Figure 3.1: (A) Hubs West, East and North in relation to (B) Search Areas 6 and 7* (ref. 7).



*Wind area locations are indicative and could be outdated, it is understood that these are subject to continuous changes as the exact location is under development and still needs to be confirmed.

Together they would contribute 34 GW of Dutch offshore wind installed capacity by 2050.

The key characteristics of the NSE energy hubs are provided in Table 3.1.

Table 3.1: NSE Energy Hub Characteristics (ref. 7).

Hub function	Characteristic	Hub West	Hub East	Hub North	Combined Hubs
Offshore wind	Installed capacity 2050 (GW)	8.7	5.4	19.5	33.6
	Max electricity production volume (TWh/a)	43	39	99	181
	NPC Offshore wind (B€)	11	10	16	38
	NPC Cables (B€)	1.8	1.2	5.3	8.2
Renewable hydrogen	Installed capacity 2050 (GW)	5	4.5	8	18
	Max Hydrogen production volume (Mt/a)	0.48	0.28	0.43	1.2
	NPC hydrogen production (B€)	4.8	6	7.1	18
	NPC Hydrogen pipelines (B€)	1.6	1.3	4.4	7.3
Natural gas	Max natural gas production volume (Mt/a)	-	2.0	5.4	7.4
	NPC natural gas production (B€)	-	0.8	0.9	1.7
	NPC platform electrification (M€)	272	47	224	544
CO_2 storage	Max CO_2 Storage (Mt/a)	27	-	-	27
	NPC CO_2 Storage (B€)	0.5	-	-	0.5
Total NPC (B€)		15-22	13-20	34-35	62-75

Hub North has 19.5 GW of offshore wind capacity with 8 GW of electrolyser capacity and is based on the common implementation of greenfield gas extraction, platform electrification, offshore wind production and partial conversion towards hydrogen. This capacity is similar to that estimated for search areas 6 and 7 (22-28GW) with a similar ratio of hydrogen production to direct power export as agreed with Gasunie/TenneT for Workstream 3.

The area is associated with significant wind developments in the long term and is under consideration for the next phases of NSWPH and NorthH$_2$. Interconnection with existing wind farms may be of interest and the area is well connected to shore via the NOGAT 36” pipeline to Den Helder.

From 2028 hydrogen production at the pilot (100 MW) and demonstration (500 MW) scale will take place with hydrogen exported via the NOGAT pipeline. By 2030 offshore wind installation is assumed to increase annually by 2 GW with hydrogen production increasing by between 1 GW to 1.5 GW per year. This roll out is similar to the 2 GW of HVDC capacity per year estimated by TenneT, although assuming it applies to wind generation then it is more conservative.

The study assumes that large-scale hydrogen production will be on multiple platforms and that sandy island structures will be unlikely given the water depths in excess of 40 m. These water depths are similar to those assumed for search areas 6 and 7 (40 m to 50 m). The selection of platforms in preference to islands is noted but does not influence the evaluation undertaken with Workstream 3. The feasibility of caisson islands is stated to be studied, as has now been done within the NSWPH programme. The programme considered that a caisson island in a water depth of 29 m is feasible, and our analysis considers that caisson islands remain feasible in water depths of 50 m (see Section 2.11.1).

The study assumes re-use of existing infrastructure with blended gas transported to the hydrogen gateway project, where hydrogen is separated onshore with the remaining natural gas used to generate blue hydrogen. The resulting captured CO$_2$ is sent to storage, potentially in Hub West, with hydrocarbon production activities in Hub North.

Gasunie and TenneT have provided the documents reference 3, 4, 6 and 12 listed in Table 1.1 and relisted in Table 3.2 below, which describe the conclusions drawn from the work they have done to develop the energy hub design.

Table 3.2: Gasunie and TenneT documentation.

Ref #	Title	Description	Authors
3	NL Energy Hub – Voorverkenning – Hoofboodschappen	NL Energy Hub Main Messages: Consolidation of key messages regarding the usefulness and necessity of (NL) Energy Hubs.	TenneT, Gasunie
4	Afwegingskader constructievormen	Proposed assessment framework between platforms and offshore islands	TenneT, Gasunie
6	NL Energiehub – Voorverkenning naar nut en noodzaak van energiehubs op de Nederlandse Noordzee (2023)	Preliminary exploration into the usefulness and necessity of energy hubs on the Dutch North Sea.	TenneT, Gasunie
12	NSWPH CBA 1.6 Final draft 22-12-2022	The study focusses on providing perspectives on the socio-economic impact from specific configurations of offshore hubs and spokes. The impact is estimated as the difference in total system costs. The evaluation of system costs includes impact on system dispatch, import of hydrogen, investments in electricity and hydrogen trade capacities and investments in other flexibility measures (batteries, hydrogen turbines, electrolysers).	NSWPH programme

Ref. 3 provides key messages regarding the usefulness and necessity of energy hubs and is compiled based documents from the NL Energy Hub pre-exploration and supplemented by insights from NSWPH. The options for search areas 6 and 7 are:

Option 1 – Platform based energy hub:

In 2031 to 2035 install offshore platforms with electrical connections (2 GW HVDC platforms) and then, depending on its technical maturity, add offshore platforms with electrolysis. This option allows continuity with current roll out of offshore wind. The first wind farms can be electrically accessed via platforms and offshore electrolysis can follow at some point.

Option 2 – Platform and island-based energy hub (hybrid option):

In 2031 to 2035 install platforms with electrical connections (2 GW HVDC platforms) and in parallel develop an island. Depending on its technical maturity, add offshore platforms with electrolysis. This option allows continuity with current roll out of offshore wind. The first wind farms can be electrically accessed via platforms and offshore electrolysis can follow at some point. By developing an island in parallel, later infrastructure can be developed on the island.

Option 3 – Island based energy hub:

Around 2026 start construction of an island with the goal of operating a 2 GW HVDC station by 2032. Further functions can then be incrementally developed on the island. This option makes continuity with the current rollout difficult as an island cannot be built until the mid-2030's. Depending on the depth of the water this option may have advantages in terms of multi-functional use, adaption of use and costs but also greater uncertainty, limitations in construction and greater organisational complexity.

These options are in line with the options selected for the initial comparison in Workstream 3 and result in key decisions 1 and 2.

The NSWPH programme included the design of offshore islands for 29 m water depth and increasing this to approximately 50 m is estimated to increase cost by 25 %.

When carrying out Cost Benefit Analyses (CBA) of energy hubs, the findings from NSWPH are that adaptions to a traditional CBA are needed to analyse the unique characteristics of energy hubs:

- Drivers for a positive CBA include:
  - The price of hydrogen imports
  - Deployment of electricity and hydrogen infrastructure
  - CO_2 price
  - Fossil fuel price
  - Degree of transplantation of offshore wind
- Potential benefits of overplanting
- Connecting UK and Norway provides additional system benefits.
- System effects on land should be included in the analysis:
  - Extensions to the offshore grid reduce the total investment costs required in the onshore grid.

Ref. 4 is an assessment framework comparing platforms and artificial islands. The criteria included are:

- Technical feasibility: Water depth, instability and modularity
- Transport and construction: Realisation, timelines

- Park cabling: Length, ways to connect parks to construction forms
- Ecology: Advantages and disadvantages of construction forms on and around energy hubs
- Environmental impact: Life Cycle Assessment (LCA)
- Safety: Occupational health and safety, external (cyber) security, sabotage.
- Cost: Difference in cost of construction forms (CBA)
- System integration/features: Collect, connect, convert and transport
- Supply capacities, flexibility and security.

These criteria have been reviewed and incorporated into the assessment criteria applied to the comparative evaluations within Workstream 3 which have been agreed with Gasunie and TenneT.

Ref. 6 is a preliminary exploration into the usefulness and necessity of energy hubs in the Dutch North Sea proposed by the Interdepartmental Directors Consultation North Sea (IDON). It states that due to an increasing share of weather-dependent electricity production, additional flexibility is required. As a result, there is a growing need for international grid connections, energy storage, flexible electricity demand and controllable CO_2-free electricity generation. Our evaluation of the energy hub concepts for search areas 6 and 7 will ensure that the concept selected facilitates inter-hub and international interconnections allowing deep access to European consumers and marrying more closely energy supply to demand. Offshore energy storage, if required, is assumed to be in sub-surface salt caverns or depleted gas wells. As these will be supported by a separate platform local to storage, they are assumed not to impact the high-level design of the energy hub.

Because of the long realisation times, uncertainties in supply and demand and developments in costs and available technologies for energy hubs, modularity in the roll-out is an important consideration. This requirement was further emphasised in our discussions with IenW who stated that uncertainties in the spatial roll-out of wind generation in search areas 6 and 7 and the areas' ultimate total capacity favoured modularity.

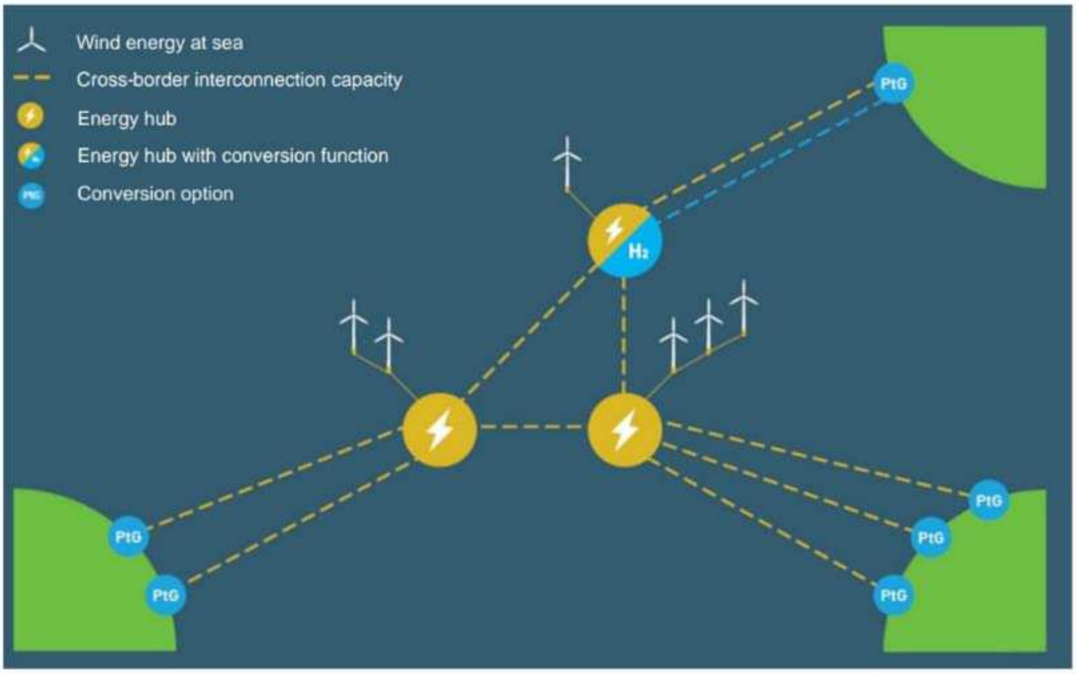
Building in modularity makes it possible to expand energy hubs more flexibly. The report states that both platforms and islands have been investigated and found to be technically feasible and can be used to realise energy hubs with interlink, interconnection and conversion functionality. This assessment is in line with our internal assessment based on our work on the NSWPH programme that both platforms and islands are feasible and a real evaluation between them is required to determine the best approach.

Based on the maximum dimensions and weight of platforms that can practically be installed, 2 GW of HVDC capacity or 500 MW of hydrogen production can be realised on a single platform. This is based on the work done on the NSWPH programme and is the basis for the build-up of our platform-based energy hub concepts evaluated within Workstream 3.

The development of energy hubs and the corresponding timeline is influenced by the properties of the different wind search areas; factors such as surface area, water depth, distance to current offshore natural gas infrastructure and timelines. It is expected that electrical hubs in search areas 1 (Nederwieck) and 2 (Lagelander) and 5-East (Doordewind) can fulfil the interconnection and interlink functions. Search areas 6 and 7 seem most suitable for an energy hub with large-scale conversion to hydrogen (in addition to interlink and interconnection). This is in line with the basis for workstream 3 which will develop a framework for selection of an energy hub including hydrogen conversion in search areas 6 and 7 from 2030 to 2040. Initial roll-out of infrastructure in search areas 6 and 7 is targeted by 2032.

The report states that the Dutch grid needs major investments to strengthen it and the interconnection between the offshore grid and the onshore grid is becoming increasingly important to transport renewable energy further inland to provide the need for direct electrification. This requirement is understood and confirmed by Ref. 15 and 16 which detail TenneT's planned investment in the onshore and offshore grid. The assumption for the search area 6 and 7 hub design is that this investment will be done.

Figure 3.2: Possible Future Meshed Network of Energy Hubs (ref. 6).



As described in section 2.3, energy hubs can fulfil multiple functions. To determine the usefulness and necessity of an energy hub, it is important to define the functions properly, since the functions are directly related to the benefits of an energy hub. The three main functions of an energy hub are:

- Collecting energy at sea before transporting it to land is most likely cheaper than direct export to shore due to economies of scale. In the case of energy conversion at sea it allows better use of pipelines.
- Connecting energy hubs with each other and different countries ensures a flexible and robust energy system, resulting in increased market integration and security of supply. It enlarges the sales area which promotes efficient electricity use.
- Being able to convert renewable electricity into hydrogen can support the integration of large amounts of energy into the energy system. This means that the direct demand can be served with sustainable hydrogen. In addition, these energy carriers can also offer advantages in terms of storage and transport.

These functionalities are visually presented in Figure 3.2. Depending on the construction form, an energy hub may be able to fulfil additional private and public functions. *Our evaluation of the energy hub concept will consider their key functions above and their potential to support other functionality, something which is more easily done on an artificial island than platforms.*

Due to the long realisation times, uncertainties in supply and demand and developments in the costs and available technologies of energy hubs, modularity in the roll-out is an important consideration. Due to the long timelines and rapid developments in the energy sector, there are important uncertainties that need to be considered, including:

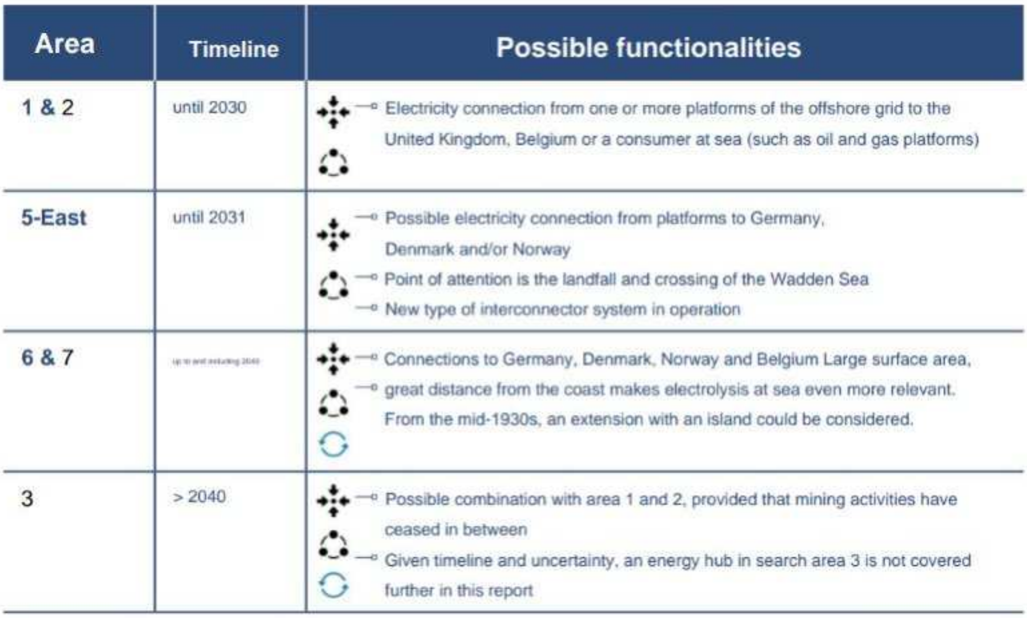
- How much wind capacity is to be developed and at what wind speed?
- Where is the offshore wind generated?

- What is the desired level of international connections?
- What is the best balance between the electricity and hydrogen infrastructure?
- How fast do new technologies mature?

The functions of the energy hubs can develop over time, from collection to conversion (Table 3.4). The characteristics of the wind search areas (location, water depth, distance to current gas infrastructure, etc.) are important here. Until 2030 or even 2035 depending on developments in offshore hydrogen production, energy hubs will mainly consist of electricity infrastructure, except for pilots and scaling up of offshore electrolysis. The collection function will be mainly fulfilled before the connection function (interlinks and interconnections). This is expected to be combined with significant onshore electrolysis capabilities, installed mainly between 2030 and 2035, to facilitate the integration of large amounts of offshore wind energy. Connections via the energy hubs with Germany, Denmark, Norway, Belgium, and the United Kingdom are currently being developed. Depending on technological developments and maturity, energy hubs are expected to also fulfil the conversion function after 2030, with electrolysis taking place not only on land but at sea.

This is in line with our concepts for the search area 6 and 7 energy hub which is based on development post 2030 and includes both capacity for interlinks and interconnections as well as offshore hydrogen production.

Table 3.3: Possible Functionalities of Wind Search Areas (ref. 6).



Area	Timeline	Possible functionalities
1 & 2	until 2030	Electricity connection from one or more platforms of the offshore grid to the United Kingdom, Belgium or a consumer at sea (such as oil and gas platforms)
5-East	until 2031	Possible electricity connection from platforms to Germany, Denmark and/or Norway Point of attention is the landfall and crossing of the Wadden Sea New type of interconnector system in operation
6 & 7	up to and including 2040	Connections to Germany, Denmark, Norway and Belgium Large surface area, great distance from the coast makes electrolysis at sea even more relevant. From the mid-1930s, an extension with an island could be considered.
3	> 2040	Possible combination with area 1 and 2, provided that mining activities have ceased in between Given timeline and uncertainty, an energy hub in search area 3 is not covered further in this report

Search areas 6 and 7 may be developed between 2030 and 2040. Given the technological developments and integration challenges in the energy system, this makes it potentially possible and desirable to realise energy hubs that serve all three hub functions.

Ref. 12 asks what is the societal value of offshore hubs and spokes in the North Sea compared to a case of pure radial connection of offshore wind? Current offshore wind generation has been developed radially with individual connections from wind farms to shore. The energy hub concept for search areas 6 and 7 developed as part of Workstream 3 is based on the hub and spoke approach.

The study focusses on providing perspectives on the socio-economic impact from specific configurations of hubs and spokes. Key questions addressed are:

- What is the societal value of offshore hubs and spokes?
- How is the evaluation impacted by
  - The expansion of hydrogen and electricity grids?
  - Development of energy prices?
  - Overplanting of offshore wind capacity?
  - The value of hydrogen production and electrolyser cost?

Key takeaways as they apply to Workstream 3 are:

- For any given scenario adding offshore wind to the system is beneficial.
- Most analysed hub and spoke configurations lead to a reduction in CO_2 emissions due to better integration of renewables in the short term.
- Overplanting offshore wind capacity at the Danish hub improves the socio-economic benefit as the importance of interconnection increases with higher offshore wind capacity. Our hub concepts are based on interconnection. IenW stated that wind blocks in search areas 6 and 7 will either be leased with 2 GW wind generation capacity or a given area to encourage maximisation of wind generation capacity. Our experience on NSWPH suggests significant benefits to overplanting a wind search area with larger WTGs with 20 MW turbines expected to be commercially available by 2030.

All hub and spoke configurations induce benefits in the surrounding energy system relative to the radial reference case.

3.4 Engagement with Stakeholders

To build on the understanding obtained from the Workstream 3 documents, engagement sessions were arranged with key stakeholders (refer to Section 2 for explanation of the roles of the stakeholders).

The first revision of this report was issued to stakeholders – Gasunie, TenneT, EBN, IenW and EZK – for comment. The comments received were discussed in follow-up sessions and then incorporated into the final version of the report as follows:

- Clear comments were incorporated directly into the report.
- Unclear comments were discussed in the follow-up sessions and then incorporated into the report.
- Comments that were out of the scope of workstream 3 or were related to follow-on work including wider stakeholder engagement were acknowledged but not incorporated into the report.
- Comments that related to our scoring of the concepts against the criteria were discussed in a new scoring workshop:
  - Where the team agreed with the comment the scoring or weighting for that criteria is updated.
  - Where the team felt the original scoring remained valid the comment was recorded and responded to in a “Stakeholder feedback” section in appendix C.

3.4.1 Engagement with IenW

Initial engagement was with IenW to understand the work done to date within search areas 6 and 7. IenW stated that whilst the overall wind generation capacity is not yet confirmed it is estimated that it could be up between 22 GW and 28 GW. It is assumed that search areas 6 and 7 would be fully developed before expansion to other search areas.

No firm plan has been developed for expansion beyond 2040. IenW stated that search area 8 has less than 2 GW of wind generation capacity and therefore will not be developed. Search areas 9 and 10 have only been investigated at a high level but have the most potential to be developed. Search Area 4 is used for military activities but does have space available.

As no official decision has been made on expansion beyond 2040 the design of the energy hub within Workstream 3 is based on expansion within search areas 6 and 7 only between 2030 and 2040. However, any impact of further expansion beyond 2040, for example in terms of interconnections, is to be considered.

In our first workshop held with IenW on 25-07-2022, we discussed the integration of the work of EIPN with the work being undertaken by IenW (ref 46). IenW confirmed to us that selection of the location of the energy hubs within search areas 6 and 7 is their responsibility and will be based on ecological impacts and their impact on other users. There will be an ecological exclusion zone at the centre of the search areas, but its size is not yet known.

To determine this, IenW are interviewing other stakeholders including:

- Oil and Gas developers.
- Other government departments to understand the requirement for heli-pads on platforms and any resulting exclusion zones.
  - Design decisions left to developers should not impact the spatial layout of the overall wind farm and therefore it is assumed that helicopter access is not required within the individual wind farm blocks.
- Gasunie and TenneT to understand their development plans.
- Ecological experts.
- NGOs.

In addition to the programme of interviews, IenW will investigate requirements for shipping lanes in consultation with neighbouring countries – the size of shipping permitted to pass through search areas 6 and 7 is not yet defined – and identify potential mining locations and required exclusion zones.

IenW stated that the region of search areas 6 and 7 is in the range of 40-50 m deep and this will be the basis of the analysis between islands and platforms.

Spatial planning of the wind farm expansion in search areas 6 and 7 has not yet been developed. EZK and IenW will work collaboratively to decide timing and location of wind block roll out. The spatial development of the wind farm will consider whether the blocks assigned to developers are based on area not on wind generation capacity. This would encourage the developer to maximise the energy yield. Whether the roll out is in a geographic sequence or scattered is not yet decided and this could impact ultimate energy hub design.

3.4.2 Engagement with Gasunie and TenneT

To understand the views of Gasunie and TenneT as key stakeholders potentially acting as the HNO and TSO and to understand their work done to date to assess the options for energy hubs in search areas 6 and 7, engagement meetings and workshops were arranged:

- Initial meeting with Gasunie and TenneT 17-07-2023
- Follow on meeting with Gasunie to develop decision funneling approach 27-07-2023
- Workstream 3 updates to Gasunie, TenneT and others 08-09-2023

- Critera scoring workshop 15-09-2023
- Scoring workshop Evaluation 1 21-09-2023
- Scoring workshop Evaluation 2 29-09-2023

The key aims of the meetings were to determine the basis of the energy hub in terms of overall capacity and the ratio of power export to hydrogen production and then to understand the key decisions needed to be made.

3.4.2.1 Capacity of the energy hub

The roll out of HVDC and offshore hydrogen production, including the ratio of 20 GW of HVDC to 9 GW of hydrogen production, proposed by workstream 1, was discussed in relation to the potential wind generation capacity of search areas 6 and 7 of 22-28 GW discussed with IenW.

The view of Gasunie, based on the analysis of grid integrated hydrogen production completed in the NSWPH programme, is that the optimal ratio of offshore hydrogen production to HVDC capacity for search areas 6 and 7 is one to one. This assessment assumes that technology readiness is not a limit on the roll-out of offshore hydrogen production but instead considers that by the early 2030s, offshore wind generation will have reached approximately 70 % of onshore demand for renewable electricity, requiring hydrogen production capacity to recover energy at peak wind speeds to provide time weighted flexibility to meet as much of the base demand as possible whilst also helping to decarbonise hard-to-abate industries. This hydrogen production should be located offshore due to limitations in the capacity to export direct power ashore via installed HVDC systems. The basis for the energy hub in workstream 3 therefore assumes that up to 50 % of wind generation capacity is exported ashore as hydrogen.

The required offshore hydrogen production capacity is also impacted by the demand for hydrogen onshore to support decarbonisation and alternative supplies. Offshore hydrogen production to recover energy when supply exceeds demand allowing for time-weighted flexibility will always be required but additional production capacity to use to decarbonise hard-to-abate industries will be affected by onshore supply. If alternative sources of hydrogen are available either as imports or from blue or other forms of hydrogen, then the total required capacity of offshore hydrogen production may be less.

The HVDC capacity in any individual location is limited to 6 GW by TenneT due to safety concerns. If a large offshore island is selected this results in an island capacity of 12 GW (6 GW of HVDC and 6 GW of hydrogen production).

The overall energy hub capacity for search areas 6 and 7 is assumed to be 24 GW of offshore wind generation based on the capacity estimated by IenW of 22 – 28 GW.

Individual wind farm blocks will be assigned to developers who will be responsible for their development under the guidance of Gasunie/TenneT working within the framework provided by EZK. The base assumption is that each wind block will be 2 GW, in line with the capacity of each HVDC system, resulting in 1 GW of direct power export and 1 GW of hydrogen production per block. Tennet in their models assume that each 2GW block can either export power or hydrogen or a combination of both. In reality it may be that each block is dedicated to direct power export or hydrogen production, and this would be a sensible approach if offshore hydrogen production is only ready later and therefore needs to be retro-fitted. The assumption of both hydrogen production and power export from each block was made to allow the concepts to be developed and to build cost estimates for comparison but it is not considered that either option would significantly impact the scoring of the overall concepts.

TenneT have developed a 2 GW standard HVDC system design for which they are responsible. Based on the expressed views of the Dutch and EU Governments regarding roles and responsibilities Gasunie will develop the design for hydrogen compression but not hydrogen production which will be left to the individual developers. On this basis hydrogen production will be located within each block unless a large island or islands is selected supporting the entire energy hub. It is up to individual developers whether hydrogen production is local to the WTGs or installed on separate platforms.

If hydrogen production is located on an island (either on a single central island or on multiple islands) then the assumption remains that hydrogen production is the responsibility of the associated wind block developer, due to the mutual dependency between wind generation and hydrogen production to facilitate energy export, and that it will be located within individual wind blocks. Locating hydrogen production within the wind blocks shortens and reduces the complexity of the array cable architecture.

Key assumptions

- Energy hub design is for search areas 6 and 7 between 2030 and 2040 only.
  - Initial roll-out of infrastructure in search areas 6 and 7 is targeted in 2032.
- As spatial planning has not yet been developed it is assumed that the blocks will be developed in a geographical sequence rather than scattered and that this will not directly impact the concept evaluation.
- EZK, with support from IenW, are responsible for setting the framework in which Gasunie and TenneT as the HNO and TSO will develop search areas 6 and 7.
- TenneT are responsible for the HVDC system design.
- Gasunie are responsible for the hydrogen compression design.
- Individual developers will be responsible for the hydrogen production design, which will be located within individual wind blocks. If it is not located on a large island, then developers are free to decide between platform-based production and production local to the WTGs.
- The offshore wind generation roll out between 2030 and 2040 is 29 GW. The wind generation capacity of search areas 6 and 7 is between 22 and 28 GW. The energy hub design is based on 24 GW of wind generation capacity of which 50 % is exported as direct power and 50 % as hydrogen.

3.4.3 Key Decisions and the Funnelling Process

Based on this understanding of the approach to development of the energy hubs within search areas 6 and 7, an initial decision framework was developed for discussion with Gasunie and TenneT during our initial workshop on the 17th of July 2023. Our initial approach assumed the development of a decision-making framework to choose between hydrogen production local to the WTGs and centralised hydrogen production either on platforms or artificial islands in line with the concepts developed during the NSWPH programme.

Gasunie advised us that this approach should be refined to consider key questions that EIPN needed to make initially to lead towards the selection of and energy hub concept:

- Key Decision 1 – Should a large island or islands be constructed to support the area 6 and 7 energy hub including PtG and HVDC equipment?
- Key Decision 2 – Should the energy hub be facilitated by platforms or a combination of an island and platforms?
- Key Decision 3 – Should compression be centralised or decentralised?
- Key Decision 4 – Should centralised compression be located on platforms or an island?

These decisions inherently lead to a funnelling process where each decision in the process defines the energy hub concept further and eliminates other concepts from selection. The consequences of each of these decisions are shown in the schematic below.

Figure 3.3: Decision Making Flow Chart

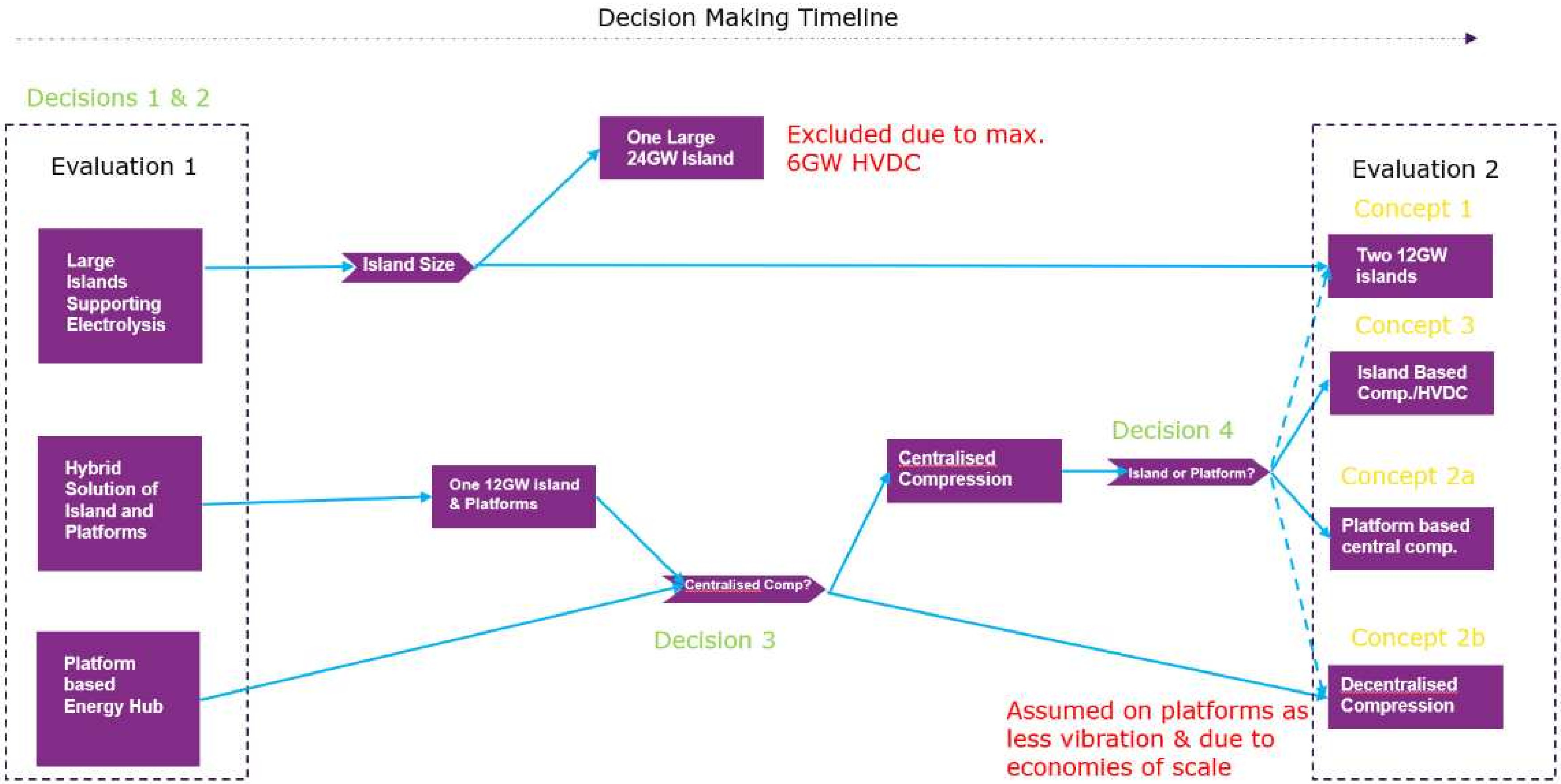


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Figure 3.3 indicates how making the key decisions refine the energy hub concept and eliminates alternative concepts. Key decisions 1 and 2 result in the selection of the base infrastructure on which the energy hub will be developed. These are key decisions which, due to the cost and complexity of constructing and installing offshore islands, will need to be made by the Government. To assist the Government in that decision making the three base infrastructure concepts defined by key decisions 1 and 2 – islands versus platforms versus a hybrid configuration – are comparatively evaluated in Evaluation 1 as described in Section 6.1.

Due to the risk to the European power system Tennet set a limit of 6 GW of HVDC equipment in any one location, meaning that selection of an island concept will result in two 12 GW islands. If all HVDC infrastructure was located in one place certain power loss scenarios would result in a European black-out.

For either the hybrid or platform-based concepts a decision is required between centralised and decentralised compression and the factors affecting this decision are described in Section 6.2. If hydrogen production is not included on a large artificial island, then it is assumed to be decentralised and located within the individual wind farm blocks on either 500MW platforms or located local to the WTG.

If a decentralised concept is selected the individual compression platform sizes are considered to make an island-based solution not credible. For centralised compression concepts a decision is required between platforms and islands, and it may be that technological or other factors drive selection of an island as described in Section 6.3.

These decisions lead to the four concepts, originally proposed by TenneT, as shown as Evaluation 2. Selection between these concepts, including the preceding decisions required for their definition, are for the Government. These concepts define the spatial layout of the wind farm and may dictate the construction and installation of offshore islands.

Table 3.4: Energy Hub Concepts proposed by TenneT.

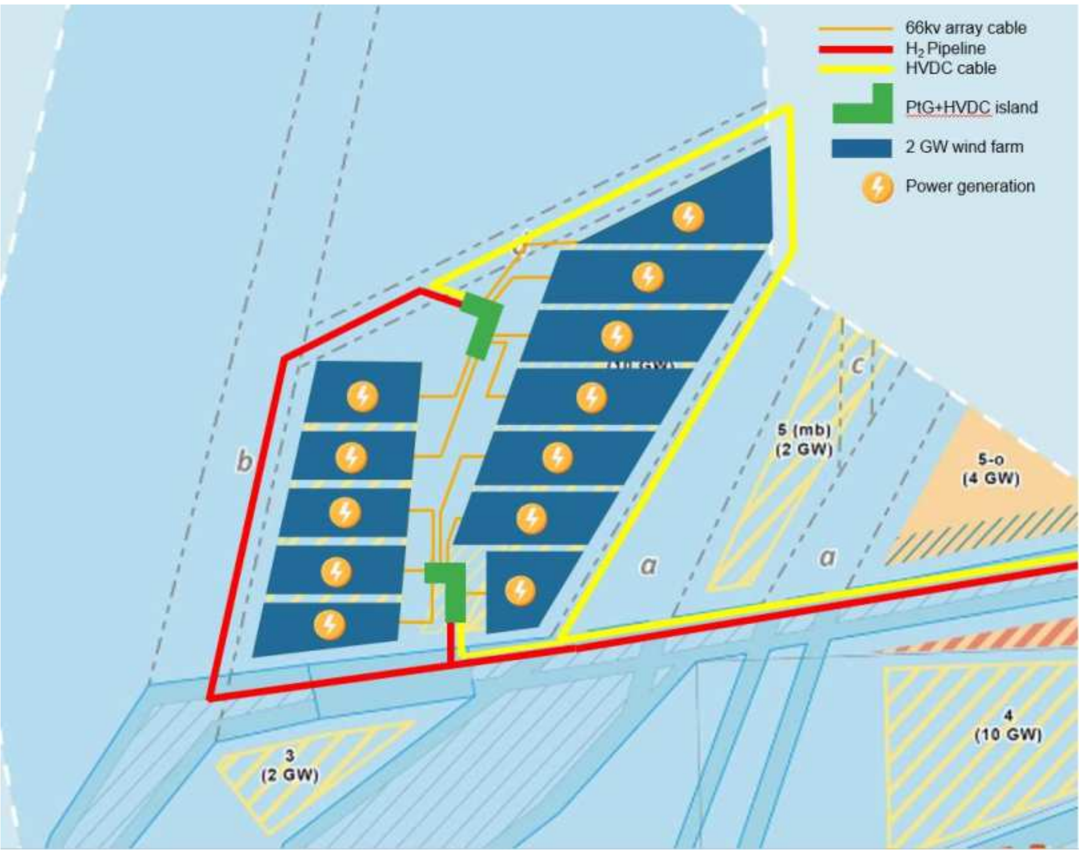
	Concept 1 Multi-purpose island incl. hydrogen production/ HVDC, etc.	**Concept 2a** Compression within block	**Concept 2b** Centralised compression (not within block)	**Concept 3** TSO/HNO island (compression/ HVDC but not H_2)
Overall wind capacity (6 GW of HVDC and 6 GW of H_2)	12 GW	12 GW	12 GW	12 GW (compress ion can facilitate full 24 GW)
Source Data	Basis is NSWPH island	NSWPH compression platform	NSPWH compression platform	TenneT/Gasunie to provide

To allow these concepts to be evaluated they must first be defined as indicated by Figure 3.4 to Figure 3.7. The intention of defining these concepts is firstly to aid understanding of them and to act as a basis for criteria evaluation. These are not intended to represent the final design of the energy hub nor intended to define the ultimate selection and are illustrative only. Gasunie and TenneT are developing layouts for search areas 6 and 7. The final energy hub developed will likely differ in significant ways:

- The total wind generation capacity of search areas 6 and 7, to be defined by IenW and EZK, and this will impact the overall design.
- The selection of wind farm blocks is similarly to be selected.
- The ratio of direct power export to hydrogen production will likely change and is influenced by factors including:
  - Ratio of offshore wind generation capacity to onshore demand for renewable electricity.
  - Degree of inter-hub and international interconnection.

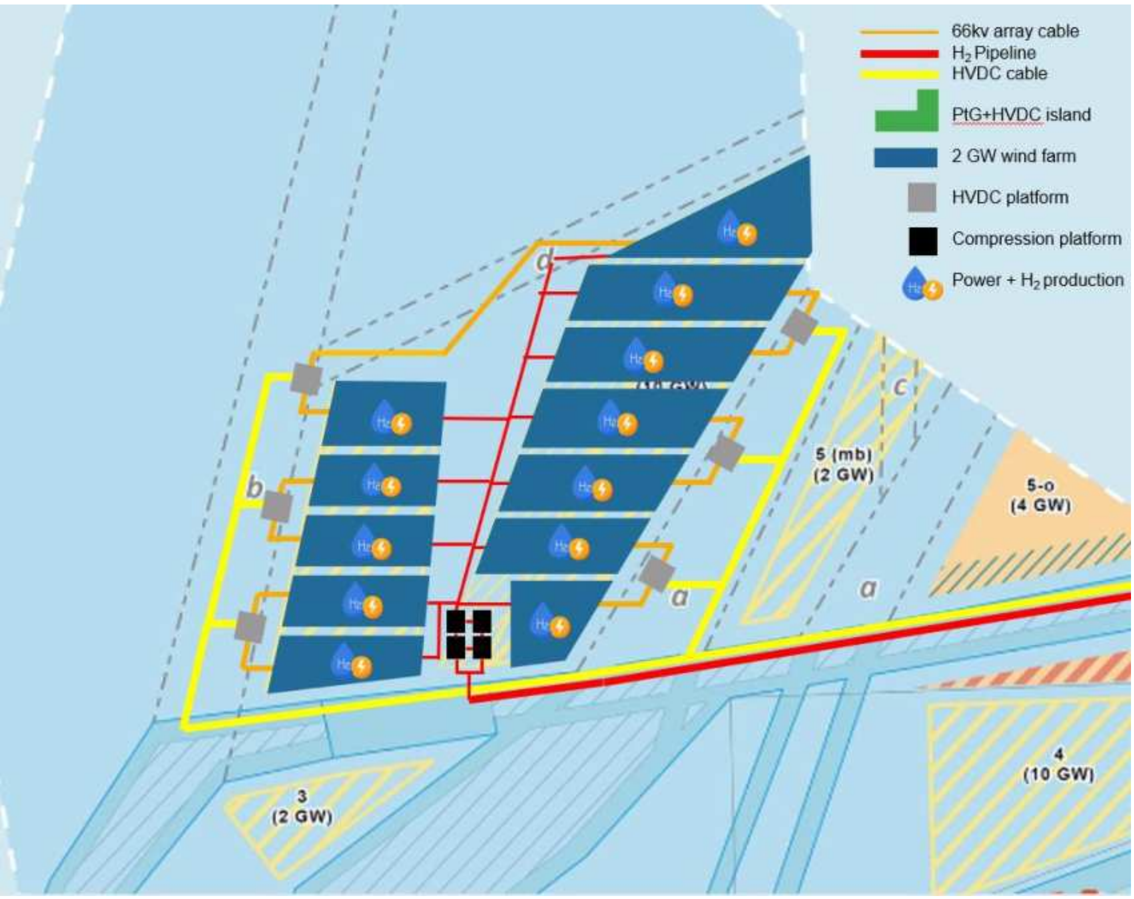
- Practicality of constructing onshore hydrogen production, influenced by factors including:
  - HVDC capacity to shore.
  - Availability of land.
  - Availability of cable land falls.
  - Permitting constraints.
  - Public consent.
  - Capacity of the onshore grid.
  - Imports of hydrogen to the Netherlands.
  - Blue hydrogen production onshore.
- The layout of the energy hub will depend on whether hydrogen is exported via existing subsea natural gas pipelines converted to hydrogen service or by new dedicated hydrogen pipelines.

Figure 3.4: Illustrative Layout of Concept 1 – Large Islands supporting hydrogen production.



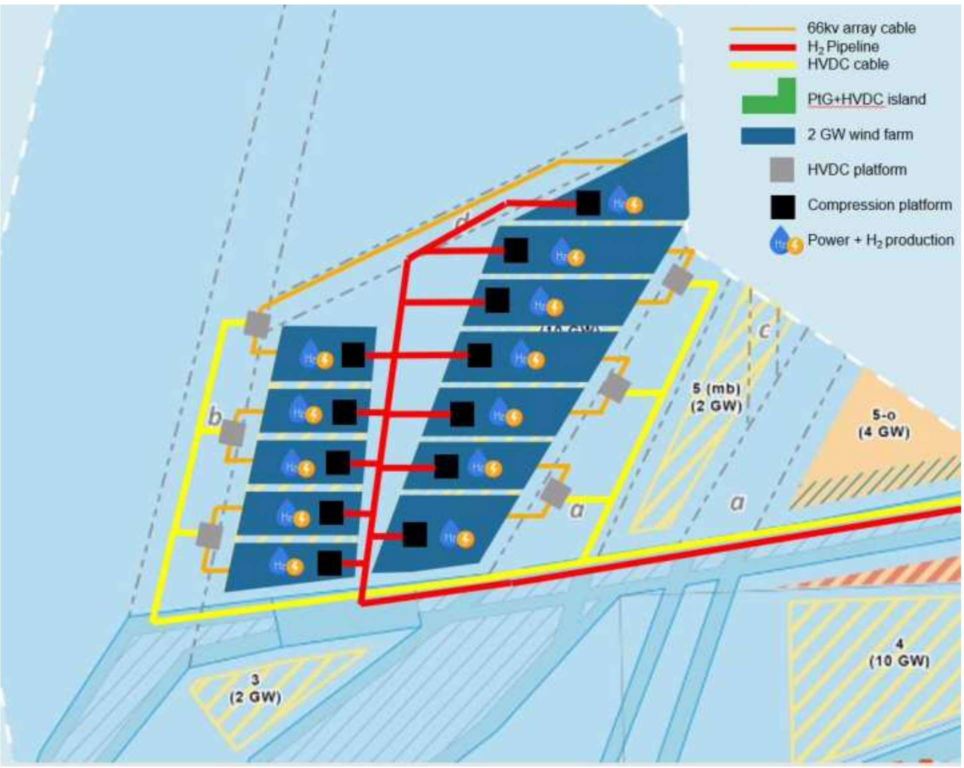
For concept 1 (Figure 3.4), all infrastructure other than the WTGs is installed on two 12 GW artificial islands. Each island has 6 GW of HVDC and 6 GW of hydrogen production and compression equipment installed on it. It is likely that other ancillary ,yet undefined, infrastructure will also be installed on the islands. Power is transmitted to the island from the WTGs by array cables.

Figure 3.5: Illustrative Layout of Concept 2a – Platform-based Hub including Centralised Compression



For Concept 2a (Figure 3.5), the wind farms and associated hydrogen production are located within the wind farm blocks. It will be for the individual developers in discussion with the Government to select between hydrogen production local to the WTGs and hydrogen production on platforms, and this decision can be made as the project progresses considering the merits of each option. HVDC equipment will be installed on TenneT's standardised 2 GW platforms and compression equipment will be located on centralised platform(s). Power from the individual blocks is transmitted to the HVDC platforms via array cables and hydrogen by flowlines to the compression platforms. Each individual compression platform will then tie-in to the subsea hydrogen pipeline to shore.

Figure 3.6: Illustrative Layout of Concept 2b – Platform-based Hub including Decentralised Compression



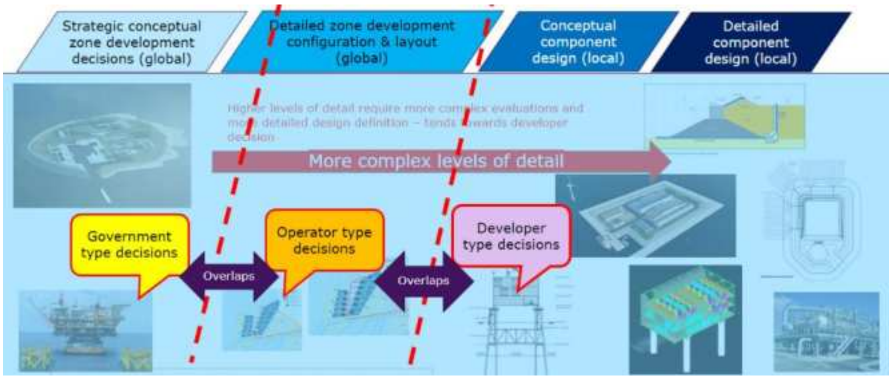
For Concept 2b (Figure 3.6), the wind farms and associated hydrogen production are located within the wind farm blocks. It will be for the individual developers in discussion with the Government to select between hydrogen production local to the WTGs and hydrogen production on platforms. HVDC equipment will be installed on TenneT's standardised 2 GW platforms. Compression equipment will be located on decentralised platforms located within each wind farm block. Power from the individual blocks is transmitted to the HVDC platforms via array cables and hydrogen by flowlines to the compression platforms. Each individual compression platform will then tie-in to the subsea hydrogen pipeline to shore.

Figure 3.7: Illustrative Layout of Concept 3 – Platform-based Hub but with Centralised Compression on an Island with 6 GW of HVDC Equipment

For concept 3 (Figure 3.7), the wind farms and associated hydrogen production are located within the wind farm blocks. It will be for the individual developers in discussion with the Government to select between hydrogen production local to the WTGs and hydrogen production on platforms. Compression equipment will be located on a centralised island. Due to the economies of scale, it makes practical sense to also locate HVDC equipment on the island up to the safety limit of 6 GW. The remaining HVDC equipment will be located on standardised 2 GW platforms. Power from the individual blocks is transmitted to the HVDC platforms or island via array cables and hydrogen by flowlines to the compression islands.

Further definition of the energy hubs is considered best left to the individual developers under the supervision of the HNO/TSO working under the framework developed by the Government as shown in Figure 3.8.

Figure 3.8: Typical Project Responsibilities



3.5 Engagement with EBN

EBN have a long history of involvement in the Dutch North Sea and are now extending their knowledge and practices into sustainable energy sources such as the transition from natural gas to hydrogen, heat transport and CO_2 transport and storage. An engagement workshop was organised to draw on their knowledge on the 21st of August). Key findings from this workshop are:

- The maturity of CCUS planning in search areas 6 and 7 is very low. No exact location for the CCUS infrastructure has been identified.
- Space needs to be retained around existing structures once decommissioning and building over existing infrastructure is not possible.
- Historically search areas 6 and 7 has been heavily fished and therefore there is a question as to what can be achieved in terms of ecology and biodiversity.
- EBN would like the overall EIPN programme to safeguard public interests.
- Geothermal energy infrastructure will be installed onshore as its low enthalpy after long distance transportation makes this impractical. Therefore, there is no requirement to incorporate this into the search area 6 and 7 energy hub.
- EBN is looking into the possibility of electrification of drilling or oil and gas platforms from the energy hub. If the cost of these is reasonable then electrification from the energy hub would be potentially attractive.
- EBN agree that technical independence of the CCUS and energy hub infrastructure is possible but that spatially they need to be considered together, e.g. for permitting. Their preference is for combined clusters to take advantage of synergies.
- EBN are currently completing a study on hydrogen storage and the white paper will be written in the coming weeks.
- EBN stated that, strategically, oil and gas extraction needs to continue in search areas 6 and 7 to avoid dependency on foreign oil and gas.
- Existing infrastructure within search areas 6 and 7 is described in the Memo on mining activities in wind search areas 6 and 7 provided by EBN (ref. 18) and described in section 2.14.

3.6 Stakeholder Engagement Timetable

Table 3.5: Stakeholder Engagement Timetable, including the date, the topic and the attendees.

Date	Title	Attendee	Minutes reference
13 April 2023	Kick Off	EZK, IenW, TenneT, Gasunie, EBN, Deloitte, Common Futures, Mott MacDonald, Norton Rose Fulbright	
26 April 2023	Stakeholder mapping	EZK, IenW, TenneT, Gasunie, EBN, Deloitte, Common Futures, Mott MacDonald, Norton Rose Fulbright	
17 May 2023	Kick off WS 3	Mott MacDonald, EZK, Deloitte, EBN, TenneT, IenW, Deloitte, Gasunie	
23 May 2023	Work session Workstream 2 and 3	Mott MacDonald, Deloitte	
23 May 2023	Knowledge sharing session	Deloitte, Mott MacDonald, Common Futures, Norton Rose Fulbright	

Date	Title	Attendee	Minutes reference
31 May 2023	Update meeting Workstream 2 and 3		
01 June 2023	Progress meeting with Min. EZK	EZK, Deloitte, Mott MacDonald, Common Futures, Norton Rose Fulbright	
06 June 2023	Start document Workstream 2 and 3	Deloitte and Mott MacDonald	
07 June 2023	Enrichment session NSPWH Pathway 1.0 and 2.0 studies	Deloitte, Norton Rose Fulbright, Mott MacDonald	
09 June 2023	Discussion on the questions from Gasunie	Deloitte, EZK, Mott MacDonald	
14 June 2023	EIPN WS Scope with TenneT	TenneT, Deloitte, Mott MacDonald	
15 June 2023	Discussion interface WS 1 and WS 3	Deloitte, Mott MacDonald, Common Futures	
16 June 2023	EIPN Workstream 3	EZK, IenW, TenneT, RVO, Gasunie, EBN, Deloitte	
16 June 2023	Scope discussion WS 3	Gasunie, Deloitte, EZK	
11 July 2023	Knowledge sharing session	Deloitte, Mott MacDonald, Common Futures, Norton Rose Fulbright	
17 July 2023	Workshop with Gasunie and TenneT	Mott MacDonald, Gasunie and TenneT	
21 July 2023	Enrichment Session with Bureau Veritas	Mott MacDonald and Bureau Veritas	45
25 July 2023	Enrichment Session with IenW	Deloitte, Mott MacDonald, IenW	46
27 July 2023	Workshop with Gasunie and TenneT	Deloitte, Mott MacDonald, Gasunie and TenneT	47
28 July 2023	Enrichment Session with EZK and RVO	Deloitte, Mott MacDonald, EZK, RVO	48
31 July 2023	Enrichment Session with TNO - North Sea Energy	Deloitte, Mott MacDonald, TNO	49
21 August 2023	Enrichment session with EBN	EBN, Deloitte, Mott MacDonald	
01 September 2023	Knowledge sharing session - Action Agenda	Deloitte, Mott MacDonald, Common Futures, Norton Rose Fulbright	50
08 September 2023	WS 3 workshop	Mott MacDonald, EZK, Deloitte, EBN, TenneT, IenW, Deloitte, Gasunie	51
15 September 2023	WS 3 workshop	Mott MacDonald, EZK, Deloitte, EBN, TenneT, IenW, Deloitte, Gasunie	52
21 September 2023	WS 3 workshop	Mott MacDonald, EZK, Deloitte, EBN, TenneT, IenW, Deloitte, Gasunie	53
29 September 2023	WS 3 workshop	Mott MacDonald, EZK, Deloitte, EBN, TenneT, IenW, Deloitte, Gasunie	54

4 Decision Making Timeline

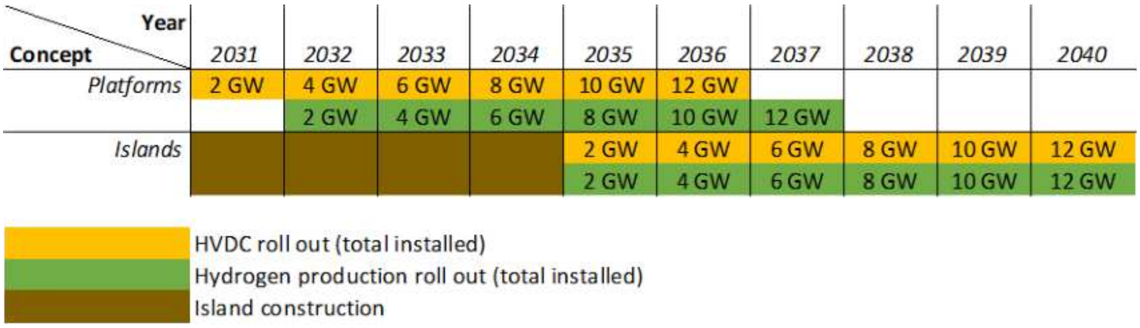
The aim of Workstream 3 is to both provide a funnelling process for decision making to define the energy hub for search areas 6 and 7 and to provide context and evidence to allow the Dutch Government to make each of the key decisions. There will never be perfect information to support the decisions and the basis by which the criteria scoring was reached is described in Section 6. Key to making these decisions is understanding their required timeline and the impact of delays in decision making as well as the timeline for further information becoming available.

As part of the conceptual design studies completed during the NSWPH programme, schedules were developed for first power export and first hydrogen production for energy hub concepts based on platforms and a caisson island. As these schedules included onshore hydrogen production, which was scheduled to operate first, and as they prioritised HVDC equipment installation on the caisson island, they have been adapted for Workstream 3 (Figure 4.1 and

Figure 4.2). Our priority is to determine how quickly offshore power export and offshore hydrogen production can be developed on platforms and island (see Appendix C for these adapted schedules).

The projected roll-out of offshore power export and hydrogen production based on these adapted schedules is shown in the table below. The schedule assumes that concept design and refinement phases are close to completion and that the FEED phase will begin in 2024. Given that the NSWPH concepts do not exactly match the Workstream 3 concepts, there is already potential slippage to the schedule.

Table 4.1: Offshore Power Export & Hydrogen Production Timeline. The schedule does not take regulation and technology constrains into account.

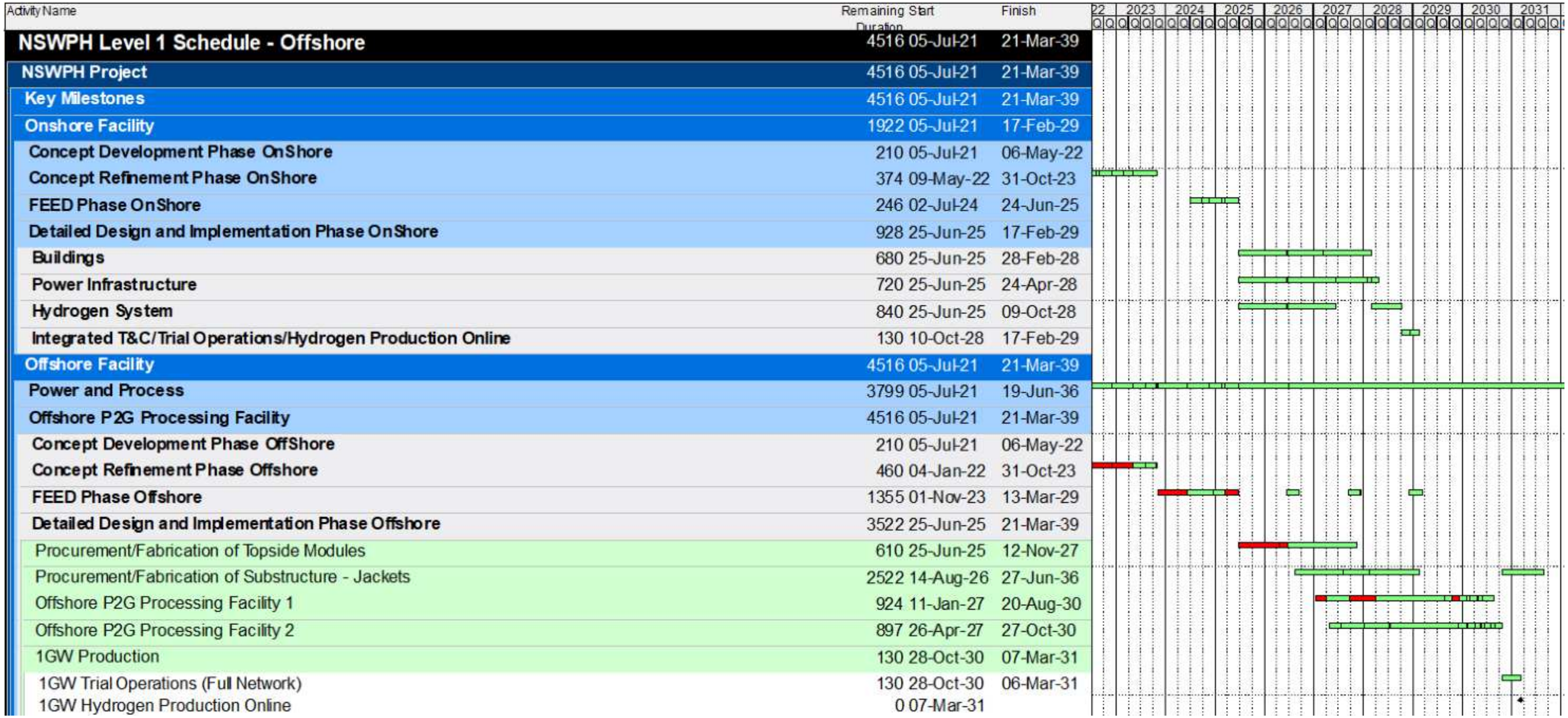


Year Concept	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Platforms	2 GW	4 GW	6 GW	8 GW	10 GW	12 GW				
		2 GW	4 GW	6 GW	8 GW	10 GW	12 GW			
Islands	🟫	🟫	🟫	🟫	2 GW	4 GW	6 GW	8 GW	10 GW	12 GW
					2 GW	4 GW	6 GW	8 GW	10 GW	12 GW

🟨 HVDC roll out (total installed)
🟩 Hydrogen production roll out (total installed)
🟫 Island construction

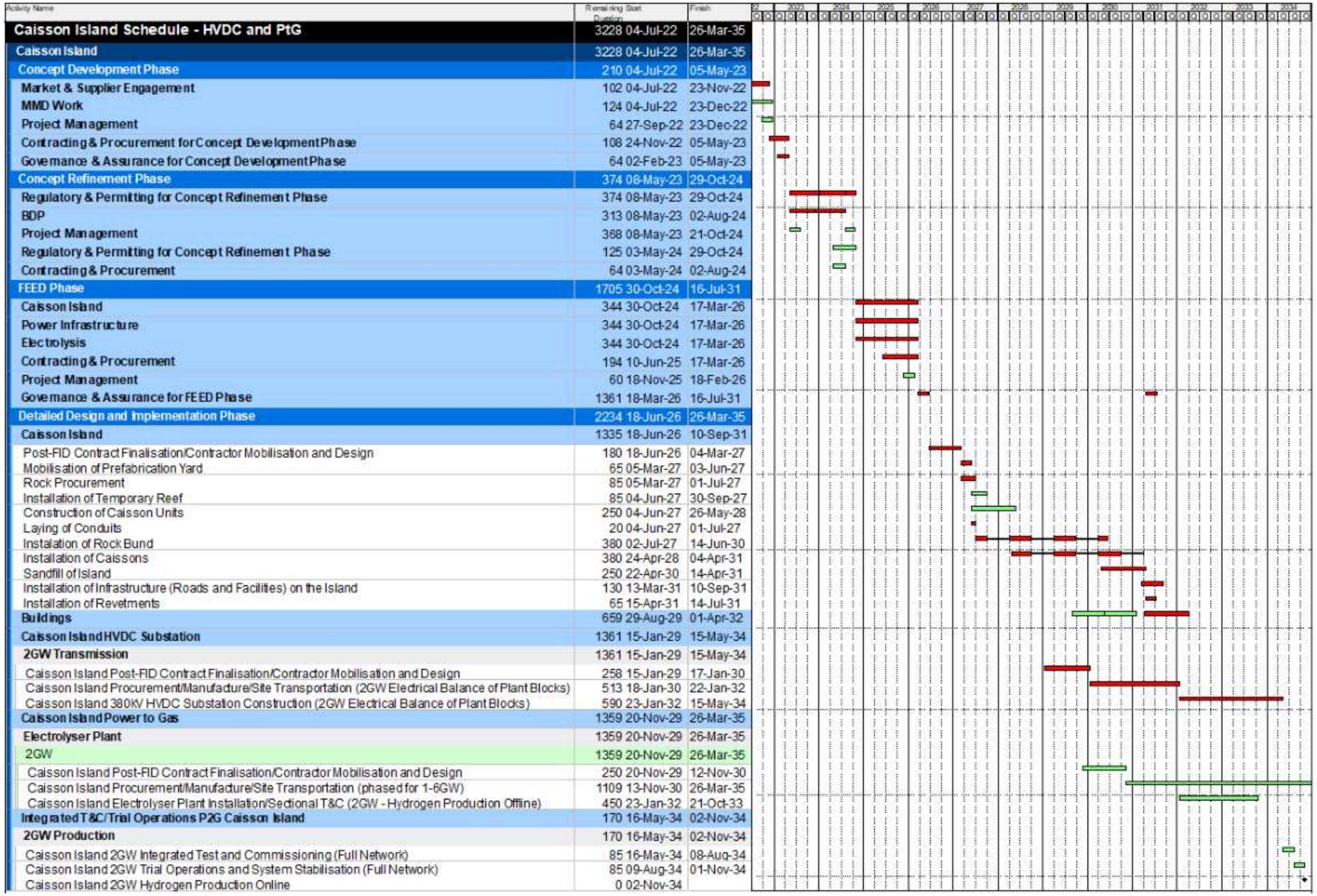
The timeline in the table above is an optimised timeline on what could be achieved assuming no constraints to roll out of either HVDC or offshore hydrogen production infrastructure and is based on an assumption that the optimal ratio of direct power to hydrogen export is one to one. It is based on the platform-based and island-based energy hub schedules developed during the NSWPH programme. In reality there will be constraints which could delay the roll-out and the optimal ratio of HVDC to offshore hydrogen production infrastructure will depend on many factors as yet undefined.

Figure 4.1: Level 1 schedule for platform-based hydrogen production (ref. 19).



Activity Name	Remaining Duration	Start	Finish
NSWPH Level 1 Schedule - Offshore	4516	05-Jul-21	21-Mar-39
NSWPH Project	4516	05-Jul-21	21-Mar-39
Key Milestones	4516	05-Jul-21	21-Mar-39
Onshore Facility	1922	05-Jul-21	17-Feb-29
Concept Development Phase OnShore	210	05-Jul-21	06-May-22
Concept Refinement Phase OnShore	374	09-May-22	31-Oct-23
FEED Phase OnShore	246	02-Jul-24	24-Jun-25
Detailed Design and Implementation Phase OnShore	928	25-Jun-25	17-Feb-29
Buildings	680	25-Jun-25	28-Feb-28
Power Infrastructure	720	25-Jun-25	24-Apr-28
Hydrogen System	840	25-Jun-25	09-Oct-28
Integrated T&C/Trial Operations/Hydrogen Production Online	130	10-Oct-28	17-Feb-29
Offshore Facility	4516	05-Jul-21	21-Mar-39
Power and Process	3799	05-Jul-21	19-Jun-36
Offshore P2G Processing Facility	4516	05-Jul-21	21-Mar-39
Concept Development Phase OffShore	210	05-Jul-21	06-May-22
Concept Refinement Phase Offshore	460	04-Jan-22	31-Oct-23
FEED Phase Offshore	1355	01-Nov-23	13-Mar-29
Detailed Design and Implementation Phase Offshore	3522	25-Jun-25	21-Mar-39
Procurement/Fabrication of Topside Modules	610	25-Jun-25	12-Nov-27
Procurement/Fabrication of Substructure - Jackets	2522	14-Aug-26	27-Jun-36
Offshore P2G Processing Facility 1	924	11-Jan-27	20-Aug-30
Offshore P2G Processing Facility 2	897	26-Apr-27	27-Oct-30
1GW Production	130	28-Oct-30	07-Mar-31
1GW Trial Operations (Full Network)	130	28-Oct-30	06-Mar-31
1GW Hydrogen Production Online	0	07-Mar-31	

Figure 4.2: Level 1 schedule for caisson-island based power export & hydrogen production (ref. 21).



Activity Name	Remaining Duration	Start	Finish
Caisson Island Schedule - HVDC and PtG	3228	04-Jul-22	26-Mar-35
Caisson Island	3228	04-Jul-22	26-Mar-35
Concept Development Phase	210	04-Jul-22	05-May-23
Market & Supplier Engagement	102	04-Jul-22	23-Nov-22
MMD Work	124	04-Jul-22	23-Dec-22
Project Management	64	27-Sep-22	23-Dec-22
Contracting & Procurement for Concept Development Phase	108	24-Nov-22	05-May-23
Governance & Assurance for Concept Development Phase	64	02-Feb-23	05-May-23
Concept Refinement Phase	374	08-May-23	29-Oct-24
Regulatory & Permitting for Concept Refinement Phase	374	08-May-23	29-Oct-24
BDP	313	08-May-23	02-Aug-24
Project Management	368	08-May-23	21-Oct-24
Regulatory & Permitting for Concept Refinement Phase	125	03-May-24	29-Oct-24
Contracting & Procurement	64	03-May-24	02-Aug-24
FEED Phase	1705	30-Oct-24	16-Jul-31
Caisson Island	344	30-Oct-24	17-Mar-26
Power Infrastructure	344	30-Oct-24	17-Mar-26
Electrolysis	344	30-Oct-24	17-Mar-26
Contracting & Procurement	194	10-Jun-25	17-Mar-26
Project Management	60	18-Nov-25	18-Feb-26
Governance & Assurance for FEED Phase	1361	18-Mar-26	16-Jul-31
Detailed Design and Implementation Phase	2234	18-Jun-26	26-Mar-35
Caisson Island	1335	18-Jun-26	10-Sep-31
Post-FID Contract Finalisation/Contractor Mobilisation and Design	180	18-Jun-26	04-Mar-27
Mobilisation of Prefabrication Yard	65	05-Mar-27	03-Jun-27
Rock Procurement	85	05-Mar-27	01-Jul-27
Installation of Temporary Reef	85	04-Jun-27	30-Sep-27
Construction of Caisson Units	250	04-Jun-27	26-May-28
Laying of Conduits	20	04-Jun-27	01-Jul-27
Instalation of Rock Bund	380	02-Jul-27	14-Jun-30
Installation of Caissons	380	24-Apr-28	04-Apr-31
Sandfill of Island	250	22-Apr-30	14-Apr-31
Installation of Infrastructure (Roads and Facilities) on the Island	130	13-Mar-31	10-Sep-31
Installation of Revetments	65	15-Apr-31	14-Jul-31
Buildings	659	29-Aug-29	01-Apr-32
Caisson Island HVDC Substation	1361	15-Jan-29	15-May-34
2GW Transmission	1361	15-Jan-29	15-May-34
Caisson Island Post-FID Contract Finalisation/Contractor Mobilisation and Design	258	15-Jan-29	17-Jan-30
Caisson Island Procurement/Manufacture/Site Transportation (2GW Electrical Balance of Plant Blocks)	513	18-Jan-30	22-Jan-32
Caisson Island 380KV HVDC Substation Construction (2GW Electrical Balance of Plant Blocks)	590	23-Jan-32	15-May-34
Caisson Island Power to Gas	1359	20-Nov-29	26-Mar-35
Electrolyser Plant	1359	20-Nov-29	26-Mar-35
2GW	1359	20-Nov-29	26-Mar-35
Caisson Island Post-FID Contract Finalisation/Contractor Mobilisation and Design	250	20-Nov-29	12-Nov-30
Caisson Island Procurement/Manufacture/Site Transportation (phased for 1-6GW)	1109	13-Nov-30	26-Mar-35
Caisson Island Electrolyser Plant Installation/Sectional T&C (2GW - Hydrogen Production Offline)	450	23-Jan-32	21-Oct-33
Integrated T&C/Trial Operations P2G Caisson Island	170	16-May-34	02-Nov-34
2GW Production	170	16-May-34	02-Nov-34
Caisson Island 2GW Integrated Test and Commissioning (Full Network)	85	16-May-34	08-Aug-34
Caisson Island 2GW Trial Operations and System Stabilisation (Full Network)	85	09-Aug-34	01-Nov-34
Caisson Island 2GW Hydrogen Production Online	0	02-Nov-34	

For platform-based concepts the current schedule of first power export in 2030 and first hydrogen production in 2031 meets the requirement for initial roll-out of infrastructure in search areas 6 and 7 in 2032 with limited concern on the roll-out of TenneT's standardised HVDC platforms. For a hybrid configuration it is assumed that initial roll-out will be platform based, meaning the target date for first hydrogen and power export from the island is approximately 2035.

The longer schedule for island-based concepts is driven by island construction and the need for initial construction to occur only during the summer weather window. Island based concepts will be more challenging and if the target date for first power export and offshore hydrogen production of 2032 is to be achieved, then government resources will need to be targeted at removing schedule constraints which include:

- Technology readiness of artificial island(s) in 50 m water depth.
- Technology readiness of key equipment operating in a marine environment.
- Material constraints for island construction.
- Equipment supply constraints.
- Developments in construction and installation techniques to widen the summer weather window.
- Regulatory constraints.
- Permitting constraints and environmental impact assessment.
- Funding availability.

Key to maintaining and optimising the schedules, in addition to making the key decisions, is progressing the project development. It is recommended that, based on the selected concept, a FEED study guided by the work done on the NSWPH is initiated as soon as possible – the schedules above assume that FEED begins in 2024 and there will be a concept refinement phase to adapt the work done during the NSWPH programme to the selected energy hub concept.

As described in Table 4.2, it may be wise to initiate parallel FEEDs of more than one concept to gain more information before a final decision is made. Guided by these schedules, the key workstream decision timeline has been developed.

Table 4.2: Decision Timeline.

Decision	Date Required	Comments
1	As soon as possible	Hydrogen production by 2032 requires immediate project development and optimised schedules, especially for island-based concepts
2	By circa 2025	As a hybrid solution allows for later island installation the project could continue on a dual path with final decision prior to beginning the Engineering Procurement and Construction (EPC) Phase
3	By circa 2025	As designs for both centralised and decentralised platforms could be developed in parallel, the project could progress to EPC before a final decision is made. Pre-FEED design efforts will be focussed on the 500MW demonstration hydrogen production platform (Demo 2). Lessons from this project should aid decision making and be incorporated into the design of the overall energy hub.
4	As soon as possible	If a compression island is required, then a decision is required as soon as possible. Greater delay may force selection of decentralised compression. Further technical studies are required to make the decision, developing on the work done in the NSWPH programme.

Key to realising the energy hubs on schedule is not just making the decisions within the timeline shown above but initiating the project and progressing through the stages of project development.

4.1 Energy Hub Location

IenW is responsible for spatial planning in the North Sea and will therefore select hub locations, in close cooperation with other ministries. Ideally the project would be able to develop with selected energy hub locations from the start. However, by selecting conservative design parameters, including water depth and metocean conditions, the initial design of the island or platforms can be generic and applicable to the whole of search areas 6 and 7.

As the project progresses towards FEED and EPC from 2024 to 2027, and more information becomes available in relation to the likely location, this can be incorporated into the hub design. Clearly, selection of developers and construction of the hub cannot begin until the location of key hub infrastructure is selected.

5 Decision Support and Assessment Frameworks

5.1 Multi-Criteria Decision Analysis

Strategic decision-making at a national level typically involves balancing subjective preferences of different stakeholder groups who have vested interests in consequences of the outcomes. Multi-Criteria Decision Analysis (MCDA) is a methodology to evaluate and compare various options with each other, with the view to ranking them in terms of preferential order. The options being compared may achieve some but not all the objectives or interests of the decision-maker. These objectives and interests establish the criteria for evaluating the various options.

These comparative decisions typically require an evaluation of multiple criteria, where there may be potential conflicts between the criteria that have an impact on the choices. Examples being where additional quality and safety may come with increased costs. Selecting the option with the lowest cost potentially results in an option with lower quality or safety. Similarly, short-term benefits may conflict with long-term benefits. These comparative evaluation problems do not always have unique, best or optimal solutions and are driven by the decision-makers preferences. Consequently, if stakeholders are involved, their contribution to the decision-making process is integral to finding an appropriate solution that represents their interests and preferences. Stakeholder involvement has the simultaneous benefit of integrating stakeholder knowledge and insights, and potentially gaining their support for the outcomes.

MCDA involves comparing a group of options against each other using a consistent set of relevant criteria. MCDA facilitates evaluations involving both quantitative and qualitative evaluations and helps to analyse complex problems. MCDA does not provide a final decision but serves to guide the decision-making process by facilitating the thinking processes and considering the available information that may be relevant to help understand the consequences of selecting one option over another.

MCDA follows the following systematic methodology to evaluate options:

- Establish the decision context (identify the objectives of the decision, the key decision-makers, the stakeholders, and the relevant data and information)
- Identify the options to be evaluated.
- Identify the criteria, objectives or interests involved.
- Evaluate the performance of each option against the criteria.
- Assign weights to each criterion to reflect the relative importance to the decision.
- Combine the weights and scores for each option to establish an overall comparative value.
- Examine and interpret the results.
- Perform a sensitivity analysis to establish the impact that different preferences have on the ranking of the options.

MCDA has many benefits over informal judgement in that it is transparent and explicit. The selection of criteria, interests or objectives used in the evaluation are open to analysis and can be modified if additional insights require more criteria to be evaluated. The scores and weights used can be cross-referenced to relevant sources of information, justified by the decision-maker based on their insights or amended, if necessary. The evaluation of performance measurements against specific criteria can be sub-contracted to experts, rather than relying exclusively on the knowledge and insights of any one group of decision-makers (in this case government). The use of scores and weights establishes an audit trail. MCDA also provides an effective way to communicate results with other stakeholders or interested parties.

5.2 Assessment Frameworks and Decision Funnelling

Making a recommendation about the decision of a construction form of an energy hub is a complex problem influenced by many different design principles, optimisation variables, technical and non-technical considerations and stakeholder interests. In requesting a funnelling process to arrive at a choice about the construction form of an energy hub, the Dutch Government recognises that there are several different options available and there is a need to make a selection decision that reduces the options to the point where the work can be commissioned for implementation.

The first step in understanding what options are available is to consider what equipment is required and then how that equipment can be configured to meet the objectives of offshore electricity and hydrogen production and the export thereof to the onshore markets. Looking at the equipment at a high level, there are:

- The Wind Turbine Generators (WTGs)
- The electrical collection system of array cables
- The High Voltage Direct Current (HVDC) conversion and transmission systems
- Electrolysis modules with power supply and water treatment facilities
- Hydrogen compressors
- Hydrogen collection and distributions systems via low pressure flowlines or high-pressure pipelines

Taking the interconnections of energy collection, transport, transmission and distribution out of the list leaves several functional blocks of equipment that need to be arranged in a way that serves the overall wind park development. This equipment (the HVDC, Electrolyser and Compressor systems) represents the heaviest components that need foundation support offshore. Given that there are several different foundation support construction forms available results in a large number of potential combinations of equipment configurations in combination with construction forms. Table 5.1 and Table 5.2 give some insight into the numerous combinations that could be considered.

Table 5.1: Combinations of islands and hybrid solutions.

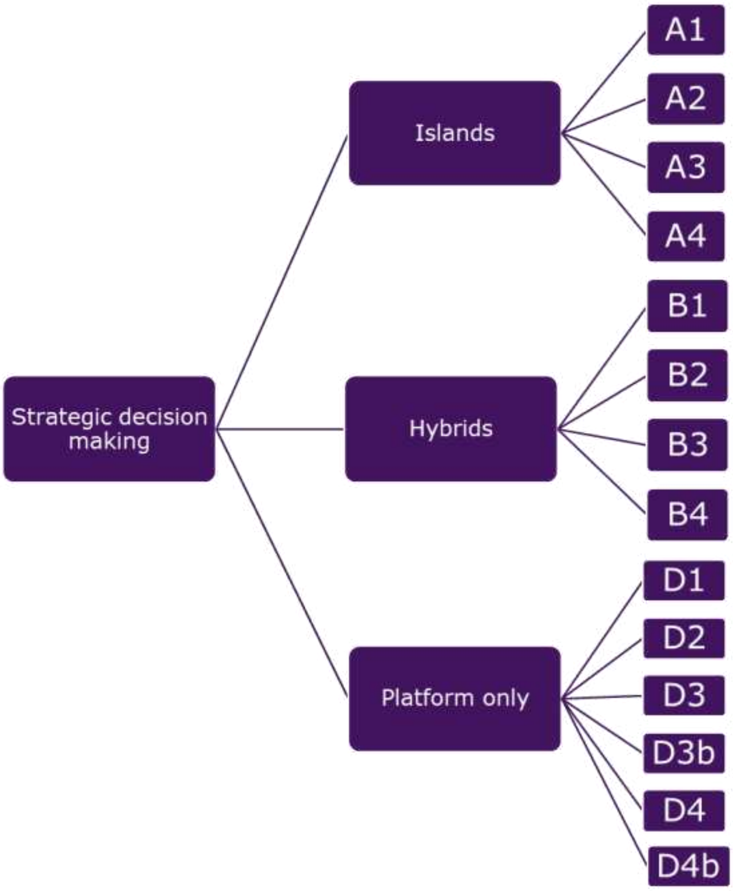
Strategic conceptual design	Combination description	Location	Equipment	Island(s)	Platform	WTG
Combination A	**Combination A1**	Power on Island	HVDC	X		
Island(s) only	1 Large Island	Compression on Island	Compression	X		
	Fully integrated	H2 electrolysers on Island	Electrolysers	X		
	Combination A2	Power on Island	HVDC	X		
	Power & Compression	Compression on Island	Compression	X		
	Island	H2 at WTGs	Electrolysers			X
	Combination A3	Power on Islands	HVDC	X		
	2 or more small islands	Compression on Islands	Compression	X		
	fully integrated	H2 electrolysers on Islands	Electrolysers	X		
	Combination A4	Power on Islands	HVDC	X		
	2 or more small islands	Compression on Islands	Compression	X		
		H2 at WTGs	Electrolysers			X
Combination B	**Combination B1**		HVDC	X		
Hybrids	Electrolyser platforms	Power & Compression Island	Compression	X		
		H2 on platforms	Electrolysers		X	
	Combination B2	Power & Compression Island	HVDC	X		
	Electrolysers at WTGs	Power & Compression Island	Compression	X		
		H2 at WTGs	Electrolysers			X
	Combination B3	Power on Platforms	HVDC		X	
	Power Platforms	H2 & Compression on Island	Compression	X		
		H2 & Compression on Island	Electrolysers	X		
	Combination B4	Power & H2 on Islands	HVDC	X		
	Compression platforms	Compression platforms	Compression		X	
		Power & H2 on Islands	Electrolysers	X		
Phased Hybrids	**Combination C1**		HVDC	Ph.2	Ph.1	
Start on platforms, then	All Ph.2 equip. on island	All Ph.2 equip. on island	Compression	Ph.2	Ph.1	
build an Island later			Electrolysers	Ph.2	Ph.1	
Ph.1 = phase 1	**Combination C2**	Power & Compression Island	HVDC	Ph.2	Ph.1	
Ph.2 = phase 2	Power & Compression Island	Elctrolysers stay on platforms	Compression	Ph.2	Ph.1	
			Electrolysers		Ph.1	
	Combination C3	Power & Compression Island	HVDC	Ph.2	Ph.1	
	Power & Compression Island	PtG at WTGs	Compression	Ph.2	Ph.1	
			Electrolysers		Ph.1	Ph.2

Table 5.2: Combinations of platform-based solutions.

Combination	Description	Equipment	Fuly Integrated	Dual purpose	HVDC only	Electrolysers only	Compression only	H2 at WTGs
Combination D1	One large fully	HVDC	X					
Large fully integrated	Integrated platform	Electrolysers	X					
		Compression	X					
Combination D2	Power Platforms	HVDC			X			
H2 multi-purpose	H2 Multi-Platform	Electrolysers		X				
		Compression		X				
Combination D3	Power Platforms	HVDC			X			
Dedicated service Platforms	Electrolyser (PtG) platforms	Electrolysers				X		
	Compression PFs	Compression					X	
Combination D3b	Power Platforms	HVDC			X			
Dedicated service Platforms	PtG at WTGs	Electrolysers						X
	Compression platforms	Compression					X	
Combination D4	Power and Compression	HVDC		X				
Power & Compression	Electrolyser (PtG) platforms	Electrolysers				X		
Multipurpose, H2 on PFs	Power and Compression	Compression		X				
Combination D4b	Power and Compression	HVDC		X				
Power & Compression	PtG at WTGs	Electrolysers						X
Multipurpose, H2 at WTGs	Power and Compression	Compression		X				

The result is an exponential increase in potential options (See Figure 5.1) resulting in too many considerations for an effective selection. There is a clear need for a decision funnelling process to avoid having to compare and evaluate too many different design permutations.

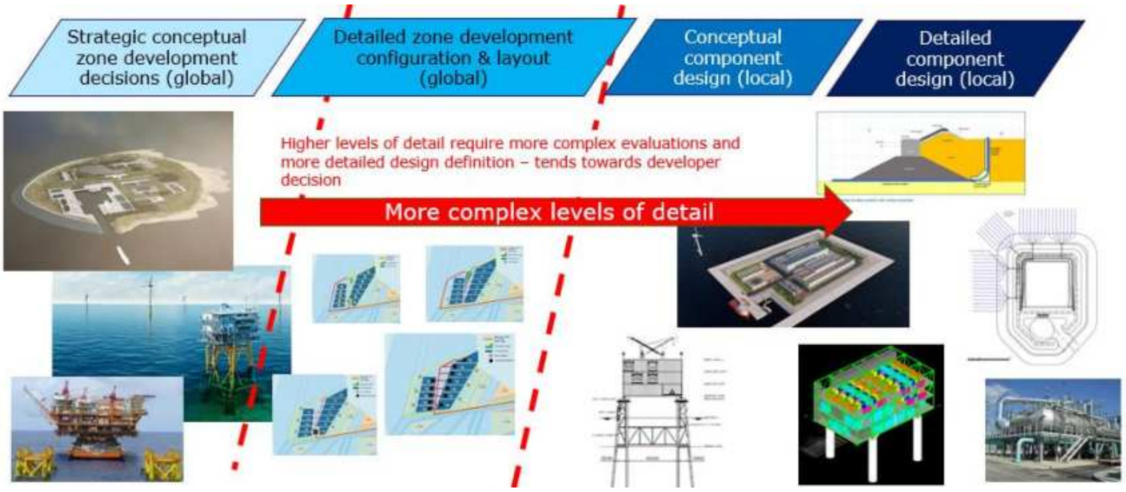
Figure 5.1: Decision-funnelling



Added to this is the complexity of spatial distribution planning and the effect that this has on the potential for different design permutations. Wind energy collection offshore is spatially distributed amongst many WTGs covering a large wind park area (referred to as a 'search area' prior to development). Key decisions involve selecting the configuration and spatial distribution of all the other equipment needed to produce and transport the converted energy streams (electricity and hydrogen) to shore. There are technical, practical and strategic limitations to how much of this equipment can be centralised in one location and how many transport routes can be used to get the energy streams to shore. There are advantages and disadvantages associated with the degree of centralisation of the different systems.

The number of combinations increases as more levels of detail are added to the definition of the solution. Once a strategic decision has been made about a foundation design, the spatial layout requirements for the overall development zone needs to be considered, followed by the conceptual design variations for each of the structural options and then the detailed configuration and layout of the various components. Figure 5.2 presents this progression in the level of detail graphically.

Figure 5.2: Transition from strategic to detailed decision-making.



As the level of detail increases the nature of the decision-making process progresses from strategic decisions (e.g. whether government is going to build an artificial island in its national economic exclusion zone) to detailed design decisions (e.g. plot plans, the layout and configuration of wires and pipes, etc.). Detailed design decisions require a high degree of scope definition and are best taken by developers and service providers. Strategic decisions that have implications for national interests are best taken by government in collaboration with relevant stakeholders. Somewhere in between these two extremes the decision-making is best made by the operators who need to own and operate the facilities. There are no obvious boundaries along this continuum which makes it challenging to decide where the boundary should lie for determining the end of the decision funnelling process.

It is clear that the potential need to construct an artificial island in Dutch national waters in the North Sea is a nationally important strategic decision. This forms the first evaluation in the decision funnelling process where the potential need for an island is compared to alternatives involving a platform-based solution or hybrid solutions involving combinations of platforms and an island. More details about this decision and other decisions further down the decision funnelling process are described in Section 3.4.3.

5.3 Evaluation Criteria and Weighting

We have used a MCDA trade-off framework to evaluate options based on their relative performance against several criteria. The selection of these criteria has been guided by the terms of reference for this study that specifically called for the analysis and completion of an objective trade-off framework taking the impact of the following design principles into account:

- Ecology: analysis of quick scan completed on behalf of IenW overseeing construction form. Supplemented with own analysis supervising ecological impact of hydrogen production, storage and transport at sea (including desalination waste streams).
- Environmental impact: Life Cycle Assessment (LCA) to reflect impacts of material use.
- Cost: analysis of the key cost drivers (CapEx and OpEx) of an energy hub, including the potential of supply chain delivery of needed inputs.
- System integration: identifying key variables in the operation and development of energy infrastructure systems and their interdependencies and technical integration based on preliminary studies provided by Client and direct stakeholders (Gasunie, EBN, IenW and TenneT).
- Security of supply: Identify key drivers of security of supply and their correlation based on preliminary studies resulting in a methodology for policy support.

Furthermore, this Workstream was tasked with identifying other elements within the trade-off framework that would have relevance to the decision-making process, taking factors like supply chain, availability of materials and people, maturity of technology and modularity, amongst others into account. During a workshop held on 27 July 2023 with Gasunie and TenneT, several performance criteria were listed as part of a brainstorming session to identify factors that are potentially important in the selection of an energy hub. These include:

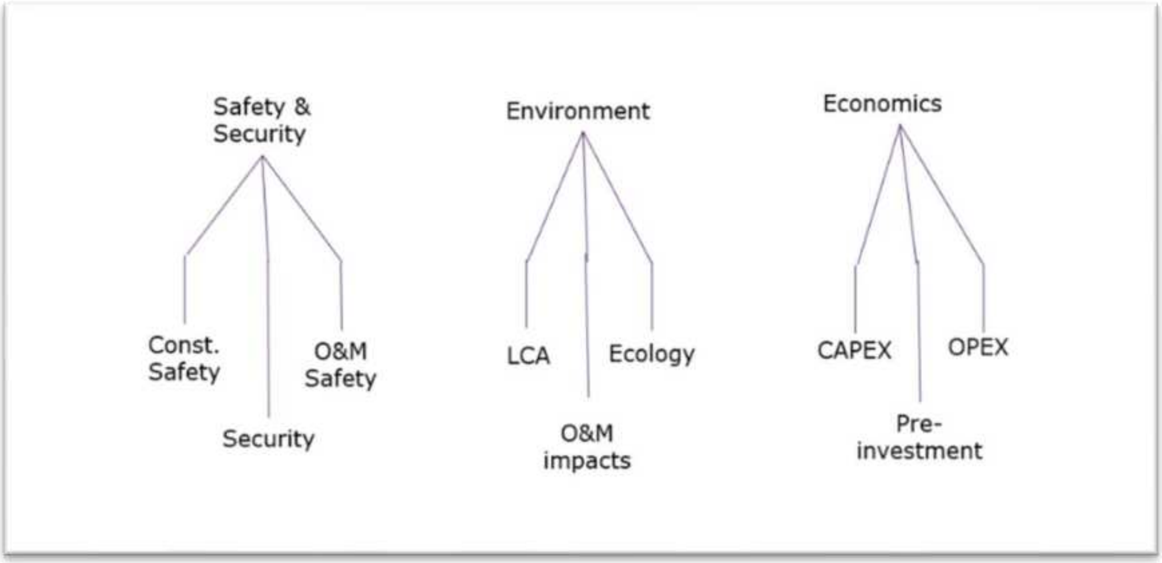
- Availability
- Reliability
- Local ecological impact
- Green House Gas (“GHG”) emissions
- Impact of materials of use
- Impact of construction
- CapEx
- OpEx
- Return on investment
- Levelised cost of electricity
- Levelised cost of hydrogen
- The need for pre-investment
- Safety and risk during construction and installation
- Safety and risk during operation
- Security
- Operations
- Maintenance
- Common failure modes
- Staffing levels
- Logistics of offshore operations
- Modularity
- Scalability
- Adaptability
- Flexibility
- Functionality
- Future expansion capacity
- Future proofing
- Design life and durability
- Longevity
- Resilience
- Robustness
- Schedule
- Construction time
- Development time to operations
- Construction / installation constraints
- Logistics
- Permitting
- Licensing

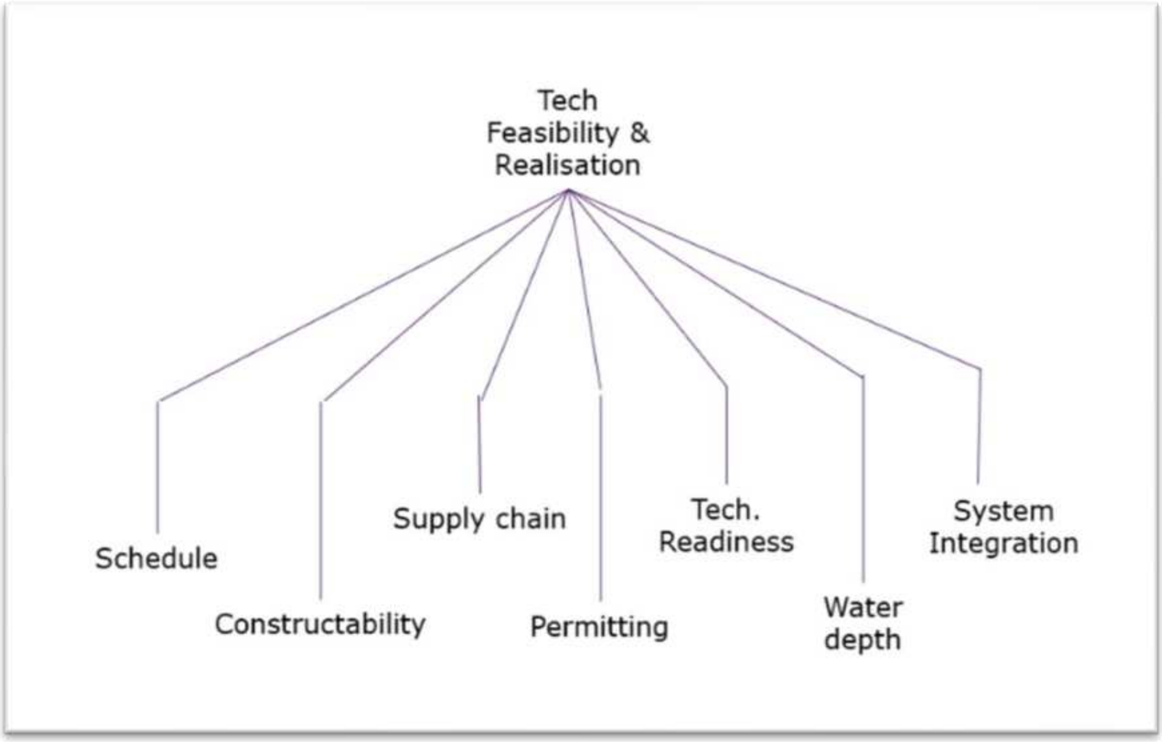
- System readiness
- Material availability / materials of supply constraints
- Local content
- Supply chain opportunities / constraints
- Complexity
- Alternative uses / 'hospitality'

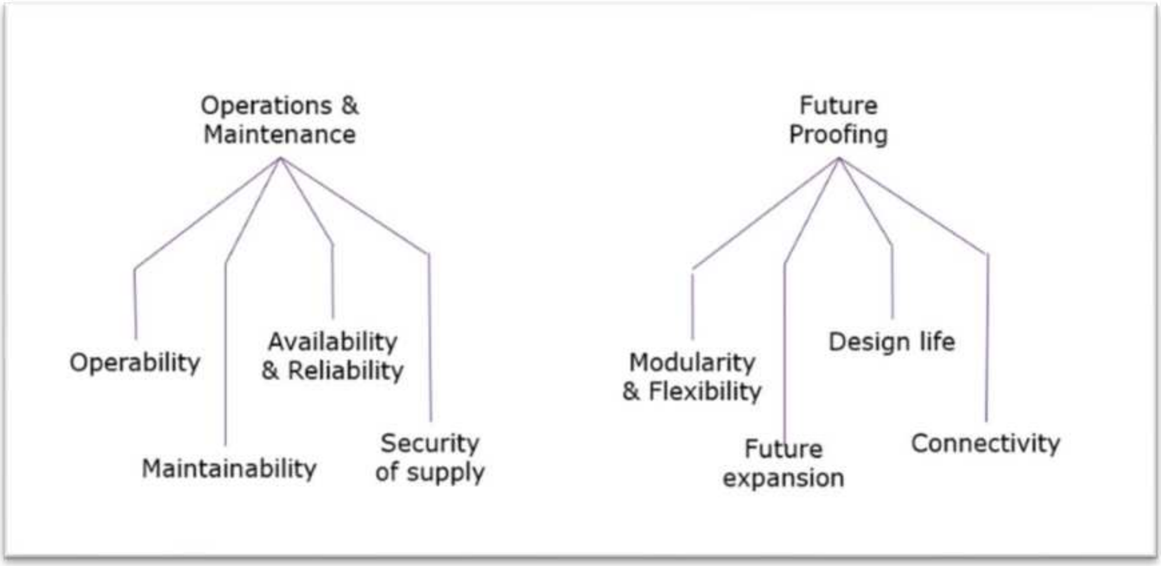
Long lists of potential evaluation criteria are typical in comparative assessment frameworks and part of the art of designing an assessment framework is selecting and structuring the criteria in a way that enables a differentiation to be made between the various options being considered. We have grouped the criteria together into categories of similar or related issues and used a value tree approach to identify levels of related detail. Two levels of detail have been used with the first level representing fundamentally different concepts and the second level elucidating the meaning and interpretation of the higher-level categories. The grouping and structuring of criteria have evolved through various restructuring and simplification exercises taking relevance, transparency, clarity, logic and pragmatism into account.

We have based the groupings on our expert understanding of project development lifecycles, engineering design principles, our experience and insights of the practicalities and challenges during construction, our understanding of operational and maintenance considerations, financial investment decision-making and the needs and requirements of other stakeholders based on the stakeholder engagement workshops we have held. The value tree of evaluation criteria is represented in Figure 5.3.

Figure 5.3: Criteria Value Tree (a, b, and c).







This value tree can also be represented as a matrix with level 2 criteria listed below the level 1 criteria as presented in Figure 5.4.

Figure 5.4: Level 1 and 2 criteria listed in matrix layout.

Level 1 criteria	Safety & security	Environment	Economics	Tech. feas.	O&M	Future Proofing
Level 2 criteria	Const. safety	LCA	Capex	Dev. Time	Ops.	Modul. & Scalability
	O&M safety	Ecology const.	Opex	Constr.	Maint.	Future expans.
	Security Risk	Ecology O&M	Pre-Invest.	Supply chain	Avai. & Reliability	Design life
				Permits	Security of supply	Connect.
				Tech. TRL		
				Water depth		
				System integr.		

In selecting and grouping the criteria in the way we have, we have avoided redundancy and double counting by eliminating duplicates of similar concepts (like longevity and design life). We have ensured that the criteria are as complete as possible within the boundary limitations set by the terms of reference scope of work (examples being topics covered by other Workstreams, such as market pricing mechanisms, security issues like susceptibility of terrorist attacks, and spatial planning interfaces like non-energy related uses of the wind search area i.e. fishing and shipping).

One of the advantages of grouping criteria together is that it helps to identify what factors are driving the ranking of options when used in combination with weightings and a sensitivity analysis.

Some criteria, like the levelised cost of hydrogen and electricity and return on investment considerations have been excluded from our evaluation due to the complexity of the calculations, and the uncertainty of many of the variables where numerous scenarios and sensitivity analyses are typically used to evaluate numerical modelling outcomes. These calculations require assumptions that are driven by decisions taken in other Workstreams like the ratio of hydrogen to electricity production being addressed by Workstream 1, and the complexity of pricing mechanisms and potential government policy support instruments being addressed in Workstream 4.

Assigning weights to the criteria enables the decision maker to give consideration to the relative importance of the criteria on the decision-making process. As technical experts we are of the opinion that technical feasibility is critically important to the decision-making process and has a higher relative importance than other factors like flexibility, that may be considered to be more of a “nice-to have” differentiator. Similarly, our understanding of the severity of certain supply chain limitations would encourage us to weight these considerations more heavily than the impact of schedule, where a delay of a couple of years doesn’t have that much of an impact on the overall objective of developing the North Sea energy resource over a long planning horizon. We have described these considerations and provided relevant justifications in Section 6 of this report. Another advantage of assigning weights to the criteria is that it enables the subjectivity of different decision-makers to be considered, which adds to the richness of the evaluation.

It is important to note that the weightings are subjective and serve to facilitate the views of different stakeholders and experts. A technical construction expert does not necessarily have the same insight into environmental matters as an environmental specialist has and the weighting of different criteria enables relevant specialists to have a say on the contribution of an evaluation criteria to the overall decision-making process. Allowing different stakeholders to score and weight the options against the criteria facilitates deeper insight into the consequences of selecting one option over another and promotes inclusivity.

By performing a sensitivity analysis of the impact of the weightings on the scoring outcomes, the relative impact of the various criteria and be evaluated at all levels of the value tree assessment. This helps to clarify what the most important considerations and critical issues are in making the decision.

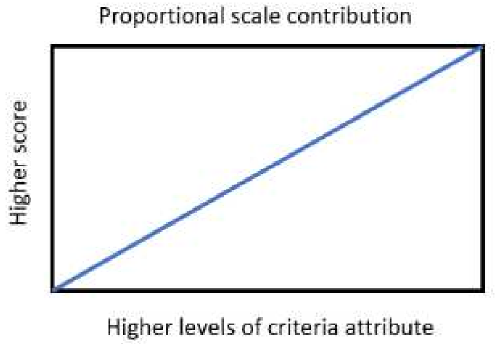
5.4 Scoring Methodology

We have allocated scores to the performance of the various options against the criteria to evaluate and differentiate between the relative rankings of the options under consideration.

5.4.1 Scoring Convention

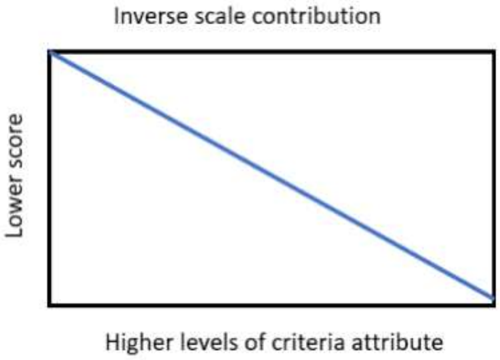
We have used a scoring convention in which high scores are not desirable to enable intuitive scoring as represented by high costs, high risks, and high levels of complexity.

Figure 5.5: Proportional scale contribution.



In cases where more of a criterion is desirable, as may be the case for higher flexibility or reliability the scoring methodology has inverted the scales to ensure consistent contribution to the scoring convention.

Figure 5.6: Inverse scale contribution.



5.4.2 Scale Intervals

Numerous scoring techniques have been used ranging from numerical scores for criteria that can be measured numerically to representative scoring for qualitative items. In some cases, qualitative scoring can be represented by stars, tick marks or by counting advantages or disadvantages, as may be applicable to the specific criteria being evaluated. We have opted to convert all evaluations to a scoring approach that can be used to aggregate results and produce a final comparison between options. Examples of numerical scoring are the value of CapEx investment measured in billions of euros or the number of years in the schedule between project kick-off and beneficial operation. Examples we have used for scoring qualitative items are the use of a three-point high-medium-low ranking for constructability and installation complexity and using a ten-point scale for more nuanced differentiation of relative differences between options where a three-point scale doesn't provide sufficient relative differentiation between options (for example operational complexity).

In the case of qualitative evaluation there are no rules for absolute scoring values. The objective is to allocate relative values that best represent the differences between the options in the opinion of the decision-maker. This qualitative interpretation is supported by a justification narrative that explains the reasoning and the sources of information that are being interpreted. This technique is not designed to be an exact science but serves to produce a differentiated ranking between the options using the best information available to the decision-maker.

5.4.3 Score Normalisation of Scale Intervals

The objective of the scoring approach is to be able to aggregate scores across all the criteria and come to an overall assessment of the relative rankings of the options being considered. This is only possible if a consistent approach has been used to score each criterion to avoid larger scoring scales from dominating the scoring process. We have achieved this by normalising all the scores to represent a comparative fraction of the overall scoring scale. In this way three-point scales differ from each other by a third of a fraction, ten-point scales differ by a ten per cent fraction and open-ended numerical scores differ by the fraction of the value relative to the highest score that sets the scale for the specific criterion under evaluation. A sample of the scoring system is presented in appendix A1.

5.4.4 Score Normalisation of Collective Contribution

When aggregating scores, a potential bias arises if one clustering of evaluation criteria has more contributing elements than another. Adding more scores increases the overall score value and creates the potential for "long-tail" bias. We have overcome this problem by normalising the overall score to represent a fraction at each level in the value tree. All scores within a group of criteria are added together and divided by the number of criteria in that group to produce a fraction.

5.4.5 Score Aggregating

Scores are allocated to the lowest level in the value tree where the highest degree of definition is available. The normalised scores are multiplied by their relative weighting and aggregated across the relevant criteria group. These aggregated scores are once again normalised to fractions and represent the overall score ranking for the criteria group. These values cascade up to the next level and represent the scores for the next level in the criteria value tree. A sample is presented in A1.

5.4.6 Use of Weightings

Weightings are based on a scale out of 100, where 100 represents a full contribution to the score. In cases where there is a relative difference in the impact and importance of the criteria, the less important criterion is given a reduced weighting. There are no absolute guidelines on scoring or weights.

Once scores are aggregated and normalised at one level they roll up and contribute to the next level in the value tree. Scores that role up remain unchanged but the weighting of the contribution of each criteria grouping can be changed based on the decision-makers opinion on the relative importance and impact of each category's contribution to the decision.

5.4.7 Interpretation of Aggregated Results

Based on our scoring convention, where the highest scores are least desirable and the relevant scale inversion corrects for criteria that are more desirable, the aggregated scores enable an interpretation where the options with the lowest scores are the better choices. Consideration should also be given to the relative difference between options to consider whether the differences are significant or not.

5.4.8 Transformation of results

Following a review of this report, several stakeholders provided feedback indicating that it was difficult to interpret results presented on a 'lowest is best approach' (golf sporting analogy), For ease of interpretation we have transformed the results to reflect the best results as being the highest value out of 100 (more of a football or cricket sporting analogy).

The transformation of ranking scores is presented in a step-by-step sample calculation presented in Appendix A. Readers need to remember that the scoring convention used in Section 6 is based on the lowest score being the best to enable intuitive rankings (e.g. low costs, low complexity) which are more desirable. In cases where "more is better" (e.g. more flexibility) the scoring calculations were inverted as described in Section 5.4.1 so that results could be aggregated to produce a consistent final result.

The low 'golfing scores' are then converted into 'high football scores' for ease of results interpretation (in the executive summary and conclusions sections) where conventional wisdom intuitively places a higher value on higher scores when considering a 'winner takes all' type of thinking framework. We hope this improves the readability and interpretation of the ranking results for those who are predominantly interested in the final results.

5.4.9 Sensitivity Analysis

A sensitivity analysis enables an examination of the impact of various criteria on the decision-making process and helps to identify the most important factors driving the decision. It also enables an evaluation of the impact that various stakeholders' subjectivity has on the decisions. In cases where there is general agreement on the weights of some criteria it helps to channel the discussion to the most influential issues affecting the areas where there is disagreement on criteria weightings. A sensitivity analysis also helps identify cases where two or more options cannot be differentiated and are non-dominated. Any selection within a non-dominated set of alternatives should be an acceptable choice.

5.5 Tools and Resources

We have developed a spreadsheet-based scoring model to record our scoring and weighting decisions and automatically aggregate the results. This resource also helps us perform a sensitivity analysis of the results. This Criteria Scoring Matrix can be shared with other stakeholders to enable them to undertake their own scoring exercises. As part of our stakeholder engagement strategy, we plan to collect scores and weightings from various stakeholders and analyse the areas where there are significant differences to help identify any potential missing information and to understand the importance of different factors according to different stakeholders. The results of this analysis will be presented in the final version of this report.

6 Energy Hub Concept Comparison

6.1 Evaluation 1 – energy hub Construction Forms

The first evaluation – Evaluation 1 – required as part of the funnelling process to define the energy hub concept for search areas 6 and 7, is to define the supporting infrastructure for the energy hub concepts. The selection between artificial islands, platforms and a hybrid solution combining both is the first decision that needs to be taken by the Government.

Making the decision between islands, platforms and a hybrid solution will then narrow the following decision making, which can, to a degree, be delayed while the project is developed. As the development of the Dutch Sector is world-leading, there is no advantage in delaying decision making pending further developments elsewhere.

6.1.1 Decision Framing

Selection between island(s), platforms and a hybrid configuration requires these concepts to be defined. Table 6.1 provides the key concept data. For all concepts the HVDC subsea cables to shore and the subsea hydrogen pipelines to shore are excluded as their routing will depend on final energy hub location and as they are assumed to be similar for all concepts.

The overall energy hub capacity is assumed to be 24 GW, based on the estimated wind generation capacity in search areas 6 and 7 of 22-28 GW and the projected roll-out of wind generation capacity of 29 GW between 2030 and 2040. The energy hub assumes up to 50 % of wind generation capacity is transported as hydrogen (12 GW of HVDC capacity and 12 GW of hydrogen production). This is based on Workstream 1 insights and the Target Grid report stating a maximum of 38 GW of electrical landing, leaving a residual 12 GW to be transported in another form (ref. 17). It is noted that this roll-out of hydrogen production and indeed overall wind generation capacity may not be achievable but is based on the expected optimal balance for grid integrated offshore hydrogen production. The assumption is that by 2030 offshore wind generation meets a sufficient percentage of onshore demand to require one-to-one step out of HVDC and hydrogen production capacity in search areas 6 and 7, to maximise energy recovery to meet as much of base load demand as possible.

The wind farm is expected to be parcelled up into approximately pairs of 2 GW blocks with licenses issued to individual developers.

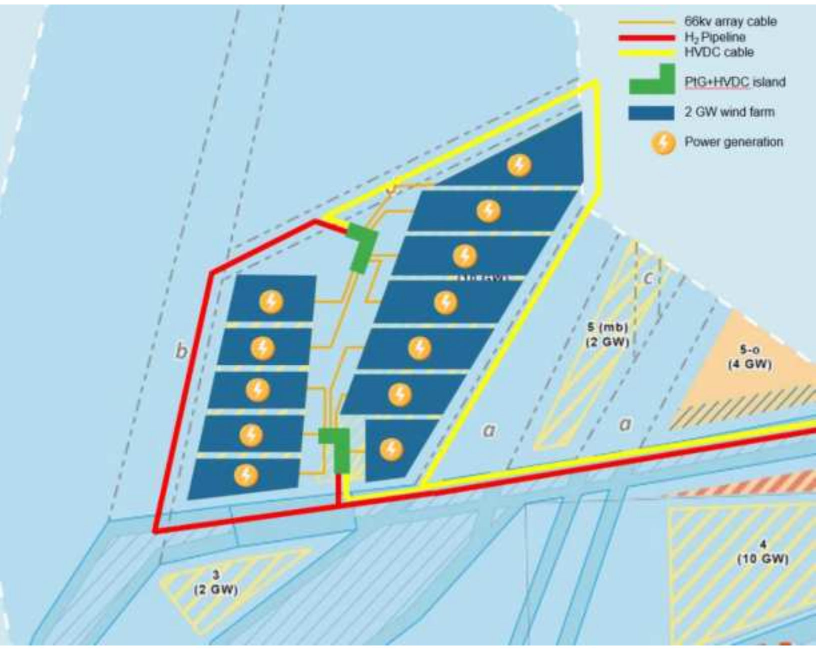
Energy hub on islands

An energy hub installed on large islands assumes that all infrastructure other than the WTGs is installed on the islands. As the overall capacity of the energy hub is assumed to be 24 GW, with 50 % of the wind energy exported as direct power and 50 % as hydrogen, two islands are required due to TenneT's limitation of a maximum of 6 GW of HVDC capacity in any one location.

Power is transmitted from the WTGs to the island via 66 kV or higher voltage (it is expected that 132kV cable technology will be suitably mature within the expected project implementation timeframe) array cables. For more distant wind farms it may be necessary to use additional (satellite) offshore HVAC platforms to step up to a higher voltage and install associated submarine cables. It is then either exported to shore as direct power via the HVDC system or used to produce hydrogen which is then compressed and exported to shore via subsea pipelines. The approach for connection of distant WTGs to the island will be selected based on techno-economical analysis for each individual case. The islands are assumed to be permanently manned with a safe harbour for transfer of equipment and personnel on and off the island. The island will include space for accommodation and warehouses for tools and spare parts.

The island-based hub design is equivalent to concept 1 in Evaluation 2 as detailed in Figure 6.1. Section 6.1.2 will further describe the caisson island concept developed in the NSWPH programme.

Figure 6.1: Illustrative Layout of Island-based Energy Hub (concept 1).



Energy hub on platforms

The energy hub installed on platforms is based on the following assumptions developed through engagement with Workstream 3 stakeholders:

- Hydrogen production will be separated from hydrogen compression as Gasunie will be responsible for compression design and the individual developers will be responsible for hydrogen production design.
- Hydrogen production will be located within the individual 2 GW wind farm blocks and can either be installed on platforms or local to the WTGs; a decision which can be made later.
  - For Evaluation 1 hydrogen production was assumed to be either local to the WTGs or on 500 MW platforms (excluding compression), depending on best available data.
- Hydrogen compression can be centralised where it supports the entire energy hub or decentralised with compression within each individual wind block.
  - For Evaluation 1 it is assumed that hydrogen compression is centralised on four 3 GW platforms as determined during the NSWPH programme. However, this design may not be the optimal solution and requires further study to optimise the cost and system reliability/availability.
- Centralised hydrogen compression can be on platforms or islands depending on technical requirements.
  - For Evaluation 1 it is assumed to be on platforms.
- HVDC equipment is installed on TenneT's standardised 2 GW HVDC platforms located within search areas 6 and 7.

Direct power is transmitted from the WTGs to the HVDC platforms via array cables and hydrogen produced locally to the WTGs is transferred to the compression platforms via flexible flowlines. Electrolysis pressure is assumed to be approximately 30 barg to facilitate this.

Power is exported ashore from the HVDC platforms via subsea HVDC cables and hydrogen is compressed and exported ashore via subsea hydrogen pipelines.

Details of designs for hydrogen production local to the WTGs (Figure 6.2), hydrogen production on platforms (Figure 6.3) and hydrogen compression on platforms (Figure 6.4) are provided as typical examples of the infrastructure required for the platform-based concepts. The platform-based hub design is equivalent to concept 2a in Evaluation 2 as detailed in Figure 6.5 below.

Figure 6.2: Hydrogen Production Local to the WTGs, a 20 MW example (ref. 22).

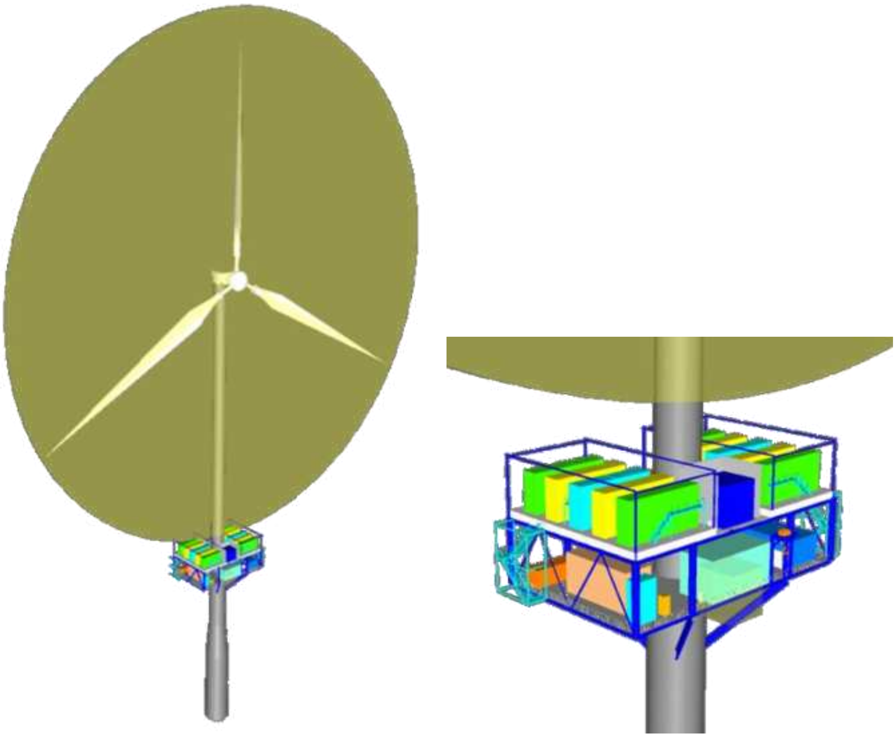


Figure 6.3: Hydrogen Production on Platforms. Example of hydrogen production platform, 500 MW. This platform includes compression which takes up a small portion of the topsides footprint (ref. 20).

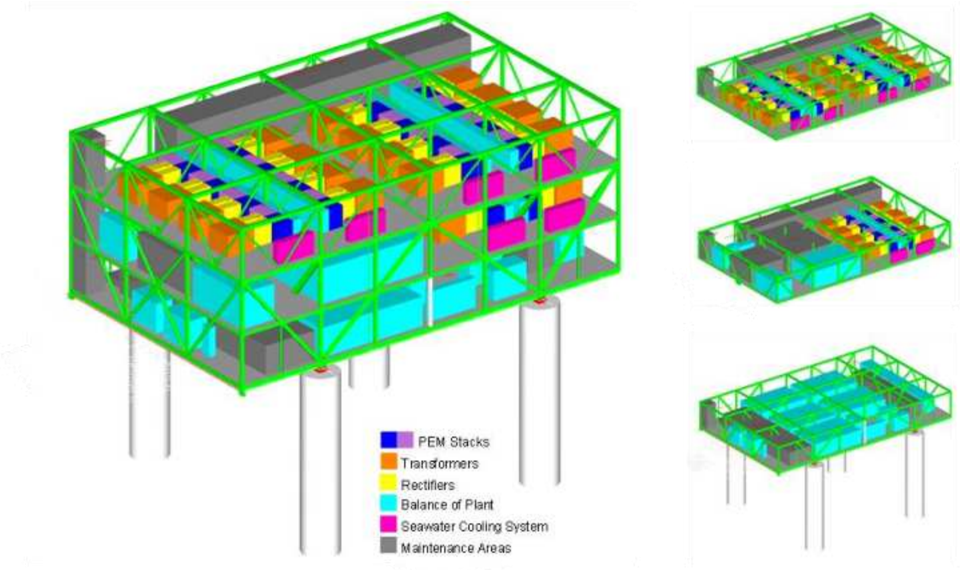


Figure 6.4: Hydrogen Compression on Platforms, a 3.24GW example (ref. 22).

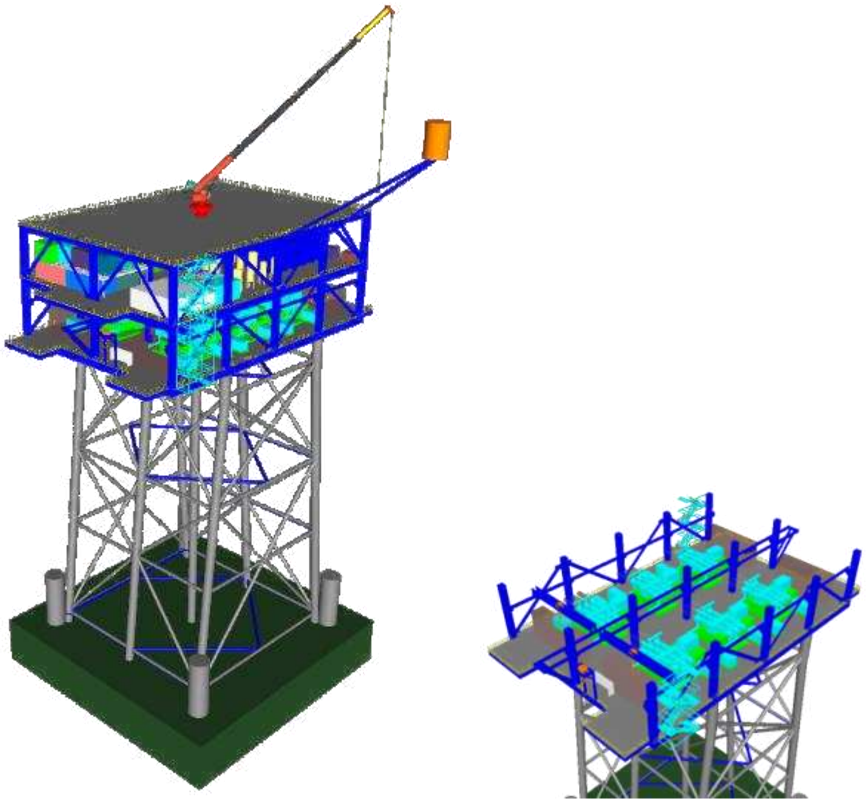


Figure 6.5: Illustrative Layout of Platform-based Energy Hub (concept 2a).

Hybrid energy hub

Due to concerns that the timeline for island construction means that it will not be ready by 2032, the hybrid concept assumes that the initial 12 GW of development is installed on platforms as described above and that the second 12 GW of development is installed on one large island (Figure 6.6).

Selection of the types of platforms or islands should be left to a later date in discussion with the developers. Sections 6.1.2 and 6.1.3 describe the platform and island options available.

Figure 6.6: Illustrative Layout of Hybrid-based Energy Hub.

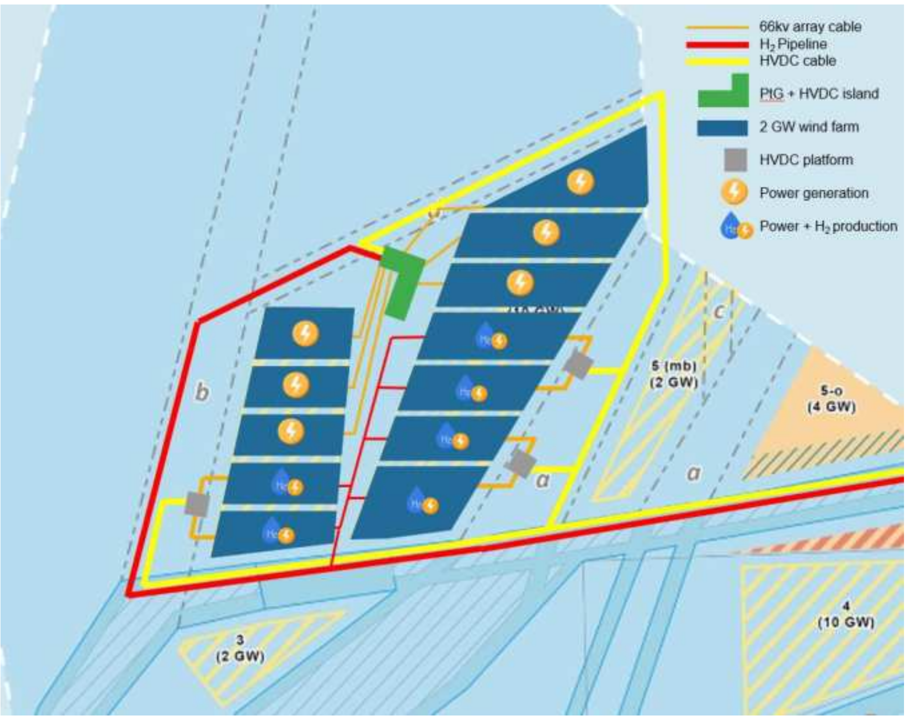


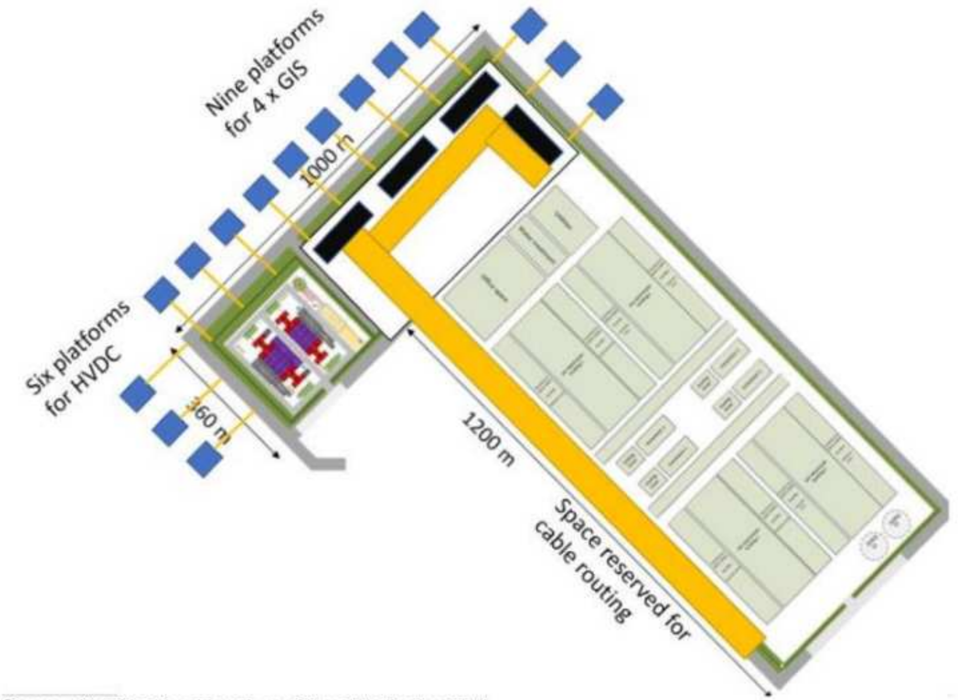
Table 6.1: Infrastructure Concept Definition.

Concept	WTGs	Array Cables	Flowlines (in case of PtG local to the WTGs)	Hydrogen Production	Hydrogen Compression	HVDC Equipment
Islands (2 OFF)	24 GW across search areas 6 and 7	24 GW connecting WTGs to islands	Not required	On islands	On islands	On islands
Hybrid configuration: Island (1 OFF) Platforms (12 GW wind generation capacity)	24 GW across search areas 6 and 7	12 GW connecting WTGs to island 6 GW connecting WTGs to HVDC platforms 6 GW connecting to PtG platforms (in case of 500 MW platforms)	6 GW connecting WTGs to compression platforms	6 GW on island 6 GW local to the WTGs or on platforms within wind blocks	6 GW on island 6 GW on centralised platforms outside wind blocks (could also be 6 GW on 1 GW platforms within wind blocks)	6 GW on island 6 GW on 2 GW standardised HVDC platforms
Platforms (24 GW of wind generation capacity)	24 GW across search areas 6 and 7	12 GW connecting WTGs to HVDC platforms 12 GW connecting to PtG platforms (in case of 500 MW platforms)	12 GW connecting WTGs to compression platforms	12 GW local to the WTGs or on platforms within wind blocks	12 GW on centralised platforms outside wind blocks (could also be 12 GW on 1 GW platforms within wind blocks)	12 GW on 2 GW standardised HVDC platforms

6.1.2 Types of Artificial Islands

One possibility for the construction of an energy hub is the construction of an artificial island. This can be done using different methods: caisson, sand, revetment or reef. Which technique is best suited depends on multiple decisions such as, water depth, weather conditions and costs. Although artificial islands have been constructed globally it is not common practice. Only the caisson-island method has been studied by the NSWPH consortium at this point at a concept engineering level. The concept has been developed for a 10 GW island with 4 GW HVDC capacity and 6 GW hydrogen production. In discussion with Gasunie and TenneT it was understood that they re-designed the island such that it can accommodate a total of 6 GW of HVDC capacity and 6 GW of electrolyser capacity. Therefore, this concept design was used for the comparison of a 12 GW offshore island.

Figure 6.7: North Sea Wind Power Hub Caisson Island (ref. 21).

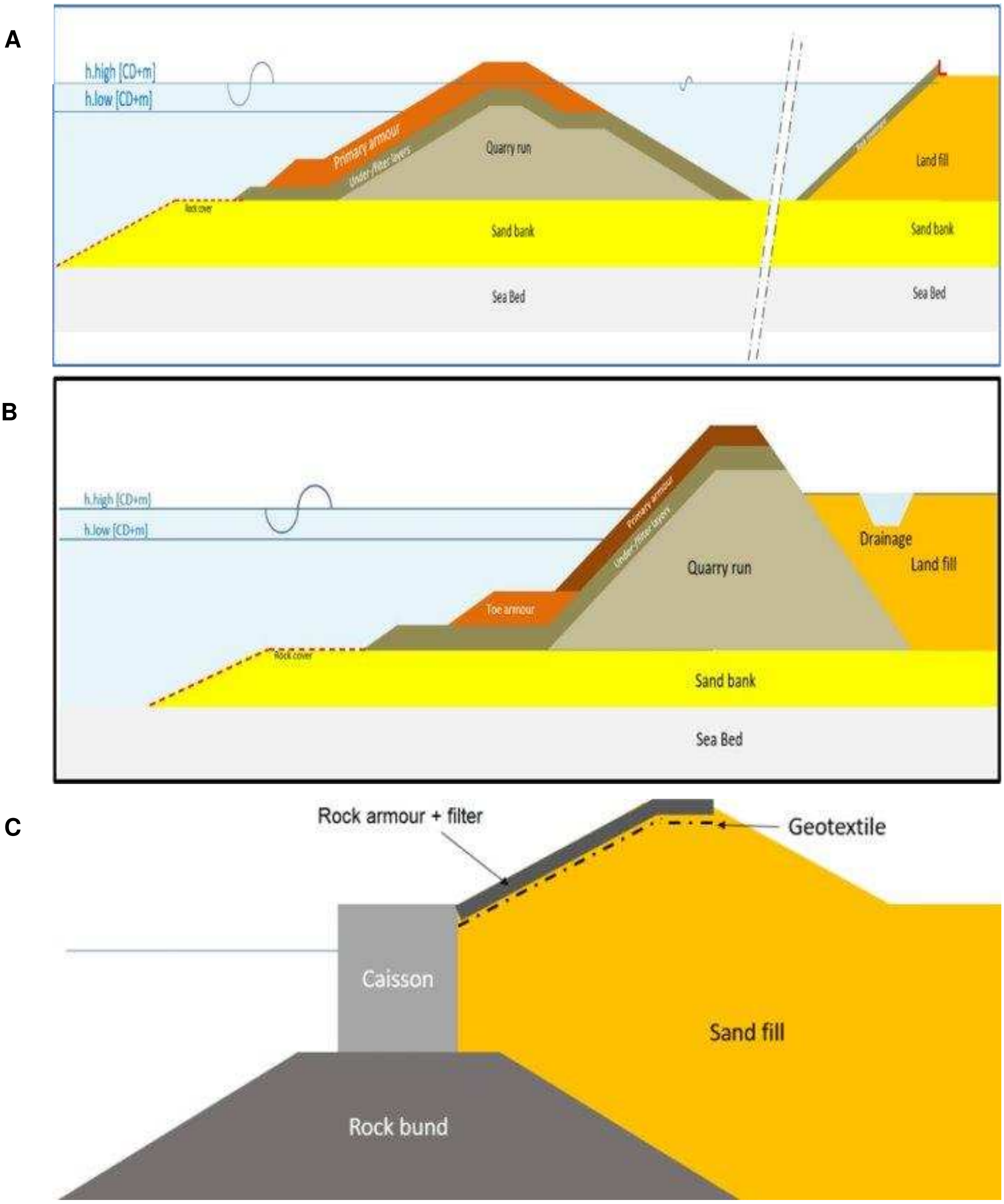


Source: Mott MacDonald mark up of Royal Haskoning DHV

The cable entry platforms (including cable bridge) shown in the figure above are small in scale and intended only to allow transfer of the array cables to the island. They are required irrespective of the array cable voltage selected and are included in the cost estimate for the island construction within the Power Infrastructure component of the CAPEX build-up (at circa €3.5 million each, supplied and installed).

There are four principal types of artificial islands characterised by their perimeter protection. The design of reef, revetement and caisson islands are schematically depicted in Figure 6.8A-C, respectively. A sand island is similar to the revetement island but with part of the quarry run replaced by sand.

Figure 6.8: Schematics of (A) Reef Island, (B) Revetement Island and (C) Caisson Island (ref. 4).



For a sand beach island to be stable in the wave climate at the site the foreshore slope would need to be very flat. This flat slope needs to extend, indicatively, down to two wave heights below

low water. The sandy beaches on Helgoland, for instance, extend about 2 km to the 20 m depth contour. Beaches are generally stable in the predominant wave direction. It is not possible for all sides of the island to support stable beaches and beach controls structures (rock groynes) would be required. It is considered that the extent of the sand required increases the material demand of the island too much for this to be a viable option.

A perimeter reef around the island breaks and absorbs the wave energy so that the perimeter of the functional island need only be protected from the reduced waves climate. The reef is as substantial as the foundation bund for a caisson island or the lower portion of a revetment island. The functional area of the island becomes surrounded by both the reef, a lagoon and the secondary protection. This will be wider than a revetment or caisson protection and more material will therefore be required for the construction of the island.

An armoured revetment of a rubble mound is generally an effective means of protecting an area reclamation. The armouring becomes very heavy for exposed wave conditions requiring large marine plant to lift It into position. In deep water the foundation pile rapidly increases in volume. The rough open textured armouring is efficient at absorbing the wave energy and controlling overtopping.

A caisson placed on an armoured mound has advantages over a pure armoured revetment in that the caisson is placed in the area of highest wave attack. This removes the heaviest armouring from the process, and it is quicker to construct from caisson formation level to protected work platform on the caisson. However, the caisson needs to be more robust than the armouring as it does not absorb any of the wave energy and is poor at controlling overtopping. In the conditions at the proposed island a riveted slope above the caisson is required to control overtopping. The caisson island uses less material and has a smaller seabed footprint than an armoured revetment.

For the NSWPH programme island-based concept a caisson island was selected but a more detailed study might conclude that a revetment structure is more economical. Both have supply chain restrictions such as a suitable location for casting the caissons, sufficient supply of large rock and access to suitable plant.

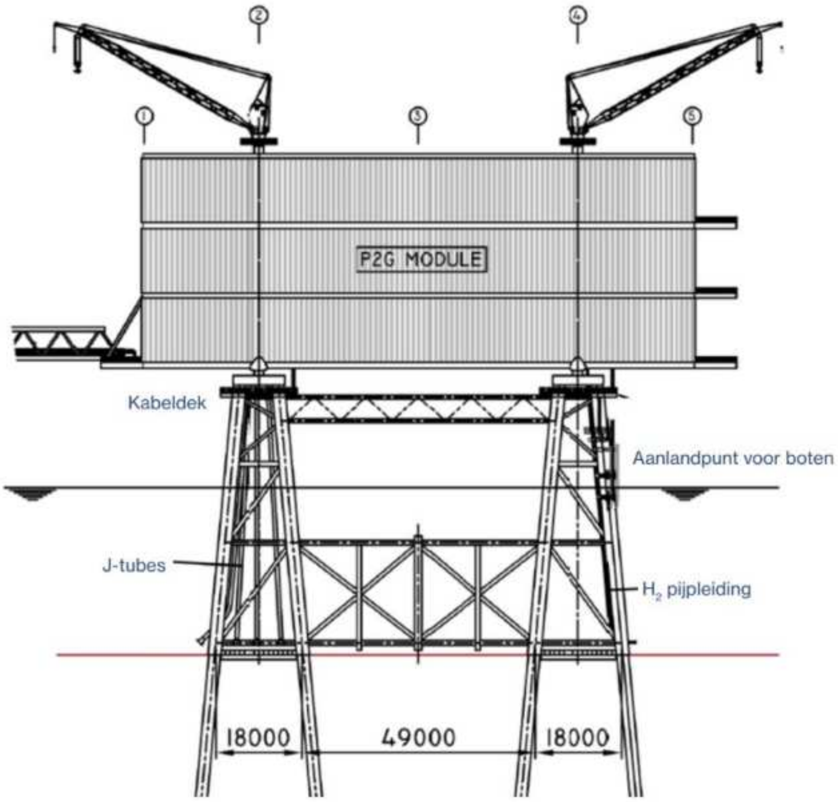
The wave exposure on the island varies around the perimeter. It is therefore possible that a caisson perimeter is most appropriate for the exposed faces and for the quays and break waters of the supply port but a riveted structure is more suitable for the remaining perimeter.

6.1.3 Types of Platforms

6.1.3.1 Platform Design (NSWPH)

Another possibility is the use of platforms which are common practice in the oil & gas industry. A platform is comprised of two main structural components: topsides and substructure. The topsides contain the process facility while the substructure supports the topsides. Different substructures for platforms can be considered: jacket, XXL monopile, gravity-based structures and floating. The most common substructure for platforms in the North Sea is currently jacket structures (Figure 6.9). It is a well-known and proven technology with a developed supply chain. How much equipment can be installed on the topsides is heavily defined by the transport and installation limitations, which will restrict the size and weight of the platform. The NSWPH programme identified several barges capable of transporting 26,000 tonnes of topsides. The substructure design will have to take into account the operating weight of the topsides. As the surface area of a platform is limited the equipment has to be installed over multiple platforms. From documentation it is known that a jacket platform can accommodate up to 2 GW of HVDC power transformation or 500 MW of hydrogen production. The standard 2 GW HVDC platform design has been developed by TenneT and the first platform should be operational by 2029, out of fourteen platforms included in the first implementation stage (due to be commissioned by 2031 (ref. 40)). The 500 MW electrolyser platform will soon start with the basic engineering phase. For the other three substructures no engineering studies are known to exist.

Figure 6.9: 500 MW PtG platform (ref. 19).



As the selection of the type of platform does not affect the spatial layout of search areas 6 and 7 it can therefore be left to individual developers. However, a brief outline of platform options is provided in section 6.1.3.2.

6.1.3.2 Platform Substructure Solutions

Concrete Gravity Base Foundation (GBF)

Two GBF options exist, the first comprises a self-floating concrete box. The topsides are constructed on the foundation box in a dry dock and the complete platform floated and towed out to site. An alternative option would comprise a self-floating concrete foundation with concrete columns to support the topsides. Mating of topsides and substructure would be at the offshore site by float-over.

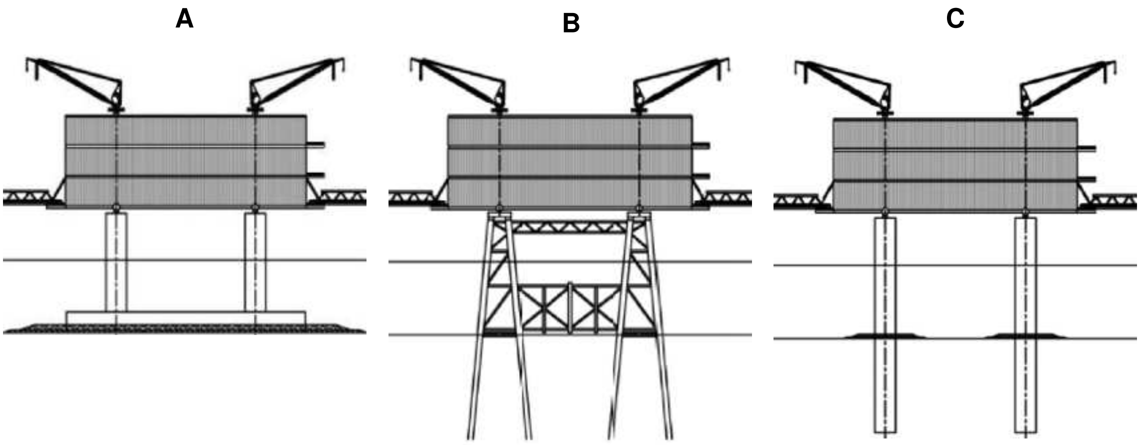
For deeper water locations the supporting columns will be longer, and the overturning loads due to wave, wind and current will be greater increasing bearing loads onto the seabed, unless the base area is made larger. This may also be necessary to control the float out draft as the GBF weight will increase.

Based on work done in the NSWPH programme, it is believed that a GBF concept can be adapted to water depths of 50 m without significant modification of the concept design (Figure 6.10A). The

GBF solution requires significant seabed preparation in the form of dredging and laying of scour protection prior to installation. This level of disturbance to the seabed is not preferential from an environmental perspective. however, this is balanced by the fact that the noise during construction is less than for other solutions such as pile driven monopiles.

The greatest benefits of GBS are that it would allow for more topsides area and weight increasing platform capacity and potentially providing greater resilience to compressor vibrations although this would need to be studied.

Figure 6.10: (A) Concrete Gravity Base Foundation Platform Elevation, (B) Steel Jacketed Platform Elevation, (C) Monopile Platform Elevation (ref. 19).



JacketA jacket comprises a structure designed to act as a template for driving groups of piles which directly supports the topsides (Figure 6.10B). A conventional piled jacket would have legs supporting the topsides attached to pile sleeves at the seabed that transfer load to the foundation piles. For deeper water applications, the substructure is simply made taller and heavier to accommodate additional water depth.

Monopiles (XXL Piles)

XXL piles are defined as larger diameter piles, as used for offshore wind turbine support structures (Figure 6.10C). The topsides support structure comprises independent piles driven into the seabed at each topsides support location. The largest piles currently used offshore is 10 m diameter. Piles are the most sensitive to application in deeper waters of the substructures.

Based on the NSWPH programme, each of the concepts are adaptable to a water depth of up to 45 m. For the NSWPH project a jacketed platform was selected as it is cheaper than the gravity base foundation and further design work is required to substantiate the feasibility of XXL pile design. The GBF has challenges and risks associated with its design, fabrication, and seabed preparation. However, this selection may not apply to the energy hub developed for search areas 6 and 7.

6.1.4 Safety & Security

6.1.4.1 Safety during Construction & Installation

Construction of a large island located offshore in the North Sea was considered to have significant safety risks associated with the installation of major infrastructure in a marine environment which exceeded those for construction and installation of platforms. Platforms including the topsides equipment installed on them are constructed onshore in fabrication yards and transported offshore complete for installation on their substructure. Based on the NSWPH programme it is assumed that the HVDC and compression platforms are jacketed structures. Hydrogen production platforms are also assumed to be jacketed but if hydrogen production is local to the WTGs then it would be installed on platforms attached to the WTG itself and the entire construction would be installed on monopiles.

For both monopiles and jacketed platforms there is extensive experience of installing them in the North Sea, reducing risks, whilst large offshore islands in up to 50 m water depth are new. These factors contributed to our scoring of islands as the highest relative safety risk, followed by the hybrid configuration then platforms. Although the large number of platforms does increase the safety risks associated with Simultaneous Operations (SIMOPs) and construction this was not considered to outweigh the risks associated with island construction, where the risk is more accute. A significant safety risk associated with construction of an island, particularly during commissioning and initial operations, is the need for construction of later phases next to the live plant installed in earlier phases and island design needs to carefully consider the increased risks associated with this SIMOPS scenario.

The island will be constructed at sea which can involve drilling, excavation etc. and it is envisaged that significant heavy lifting will be required for construction and installation of equipment, rock and sand filling, concrete pouring etc. This will create a hazardous environment. Process plant modules will be assembled in a shipyard onshore and transported to the island for installation, so there will be more construction activities at sea compared with an island. For the NSWPH, a single module to be transported to an island was maximised and limited to 500 tonnes (18m x 75m), which is much smaller than the 26,000 tonne platform topside (45m x 70m). While the smaller modules are individually more manageable to transport, this basis resulted in 430 modules to transport for a 4 GW island. Each of these 430 modules would also require stick-built interfaces (e.g. for water, electrolyte, hydrogen, oxygen, nitrogen, power, cooling), further increasing construction activities on the island. SIMOPS considerations for construction and operation need to be considered due to the space limitations on an offshore island.

Platforms, including the topsides equipment installed on them, will mostly be constructed onshore in fabrication yards and transported offshore complete for installation on their substructure, with minimum tie-ins at sea. However, tie-ins on a remote offshore platform could be seen to be higher risk than on an island due to harsh sea environment working conditions, working at heights, etc.

In order to provide a safe installation environment, weather patterns will need to be observed to avoid transportation and offshore works during extreme weather conditions such as strong storms, large wave heights (above 2 m), high speed winds (up to 20 m/s) and extratropical cyclones as credible in the North Sea environment. While this is applicable to both islands and platforms, islands will have more construction staff offshore than platforms and for longer periods, as well as more frequent transport and therefore is perceived to have a higher risk.

Based on the above factors, islands are perceived to have the highest safety risks during construction and installation, followed by hybrids and then platforms. However, the combined safety risks associated with the hybrid concept, which requires integration of both platforms and an island, were considered to be closer to islands than platforms (although the smaller island is easier to construct, many of the same safety risks apply during its construction albeit with a smaller construction team). As such a relative score out of 10 was applied rather than simply high, medium and low with the scores given in Table 6.2 with the higher the number the greater the risk.

Table 6.2: Evaluation 1 Scoring – Safety During Construction & Installation.

Concept	Scale	Islands	Hybrid	Platforms
Safety during Construction & Installation	Higher scores for higher risks	8	7	5

6.1.4.2 Safety during Operation & Maintenance

Platforms, due to their construction limitations, are inherently more constrained in their layout than artificial islands. Although the overall capital investment of a large offshore island is very significant the cost per unit of area is less than for platforms, allowing for a less constrained design. Layout constraints on platforms impact technology selection and do not allow for large exclusion zones. To prevent escalation if a release occurs risks are mitigated through design, for example, by the installation of blast and fire walls. However, these mitigations are not as inherently safe as the exclusion zones allowed for by a less constrained layout (as permitted by an island).

Assuming the same approach taken for the NSWPH programme, the platforms would be unmanned whilst the large offshore islands would be permanently manned with teams on rotation. To support the operation and maintenance of the platforms, a manned support vessel would operate permanently offshore. Therefore, the safety risk to personnel needs to be considered balancing the permanent occupation of the island with the greater risks associated with operations on the platforms especially for teams who are not fully familiar with the platform layout and will be travelling between different types of platforms – hydrogen production, compression and HVDC – in different locations. Due to the unmanned nature of the platforms, limited facilities are provided for personnel with buildings limited to emergency shelters, local admin & control rooms.

Transfers to and from the platforms, as is required for maintenance or chemicals top-up, are one of the highest risk activities during operations and maintenance. Transferring from a ship to the platforms, particularly in not calm conditions, risks personnel falling into the sea or being impacted by the support vessel. By contrast, transferring to and from the island will be from a protected quay with bridges linking the vessel to the island.

On the islands there will be permanent living quarters assumed to be located outside the impact of any credible upset scenario. The philosophy for island operation will be for operators to only enter identified hazardous areas of the island when necessary. Hydrogen production is a novel process, more so than hydrogen compression, and there are known risks identified within operating facilities that need to be better understood and mitigated against as the technology is rolled out. For electrolysers, hydrogen or oxygen can pass through the membranes resulting in explosive mixtures in the presence of electricity. Operating at low loads and high pressures increases the risk of gas crossover. Careful attention should be paid to water quality which can have an impact on membrane degradation and therefore crossover. PEM requires a higher water quality and is hence more sensitive to impurities in the feed water. Particularly for alkaline electrolysers minimal pressure imbalance is critical to mitigate crossover and ramp up and down with the wind power profile should be done in such a way to ensure uniform distribution throughout the cell (dry spots and gas pockets can degrade the member and increase gas cross-over).

Whilst these risks can be managed through similar approaches taken to risks within oil and gas, the permanent presence of operators on an island and the required two weeks of maintenance per reciprocating hydrogen compressor do leave them more exposed to this or other risks associated with hydrogen production. For analysis of the impact of compressor vibration on platforms refer to Section 6.3.1.

This risk along with other identified risks associated with hydrogen production will need to be carefully considered as the project progresses including within safety reviews such as HAZID, HAZOP and QRA with appropriate mitigation measures identified to reduce these risks to ALARP.

TenneT has a standardised design for HVDC offshore platforms. Whilst there is less space on a platform as compared to the island, it is considered that standard design will reduce risk for the maintenance teams. We understand that (removable) modular living quarters are available on the platform which provide accommodation facilities for multi-day visits or maintenance campaigns. Considering that numerous HVDC platforms will be installed in TenneT’s offshore grid in the North

Sea, it is assumed that trained and experienced teams will be able to execute assigned tasks considering that all new HVDC platforms will be based on the same design which was developed together with leading HVDC suppliers.

HVDC converter transformers installed in HVDC stations contain oil which represents a potential fire risk. It is expected that TenneT has implemented in its technical specification safety measures to minimise possible hazards associated with the converter transformers, such as use of blast and fire walls, foam firefighting systems, etc.

As HVDC converter stations are unmanned, it is expected that only maintenance teams will visit these facilities. HVDC platforms will not include any hydrogen equipment and, by their nature, will only be accessible to HVDC operations teams. For islands, HVDC and hydrogen plant will be physically co-located with operational personnel from several disciplines living on the island. It is assumed that the appropriate segregation will be provided on an island between different areas (such as HVDC and hydrogen production areas). This will reduce safety risks associated with personnel accessing areas for which they have no authorisation, such as hydrogen teams accessing HVDC areas or vice versa. If this is implemented, then it is assumed that there is no major difference between islands and platforms in this regard.

Islands are expected to have several advantages over platforms in respect of maintenance of electrical equipment. It is expected that more space will be available for installation of HVDC equipment, and access to the equipment will be easier as it doesn't involve multilevel structures, where equipment is stacked one above the other.

It is assumed that the island and platform concepts don't include hydrogen storage. Potential hydrogen storage is expected to be on a separate platform to facilitate subsurface storage. Therefore, it doesn't affect the scoring.

The infrastructure of hydrogen transport is expected to not be significantly different between the three concepts. Therefore, this does not affect the safety risks associated with transport between the concepts.

Even though there are more personnel permanently on the island, it is assumed they are sufficiently segregated from the high risk gas-plant areas, and considering the access philosophy for these areas would be on a needs-basis only for both the island and the platforms, the fact that islands allows for greater scope for exclusion zones leads it to have an lower risk rating during operations & maintenance. Operating and maintenance risks for the concepts is shown in with a higher score indicating a higher safety risk.

Table 6.3: Evaluation 1 Scoring – Safety During Operation & Maintenance.

Concept	Scale	Islands	Hybrid	Platforms
Safety during Operation & Maintenance	Higher scores for higher risks	6	7	9

6.1.4.3 Security

Sabotage of the energy hub infrastructure is specifically excluded from the scope of our analysis and is to be assessed by the Dutch Ministry of Defence. The security criteria included here is limited to the risk of intruders or members of the public accessing the infrastructure. Due to the location of search areas 6 and 7 being over 100 km from the coast, it is not considered credible that the general public would access the infrastructure, but it is possible that personnel for fishing vessels or other craft could access it. It is considered that a large artificial island that is permanently manned and with associated security is at a lower risk then dispersed unmanned platforms resulting in the scoring in Table 6.4, with a higher ranking indicating greater security risk. The risk for any concept is, however, considered low and this is reflected in the weighting for this criterion.

Table 6.4: Evaluation 1 Scoring – Security.

Concept	Scale	Islands	Hybrid	Platforms
Security	Higher scores for higher risks	4	5	7

6.1.4.4 Safety & Security Weighting

Safety during construction and installation is weighted at the maximum score of 100 due to the known concerns and uncertainties associated with offshore island construction in water depths of 50 m (Table 6.5). The scale of the development and the number of platforms and resulting SIMOPs also increases the risks.

Safety during operation is also a key concern and is weighted 80 out of 100. Its weighting is lowered as operation of platforms is a known concept and, once constructed, operation on the island is like operations onshore except for transfers to and from the island.

Security is weighted at only 30 due to the limited risk of intruders at this distance from shore.

Sabotage is not within the scope of workstream 3 but large island concepts where all infrastructure is in one location are potentially more at risk than platform-based concepts where infrastructure is dispersed throughout areas 6 and 7.

Table 6.5: Evaluation 1 Weighting – Safety & Security.

Criteria	Scale	Islands	Hybrid	Platforms	Weighting
Safety during Construction & Installation	Higher scores for higher risks	8	7	5	**100**
Safety during Operation	Higher scores for higher risks	6	7	9	**100**
Security	Higher scores for higher risks	4	5	7	**30**
Normalised Results	**Highest score is best**	**100**	**99**	**98**	

6.1.5 Environment

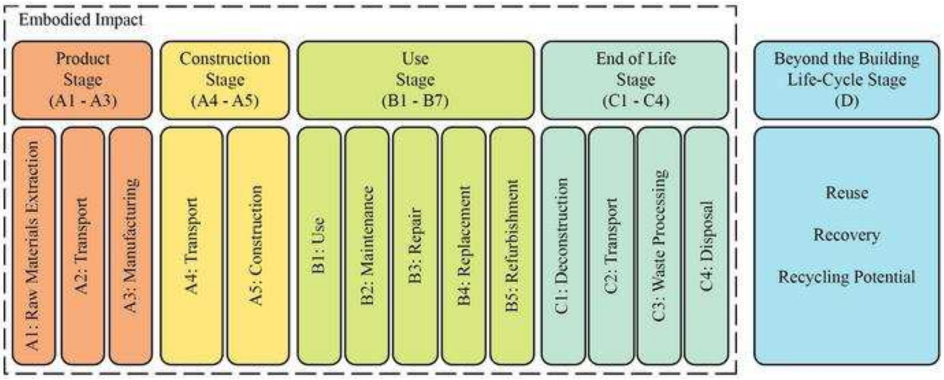
The environmental & ecological impact of the structures are important criteria for the decision making between the three concepts. Environmental impact & ecological impact can be measured in local and global change in biodiversity over a certain period. Change in ecology can be a result of five different activities: habitat change, pollution, overexploitation, invasive species, and climate change. Habitat changes are classified as all offshore changes in the marine environment or on the seabed, resulting in a positive or negative effect on biodiversity. For the EIPN project, habitat change is investigated in the ecology impact study commissioned by IenW and will be discussed in the last Section 6.1.5.4. Pollution can be in the form of chemicals, but also noise and other disturbances in habitats are classified as pollution. Pollution is mainly related to power transmission or hydrogen production. This will be discussed in Section 6.1.5.3. In this study, overexploitation and invasive species are considered irrelevant. Lastly, climate change is the effect of global warming. In this section, the impact of the structures will be discussed in a qualitative way for habitat change and pollution. The effects of global warming are quantified using life cycle assessment and will be discussed in section 6.1.5.1.

6.1.5.1 Greenhouse Gas Emissions (Life Cycle Assessment)

The envisioned energy hub will contribute to the Dutch climate goals by facilitating the transport of sustainable energy to shore and resulting in a lower use of fossil fuels. This will contribute to the national goal of reducing CO_2 emissions by 95 % in 2050 compared to 1990. Although sustainable energy suggests that no emissions are involved, this is not 100 % correct. More specifically, the materials required for the construction of a windfarm and energy hub are currently produced using fossil fuels. Large quantities of materials are needed, leading to a significant amount of CO_2 emissions that must be considered. Research shows that around 80 % of the so-called carbon footprint of offshore wind energy is related to material use and manufacturing (ref. 42). A typical carbon footprint for offshore wind energy is around 10 g CO_2/kWh. As materials, such as steel, can be excavated and produced more sustainable, the carbon footprint of sustainable energy will decrease over the years.

A suitable and frequently used method for calculating the carbon footprint of a product, project or system is the Life Cycle Assessment (LCA, Figure 6.11). This method is widely used for the assessment and quantification of the environmental impact, linking emission factors to materials and processes. For example, 1 ton of steel relates to 1.27 ton of CO_2 emissions. In LCA software, a database of emission factors is used where materials and processes are inputs and carbon footprint can be calculated. Generally, the LCA is split into four different phases: product (A1-A3), construction (A4-A5), use (B1-B7) and end of life (C1-C4).

Figure 6.11: Life Cycle Assessment project phases (ref. 41).



Method & Scope

Previously, North Sea Energy (NSE) has done a comparative study on the carbon footprint of islands and platforms (ref. 11). As the water depth assumed for that study was 25-30 m and the water depth of search areas 6 and 7 is 45-50 m, it was concluded that this can only partly be used for this study. The North Sea Energy study was therefore combined with information from the NSWPH programme to give new insights. This study only focusses on carbon footprint and no other impact categories, such as acidification and eutrophication, are considered. Hence, the inhouse LCA software developed by Mott MacDonald “The Moata Carbon Tool” was used.

The Moata Carbon Tool is Mott MacDonald’s digital twin platform, which includes over 20 digital tools for a wide range of projects and disciplines. One of these tools is the Moata Carbon Portal. Moata Carbon Portal allows detailed embodied carbon accounting and planning at all stages of the project and is globally compliant with PAS2080 certification. The Portal delivers rapid calculations and insights that highlight major opportunities for innovation and efficiency. It allows designers to identify carbon hotspots in a project, enabling a net zero future through facilitating low carbon design.

Data was combined in an excel file to produce graphics, showing the breakdown of carbon emissions by folder (separated as per the users' requirements) by material and by activity. These outputs can help give valuable insight to the overall project emissions.

As the environmental impact of offshore constructions is 80 % driven by material use and construction the main focus in this study will be A1-A5. Furthermore, the study of NSE shows that the carbon footprint of an island is mainly related to the fuel consumption for transport and installation of rock, sand and concrete.. This is a so-called cradle-to-site approach. The use phase is not considered, since there are only emissions related to maintenance vessels, and it is assumed those emissions are not significant. In contrast with the study performed by NSE, end-of-life is not considered because it is assumed that decommissioning of the island and platform is assumed to be done with sustainable fuels and therefore the footprint can be neglected.

For the analysis the three concepts were defined in more detail in Table 6.6 as required for a comparison:

Table 6.6: Concept Information.

Concept	Islands	Hybrid	Platforms
Wind farm capacity (GW)	24	24	24
H_2 capacity (GW)	12	12	12
HVDC transport (GW)	12	12	12
HVDC on platforms (GW)	0	6	12
Turbine capacity (MW)	15	15	15
H_2 on platforms (GW)	0	6	12
Array-Cable length (km)	7,500	5,375	3,000
No. of Islands	2	1	0
No. of turbines	1,600	1,600	1,600
No. of compression platforms (3 GW)	0	2	4

Island design

Island data comes from the NSWPH programme and considers aspects of the concept design by both Royal Haskoning DHV (RHDHV) and Mott MacDonald. As described before, the design is based on a caisson island. The island is constructed first by a layer of rock where subsequently a concrete caisson is built on. The caisson is the outside perimeter of the structure that will be filled with sand. The island considered has the following dimensions:

1,000m x 360m + 890m x 720m = 1,000,800 m^2 (100 ha)

In consultation with Gasunie and TenneT, it was found that this island is sufficient to provide enough surface area for the construction of 6 GW HVDC capacity and 6 GW of hydrogen production, including desalination, compression and all required equipment. It is expected that this is the limit for an artificial island, as investment costs will increase significantly with size. Furthermore, TenneT stated that 6 GW of HVDC capacity is the limit in a single location for safety reasons.

Materials required are limited to the rock, sand and concrete. The related carbon footprint is assessed using the Moata Carbon Tool. Diesel use and energy use are estimated using Moata and using the estimated distances from harbour to the installation location. Diesel consumption is converted to CO_2 emissions using the following data from the NSE report:

- Diesel density = 0.885 kg/L
- Diesel emissions = 3.75 kg CO_2 / kg diesel

The required materials for the caisson island in this study are presented in Table 6.7.

Table 6.7: Life cycle inventory of a caisson island.

Material	Substructure	Quantity	Unit	Source
Rock / Quarry	Quarry run ‘Berm’	13,481,640	m^3	Mott MacDonald / NSWPH
	Core of Revetment:	243,299	m^3	Mott MacDonald / NSWPH
	Rock Fill behind Perimeter	300,000	m^3	Mott MacDonald / NSWPH
	Total	**14,024,939**	$\mathbf{m^3}$	**Mott MacDonald / NSWPH**
Sand	Sand Infill to perimeter	1,911,000	m^3	Mott MacDonald / NSWPH
	Island sand in-fill	51,156,000	m^3	Mott MacDonald / NSWPH
	Sand capping layer	182,700	m^3	Mott MacDonald / NSWPH
	Total	**53,249,700**	$\mathbf{m^3}$	**Mott MacDonald / NSWPH**
Concrete	Production Caissons	819,000	m^3	Mott MacDonald / NSWPH
	Cover	170,625	m^3	Mott MacDonald / NSWPH
	Nose Blocks	162,000	m^3	Mott MacDonald / NSWPH
	Port Basin	50,000	m^3	Mott MacDonald / NSWPH
	Compressor / Equipment Bases including Piling	75,000	m^3	Mott MacDonald / NSWPH
	Total	**1,276,625**	$\mathbf{m^3}$	**Mott MacDonald / NSWPH**

Platform design

The platform design was based on the design of the 500 MW platform in the NSWPH programme. Furthermore, the platform should be able to facilitate the 2 GW HVDC platform design of TenneT or 3 GW of hydrogen compression capacity. The platform dimensions are:

110m x 70m x 3 floors = 23,100 m^2 / platform

Since the design was based on a water depth of 35 m the quantities have been scaled to a water depth of 48 m in consultation with the original developer of the platform designs: Sea and Land Project Engineering (SLPE). It should be noted that scaling the quantities comes with uncertainties in comparison with making a new design for a specific location. The steel quantities were multiplied by the emission factor for steel taken from the Moata tool (1,270 kg CO_2 / ton steel) and the value for metal working and energy for installation from NSE.

Table 6.8: Jacket platform 2 GW HVDC, 500 MW PtG or 3 GW compression material inventory (ref. 20).

Material	Substructure	Quantity	Unit	Source
Topside	Primary Steel: Framing	7,084	Tonne	Mott MacDonald / SLPE
	Primary Steel: Floor	2,151	Tonne	Mott MacDonald / SLPE
	Secondary Steel	2,727	Tonne	Mott MacDonald / SLPE
	Cladding	775	Tonne	Mott MacDonald / SLPE
	Tertiary Steel	500	Tonne	Mott MacDonald / SLPE
	PtG Processing	0	Tonne	Mott MacDonald / SLPE
Jacket	Primary Steel	9,328	Tonne	Mott MacDonald / SLPE
	Secondary Steel	417	Tonne	Mott MacDonald / SLPE
	Piles	9,888	Tonne	Mott MacDonald / SLPE
Grillage	Jacket steel	4,908	Tonne	Mott MacDonald / SLPE
Total	**Structural steel**	**37,778**	**Ton**	**Mott MacDonald / SLPE**

Table 6.9: Compression life cycle inventory (ref. 22).

Item	Steel weight [tonnes]			
	2 GW	**3,2 GW**	**4 GW**	**5,34 GW**
Topside steelwork	3,487		4,848	6,353
Vent boom	100		1,000	100
Topside cladding	231		276	388
Sub total: topside	**3,818**	**4,017**	**6,124**	**6,841**
Jacket	2,615		3,556	3,950
Piles	1,585		2,113	2,113
Sub total: sub structure	**4,200**	**3,339**	**5,669**	**6,063**
Total construction steel	**8,018**	**7,356**	**11,793**	**12,904**

Wind farm design

Lastly, to put the results into perspective, the carbon footprint of other major equipment of search areas 6 and 7 were also included. This was done using previous work in the NSWPH programme and extending it to the full search area. The following assumptions needed to be made in order to get the results:

- Wind turbines are assumed to be 15 MW each.
- Distance to shore/dredging site is 150 km.
- Rock is excavated 1,500 km from the installation site and 25 km on shore transport is assumed.
- Each 4 GW of wind farm require 500 km of inter-array cables. The island concepts require twice as much inter-array cables.
- Pipeline to shore is excluded as repurposing is potentially feasible.
- All wind turbines are assumed to be power only.
- Electrolysers for all concepts are based on PEM (for islands alkaline is also possible).
- This is a preliminary assessment of the main components, BOP is excluded for simplicity.

The WTG (Table 6.10), PEM electrolyser (Table 6.11), and array cable (Table 6.12) life cycle inventories are provided for the wind farm:

Table 6.10: WTG life cycle inventory (ref. 22 & 42).

Material	Substructure	Quantity	Unit	Source
Steel	Rotor	40.5	Tonne	(Bonour et al, 2016), Mott MacDonald
	Tower	1,237.5	Tonne	(Bonour et al, 2016), Mott MacDonald
	Nacelle	192.2	Tonne	(Bonour et al, 2016), Mott MacDonald
	Foundation	2,250	Tonne	(Bonour et al, 2016), Mott MacDonald
Carbon fibre	Rotor	27.7	Tonne	(Bonour et al, 2016), Mott MacDonald
Fibre Glass Reinforced Plastic	Rotor	59.7	Tonne	(Bonour et al, 2016), Mott MacDonald
	Nacelle	48	Tonne	(Bonour et al, 2016), Mott MacDonald
Cast iron	Tower	63.8	Tonne	(Bonour et al, 2016), Mott MacDonald
	Nacelle	123.5	Tonne	(Bonour et al, 2016), Mott MacDonald
Copper	Nacelle	17.6	Tonne	(Bonour et al, 2016), Mott MacDonald
Aluminium	Nacelle	4.05	Tonne	(Bonour et al, 2016), Mott MacDonald
Lubricant	Nacelle	48	Tonne	(Bonour et al, 2016), Mott MacDonald
Concrete	Foundation	2,343.8	Tonne	(Bonour et al, 2016), Mott MacDonald

Table 6.11: PEM electrolyser life cycle inventory (ref. 22 & 43).

Material	Mass	Unit	Source
Titanium	528	kg / MW	Bareiß et al, 2019, Ecoinvent
Aluminum	27	kg / MW	Bareiß et al, 2019, Ecoinvent
Stainless steel	100	kg / MW	Bareiß et al, 2019, Ecoinvent
copper	4.5	kg / MW	Bareiß et al, 2019, Ecoinvent
activated carbon	9	kg / MW	Bareiß et al, 2019, Ecoinvent
platinum	0.075	kg / MW	Bareiß et al, 2019, Ecoinvent
plastic	0.3	kg / MW	Bareiß et al, 2019, Ecoinvent
electronic material	1.1	kg / MW	Bareiß et al, 2019, Ecoinvent

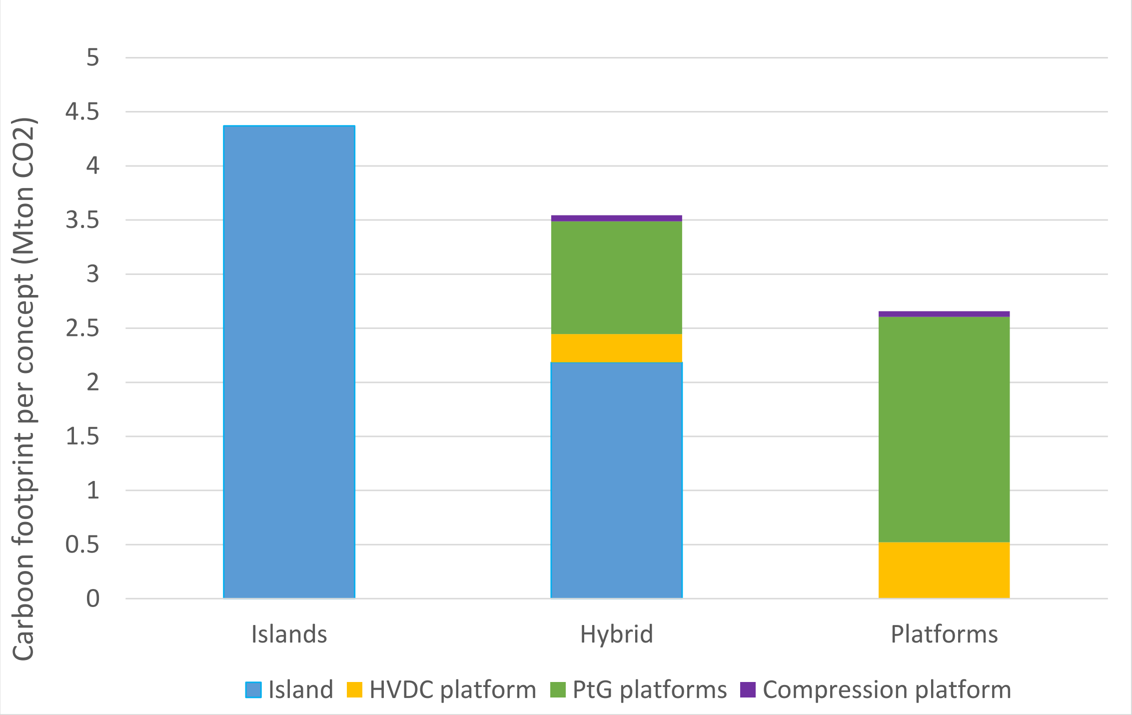
Table 6.12: Array cable life cycle inventory (ref. 22).

Material	Mass	Unit	Source
copper	6.33	kg / m	NSWPH / Mott MacDonald, Ecoinvent
polyethylene	2.53	kg / m	NSWPH / Mott MacDonald, Ecoinvent
lead	5.65	kg / m	NSWPH / Mott MacDonald, Ecoinvent
polyethane	0.58	kg / m	NSWPH / Mott MacDonald, Ecoinvent
pvc	0.08	kg / m	NSWPH / Mott MacDonald, Ecoinvent
polypropylene	8.90	kg / m	NSWPH / Mott MacDonald, Ecoinvent
steel	20.13	kg / m	NSWPH / Mott MacDonald, Ecoinvent

Results

Figure 6.12 shows the result of the executed LCA, comparing the three concepts. Results are presented per construction form in total CO_2 footprint over the lifetime. The island lifetime is expected to be 100 years while the platform only is 50 years. It is expected that replacement of the platform after 50 years (after 2080) will be carbon neutral, as green steel will be developed, and installation can be done without use of fossil fuel. From the results the CO_2 footprint of the island concept one is 4.4 Mton. This is almost twice as high as the platform only concept with a CO_2 footprint of 2.6 Mton.

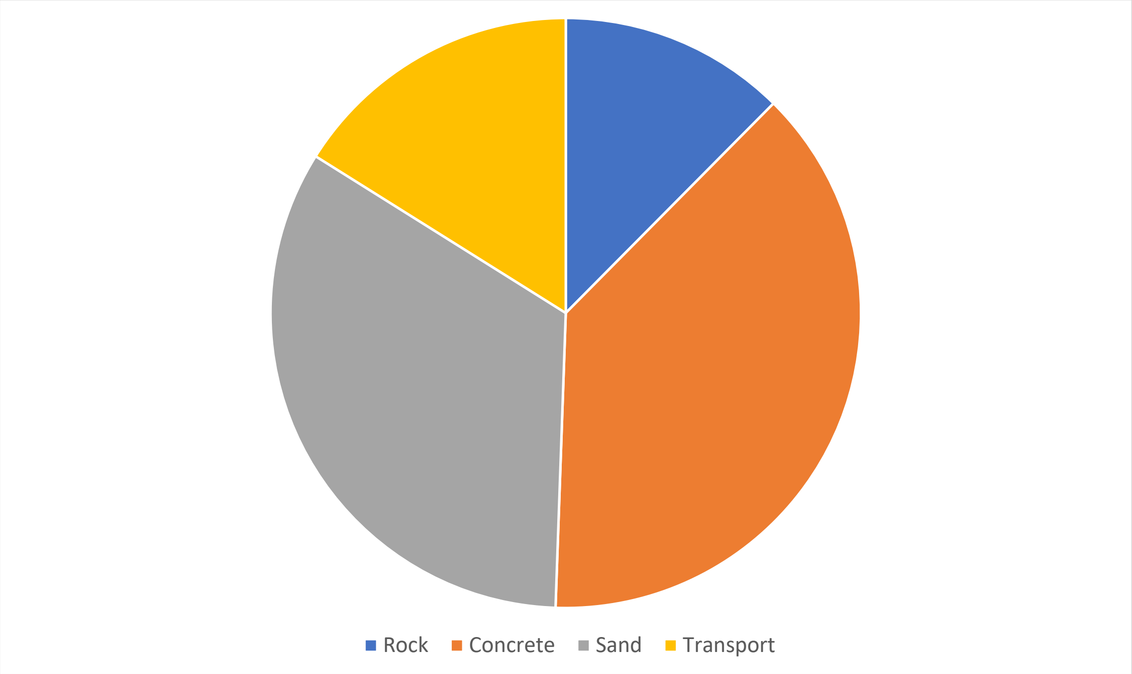
Figure 6.12: Comparison of carbon footprints of 24 GW energy hub construction forms.



It should be noted that these results will change over the years as parties are becoming more sustainable. From the NSE report it is known that the carbon footprint of the platforms is more than 90 % related to steel & metal working. Both values used in this study are calculated very conservatively and are therefore expected to decrease in the coming years, e.g. emissions values for steel will decrease in the coming years and are expected to decrease until zero approaching the year 2050.

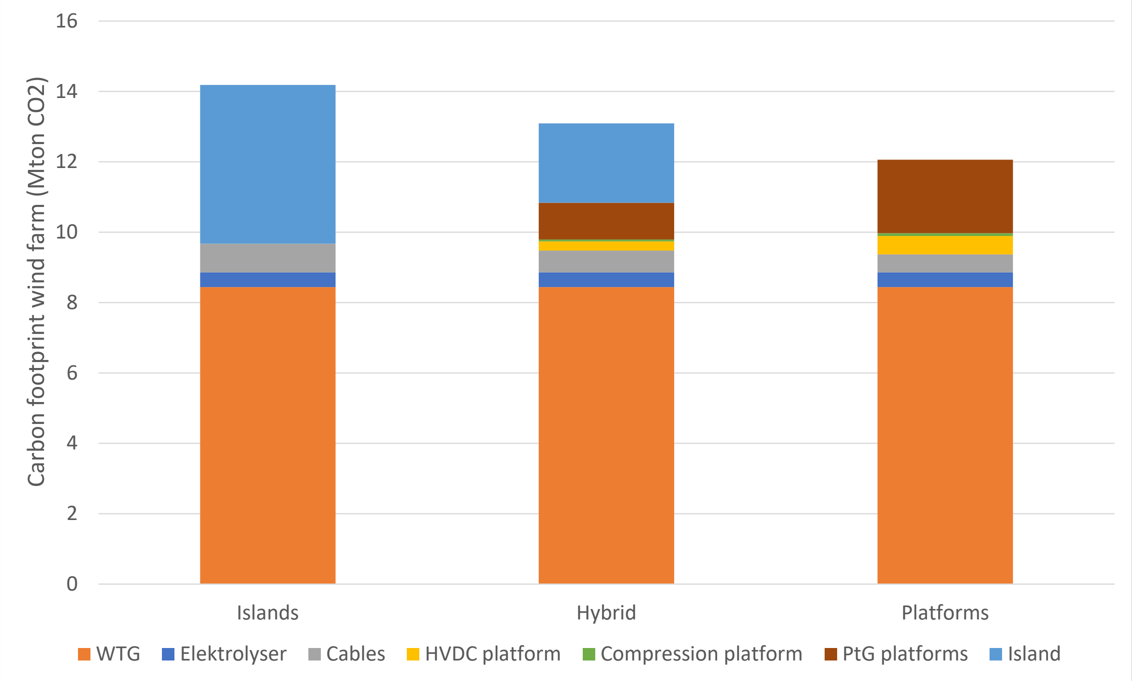
Figure 6.13 shows the contributions of materials to the overall carbon footprint of the island. The carbon footprint of the island is more than 50 % related to diesel use in transport and sand dredging. In the coming years, diesel is expected to be substituted by non-fossil based fuels for transport and installation of the materials required for the island.

Figure 6.13: Material contribution to carbon footprint of the island.



Lastly, the construction forms were compared to the overall carbon footprint of the 24 GW wind farm concept. Results are shown in Figure 6.14. It was found that the overall carbon footprint of the wind farm would be around 12-14 Mton if the current emissions factors were used. The highest contribution to the carbon footprint is related to the WTGs. From the data it was found that 70 % of the carbon footprint of the WTGs is related to steel use. Adding up the total of steel requirements for 1,600 WTGs produced these results. Around 30 % of the carbon footprint in the island concept is related to the construction form of the energy hub. For platforms, the contribution is less than 20 % and for hybrids around 25 %. The total contribution to the overall carbon footprint is useful information to consider in the scoring & weighting.

Figure 6.14: Carbon footprint of full 24 GW wind farm concepts.



As described in the methodology, the scoring can be done quantitatively or qualitatively. As this assessment is done quantitatively, the scoring will be done too. It was decided to use the carbon footprint of the construction form to value the different concepts. The values given were based on the Mton CO_2 per concept. Therefore, islands are scored at 4.4, the hybrid configuration is scored with a 3.5 and platforms are scored with a 2.6 (Table 6.13).

Table 6.13: Evaluation 1 Scoring - Climate Change.

Criteria	Scale	Islands	Hybrid	Platforms
Climate change	Higher scores for higher impact, values based on Mton of CO_2. per 24 GW energy hub	4.4	3.5	2.6

Discussion

This life cycle assessment is a first step in analysing the environmental impact of the construction form for search areas 6 and 7 and gives an indicative comparison of the three concepts. As discussed, emissions factors are expected to change over time with the industry becoming more sustainable. It is expected that the emissions factor will decrease at a similar rate for diesel use as for steel quantities. For future steps it is recommended to extend this study with more detailed analysis.

Furthermore, this is a high-level life cycle assessment focussing only on the main materials and wind farm components. With a high-level assessment there are large numbers of uncertainties. It is expected that the included materials contribute the most to the overall carbon footprint of the wind farm. Furthermore, due to the limited engineering documents available the LCA couldn’t be executed in more detail at this stage. For future steps it is recommended to extend this life cycle assessment and include the balance of plant, HVDC system, pipelines, etc. when the energy hub concept is designed in more detail.

Since the results were in contrast with the results found by NSE, a discussion with TNO was arranged. After the discussion and new insights, NSE has adjusted their results and are now showing a similar result. The revised results are presented in Figure 6.15.

Lastly, the Belgium Energy Island also did a comparison life cycle analysis for locations at around 25 m water depth (ref. 35). Results are presented in Figure 6.16. Similar results were produced that are in favour of the platforms.

Figure 6.15: New carbon footprints calculated by NSE (ref. 11).

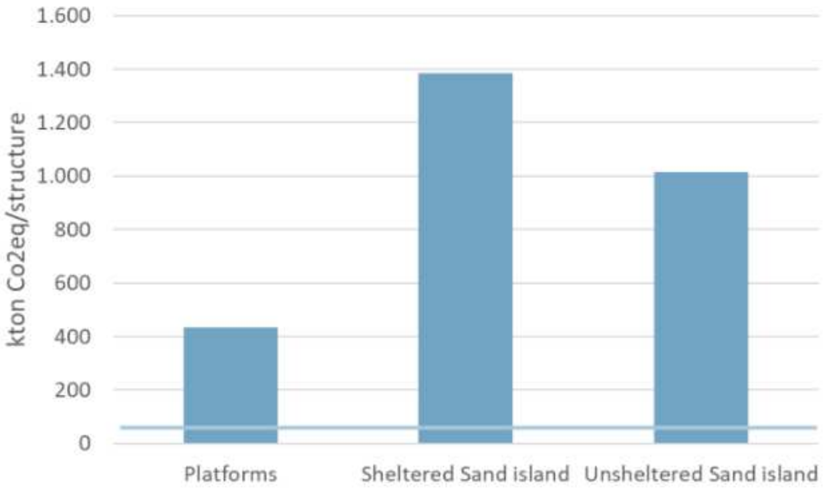
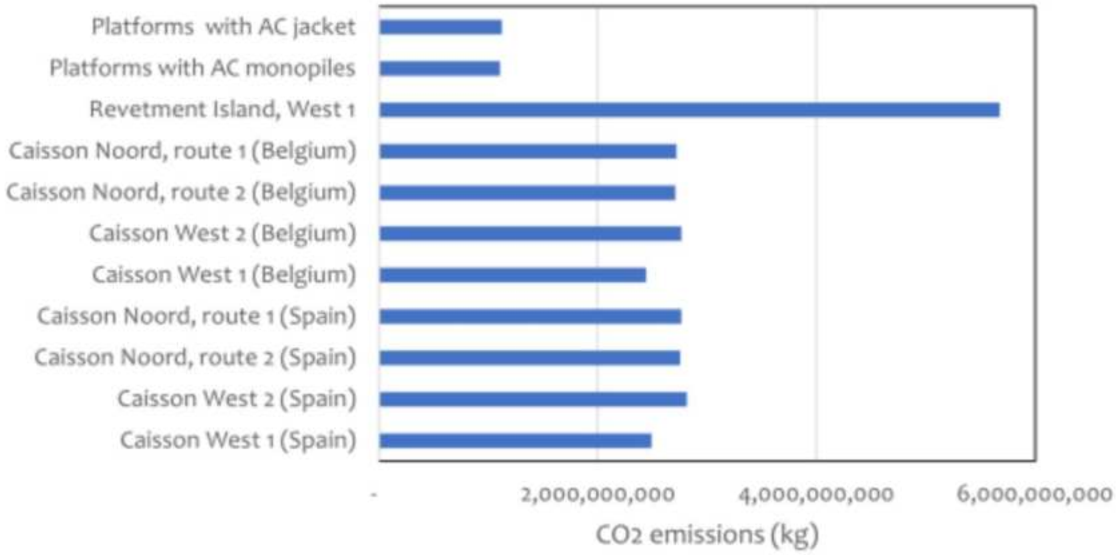


Figure 1: Total carbon footprint of each structure over the entire life cycle. The blue lines indicates the carbon footprint of an oil and gas platform as reported by ecoinvent. (Correction 21/08/2023)

Figure 6.16: Belgian Energy Island Life Cycle Analysis.



6.1.5.2 Ecological Impact During Construction

The local impact to ecosystems is currently being investigated in a quick scan commissioned via the ministry of infrastructure and waterworks (IenW). This quick scan should have finished by Q1 2023 but has been delayed and is to be finished in Q4 2023. Therefore, information about the quick scan is not incorporated in this report. From discussions with IenW, EZK, and stakeholders, it is understood that in general the island concept will have a more significant impact on local ecosystems than the platform concept. This is also in line with the results of the environmental effect research for the Belgian Island (ref. 35). This is explained by the fact that the overall change in habitats is higher and on a larger area with the construction of an island, as the seabed needs to be covered with new materials, building the foundation of the island impact seabed and marine life. Recovering ecosystems or setting of new ecosystems is possible but is a time-consuming process and can take decades. The construction of platforms requires drilling for the platform foundation but is expected to have lower overall ecosystem impact. As local ecology is not mapped and the ecology impact is dependent on construction location, the impact on local ecology might differ. If an island construction is chosen, it is advised that IenW will decide on a location that has the least impact on ecology.

Furthermore, habitats can also be impacted indirectly. This impact route is mainly the result of the use of materials. For example, in the island concept, large quantities of building materials are required. From research in the NSWPH, it was estimated that one 10 GW island concept already requires a new quarry to be opened for mining the materials. Opening a quarry has a high impact on local ecosystems and the impact of two 12 GW island is therefore even higher. Furthermore, dredging the required amounts of sand will have a significant impact on seabed ecosystems. From this information it is expected that the ecosystem impact from construction is higher for islands than for platforms. This is also supported by the studies in Belgium.

Since the information available for the comparison is limited, the scoring is on a high-level basis (Table 6.14). Although the ecology quick scan, commissioned by IenW, has not been finished, it is expected that the island only concept will have the highest environmental impact on habitat change and therefore is scored with a “High”. Secondly, the platform concept is expected to have a lower impact and is therefore scored with a “Low” for impact on ecology. The hybrid concept is scored with a “Medium”.

These results are expected results and highly depended on local ecology. Therefore, these scorings are not considered in the overall scoring. A high score indicates greater impact.

Table 6.14: Evaluation 1 Scoring – Ecological Impact during Construction.

Criteria	Scale	Islands	Hybrid	Platforms
Ecological impact during construction	Higher scores for higher impact	High	Medium	Low

6.1.5.3 Ecological Impact During Operation

As described in the introduction, ecosystem impact during operation is mainly in the form of pollution. This can be in the form of chemical pollution, noise pollution and habitat disturbances. Pollution will be mainly focussed on pollution during operation of the hydrogen production process. There are multiple routes of pollution possible on an offshore energy hub, the most likely routes are discussed:

- The first process is the desalination system. Desalination can be done using thermal desalination (MED) or mechanical desalination (SWRO). It is expected that MED will be used on the island as waste heat from electrolyser can be recycled more easily. Platforms will be equipped with SWRO. Waste streams are comparable in both processes. In desalination there are two outlet streams, one with the desalinated water used for demin. and subsequently electrolysis, and one with a by-product liquid stream containing pre-treatment additives, organics, microbial and particulates rejected from the reversed osmosis process. The by-product stream is directed to the wastewater treatment system that is present at either the platform or the island. The discharge contains large quantities of brine. Although it is expected that disposal of brine in one location (island) could be more harmful for ecosystems than spreading the disposal across search areas 6 and 7, the impact is not expected to be significant as long as proper mitigation measures, such as diffusers and submerged disposal, are in place. If the island is chosen to be the best option, hydrodynamic modelling is required to ensure ecosystems are not affected by the waste streams.

- The water stream is fed into the demineralisation system. Demineralisation can be done using two methods: Electrodeionisation (EDI) or Ion-exchange resin. Generally, EDI is used on smaller scale PtG facilities and could be applicable for hydrogen WTGs. The ion-exchange resin method is used for large capacity hydrogen plants such as the 500 MW platform and 12 GW island. Under normal operating conditions, the demin. system does not produce any significant waste streams but a regeneration cycle must be performed, this is done with HCl. Subsequently, NaOH is added to increase the pH, resulting in an additional brine stream, and thereby fully neutralising the toxic HCl and NaOH. The waste stream would consist of 20 % brine from demin. and 80 % brine from desalination. Equally, proper mitigation measure should be in place. These are smaller quantities and therefore this does not significantly impact the scoring.
- Hydrogen production equipment uses oil, e.g. for the electrical transformers. Under normal operating conditions, equipment is sealed in such way that if oil is leaked this would be collected and not end up on the platform or island. In the rare case of an oil leakage, small amounts of oil on platforms is easily washed to sea in times of rain. On islands, there are more sources for oil leakages, such as utility vehicles. The nature of the foundation will block the oil from getting into the environment, but the foundation can be contaminated. With platforms, small quantities of oil can end up in the seawater from the vessel. The quantities of oil leakage are expected to not be significant, especially with proper mitigation measures oil leakage can be prevented. Therefore, it is assumed that oil leakage will not influence the scoring for islands, hybrids or platforms.
- Sewage handling on platforms and island requires proper wastewater treatment systems. The expectation is that personnel presence on platforms is in general lower than on islands and therefore less sewage handling is required on platforms. On the other hand, the construction of an island allows for more free surface area to install proper wastewater treatment. Therefore, the environmental impact of sewage handling is expected to not be significantly different if it meets regulation standards.
- During operation, more disturbance is expected from the island in one location from pumped water and brine. Platforms have the disturbance more evenly spread across search areas 6 and 7 and it is therefore expected to have a less intense impact. During the environmental impact assessment, noise pollution should be assessed, and mitigation measured should be in place.
- More noise is expected from islands than from platforms from compression, venting, and cooling. Proper mitigation measures need to be in place at the island to decrease environmental impact.
- Platforms can be affected by corrosion if the metal is exposed. Cathodic protection in the form of galvanic anodes can prevent corrosion of the metal but can have an impact on the marine ecosystems. Mitigation measures, such as the use of ICCP, need to be in place to avoid contamination.
- More disturbance and pollution is expected from marine activities during operation for the platform concept, since there are more locations.

- If seawater cooling is employed, hydraulic modelling and environmental impact assessments will need to be carried out to ensure no disruption to marine life for the volume of water displaced and heat disposed for cooling. It is expected that heat disposal would not cause problems due to the nature of the North Sea being at relative low temperatures. In high temperature areas, species might be already at their temperature limits and therefore additional heat might cause problems. If heat disposal is found to be problematic, a combination of cooling technologies may be employed (e.g. air coolers), to reduce the water consumption and heat disposal. Within the NSWPH programme platforms are designed with water cooling and islands with air cooling; therefore, islands are expected to have a lower environmental impact.
- For a 6 GW concept it is expected that oxygen will be vented at a rate of around 800 ton/hr. Oxygen is expected to be vented at on location on island or vented at multiple locations if platforms are chosen. Oxygen venting impact can be mitigated by spreading the oxygen disposal with multiple vents. Oxygen disperses very quickly and is expected to not cause ecological impact.
- Electrolyte disposal: The electrolyte used in electrolysers can be hazardous. This is mainly expected from alkaline electrolysers. Liquid electrolytes (KOH) can be lost from pipework or venting and the design should therefore be made to mitigate KOH losses as much as possible.

To conclude, differentiation between the concepts is challenging without any further information. It is expected that, with the proper mitigation measures, the differences in impact to local ecosystems is not very significant. In the island concepts the pollutants are expected to be more concentrated and therefore should be scored higher. However, mitigated in one location might be easier. A high-medium-low scoring would not be fitting as this suggests that there is a significant difference in high and low. Therefore, a qualitative scoring was chosen to make the relative differences as low as possible. The concept scorings are presented in Table 6.15. A higher score indicates greater impact.

Table 6.15: Evaluation 1 Scoring – Ecological Impact During Operation.

Criteria	Scale	Islands	Hybrid	Platforms
Ecological impact during operation	Higher scores for higher impact	9	8	7

6.1.5.4 Environmental Weighting

The weighting of the environmental criterion is presented in Table 6.16. As the impact of climate change is very significant and noticeable all around the world, climate change is weighted 100 out of 100.

The ecological impact during construction is expected to have a significant impact on the local ecosystems and should therefore be rated as 100 out of 100. Since the results of the quick scan are yet to be received, it was chosen to put ecology on hold, so results can be added or adjusted at a later stage.

The impact due to operations is expected to be low on ecosystems since the toxicity of the pollutants is low. Most chemicals that are worked with are abundant in nature and consist mainly of brine, water, H_2 and O_2. Furthermore, there are available mitigation measures that can be set in place. Therefore, the weighting for impact during operation is advised to be 20 out of 100.

Table 6.16: Evaluation 1 Weighting – Environment.

Criteria	Scale	Islands	Hybrid	Platforms	Weighting
Greenhouse Gas Emissions (Life Cycle Assessment)	Higher scores for higher impact, values based on Mton of CO_2.	4.4	3.5	2.6	**100**
Ecology impact during construction	Higher scores for higher risks and impact	High	Medium	Low	**0**
Ecology impact during operation	Higher scores for higher risks and impact	9	8	7	20
Normalised Results	**Highest score is best**	**79**	**90**	**100**	

6.1.6 Economics

The initial evaluation between island(s), platforms and a hybrid solution does not require these options to be fully developed. However, as a basis for providing an economic evaluation between the concepts, CapEx and OpEx estimates have been developed based on what is considered the base case assumptions for each of the concepts.

For the platform portion of the energy hub the assumption is that hydrogen production is not co-located with compression and that it is located within the individual wind farm blocks. It will be up to the developer to either install hydrogen production on platforms or local to the WTGs but the cost estimate for platform-based concepts assumes hydrogen production local to the WTGs.

HVDC equipment not located on the island will be located on standard 2 GW HVDC platforms. The compression equipment can either be centralised (on platforms or an island) or decentralised within the individual wind blocks. As a base assumption for the cost estimate compression is assumed to be centralised on platforms.

The cost estimates are developed from the work done on the NSWPH programme:

- The island costs are based on the caisson island developed to support 4 GW of HVDC equipment and 6GW of hydrogen production and compression equipment. Following discussion with TenneT it is assumed that 6 GW of HVDC equipment can be installed on this island without increasing its size. In reality, additional ancillary infrastructure is likely to be installed on an artificial island potentially increasing its size, but this is not considered. The NSWPH island was designed for 29 m depth, and the material requirements have been increased for the 48 m water depth of search areas 6 and 7. The level of the seabed can be increased using dredged sand without the need for additional quarry run as wave action will not impact the sand at this depth. The HVDC equipment costs were excluded during the NSWPH programme, and these have been requested from TenneT.
- The Steel weights adopted for the costing of the HVDC Platforms and the Compression Platform(s) are consistent with the tonnage data included for such in tables 6.8 & 6.9. The most recent phase of the NSWPH programme was based on hydrogen production local to the WTGs. These costs will be the basis of hydrogen production for the platform concepts. This phase also includes a 3.2 GW compression platform located in 48 m of water depth which will be the basis for the costs associated with the compression platforms.
- The remaining energy hub infrastructure including the WTGs, array cables and flowline infrastructure will depend on the developed design within search areas 6 and 7 including the

island and platform locations. From the latest phase of the NSWPH programme a range of costs for these per GW of wind generation capacities are available which are used as the basis for this cost estimate. The costs of the subsea HVDC cables and subsea hydrogen pipelines are excluded.

6.1.6.1 CapEx

The CapEx scores included below are estimated based on updates to the NSWPH programme cost estimates and are shown as real values in € billions.

The methodology used follows recognised industry best practice methods commensurate with project definition available at this current stage of project screening.

The primary source for costing at this time is in-house project and cost data base held by the individual technical discipline leads. The CapEx costs have been derived from and ‘benchmarked’ against this data base.

The in-house project / cost data base is extremely comprehensive. It covers multiple international projects in which Mott MacDonald’s technical leads have been involved over time, across multiple workstreams. As such it provides a considerable number of cost data points from which we have been able to extrapolate corresponding and representative cost estimates to align with the envisaged scope.

Where identified, the estimated costs reflect the indicative schedule developed in terms of scope, durations, and expected timing of operations contained therein.

Where detailed norms are not available a top-down approach has been used from the level at which norm data exists within the MML database.

Supplier information on prices has not been available from a supplier engagement process however relevant data obtained from such in relation to the NSWPH programme has been referred to where relevant.

In the majority of cases CapEx rates and prices have been benchmarked against the NSWPH programme and adjusted accordingly, which is the primary source of the cost data for this exercise. The methodology used for the NSWPH programme was to produce cost estimates following a detailed top-down schedule approach building a high-level strategy around key progressive milestones (supported by benchmark durations from in-house cost database). This methodology adopted considerations such as design maturity, limitations of input cost estimating data, and available benchmarks and as such, limitations on the potential approaches to reaching credible conclusions relating to confidence levels.

Overall, the CapEx costs reflect the expected costs associated with an EPC / EPCM type contracting strategy and its associated risk profile. As such the ‘component’ elements that comprise the total installed ‘package’ price, include such items as: -

- Package Contractor Project / Construction Management
- Engineering / Procurement Services + related Survey costs
- Delivery / Transportation / Freight + Insurances
- Pre-Assembly (off-site) / Storage / Temporary Facilities
- Commissioning Costs
- Other

The following key assumptions / qualifications / exclusions apply to the CapEx cost estimates.

- The CapEx cost estimates reflect a Class 4/5 AACE (P50) status 'Mid-point’ estimate with an indicative tolerance / accuracy level of +/-50 %

- No separate Client contingency allowance has been identified or added to the reported CAPEX estimates. A 10% - 15% project Contingency / Risk provision (on average) is encompassed within the ‘build-up’ of the CapEx estimate rates and prices and is reflected in the resultant Cost Estimate accuracy tolerance (band width).
- The estimates are presented in Euros and represent ‘factored’ estimates based on MML in-house Cost ‘benchmarks’.
- The CapEx / OpEx prices reflect a 'base date' of 3Q 2023. Escalation and / or Inflation beyond this 'base date' is excluded.
- No taxation issues have been considered.
- Allowances for unit economies of scale / bulk purchasing discounts / learnings during installation are built into CapEx estimates.
- Owner / Consortium Development Costs and other 3rd Party Services are excluded.
- No decommission costs or residual value have been included in the estimates, the implicit assumption being that these costs will offset to zero, (i.e. decommissioning costs are assumed to be offset by the residual / salvage value of the assets).
- Principal Scope Exclusions are:
  - Hydrogen Export Pipeline(s)
  - Hydrogen Export grid connection(s)
  - Hydrogen Storage
  - HVDC Systems & Equipment
  - HVDC Converter Stations
  - HVDC Export Link(s)
- HVDC grid connection(s)

6.1.6.2 OpEx

The OpEx values included are real values estimated in €millions per annum calculated as a percentage of CapEx with appropriate factors selected for each of the concept sub-systems.

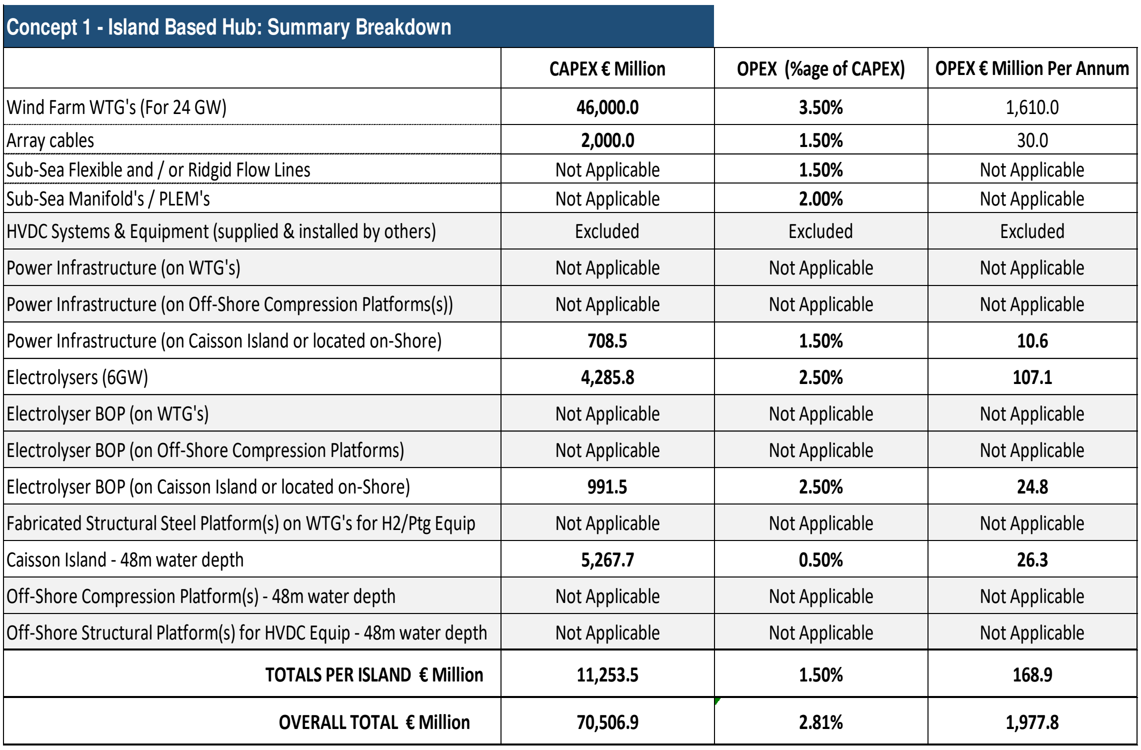
The OpEx values included are real values estimated in €millions per annum calculated as a percentage of CapEx with appropriate factors selected for each of the concept sub-systems.

OpEx values have been derived predominantly from the in-house cost data base. At this current stage of project screening, it is too early to consider rates and prices reflective of any specific operations and maintenance regime. At the current stage of development there is no definitive O&M strategy in place or defined maintenance sparing philosophy developed, linked to each envisaged project workstream.

As such, for this current exercise OpEx values have largely been determined through extrapolation of comparable OpEx data held on a project by project basis within the cost data base. In the majority of cases OpEx estimates primarily reflect the average annual cost to operate and maintain the system components based on a factor, or percentage, of CapEx, ‘benchmarked’ against other comparable projects.

As such OpEx is expressed as a ratio (i.e. percentage) of CapEx, based on the in-house benchmarks.

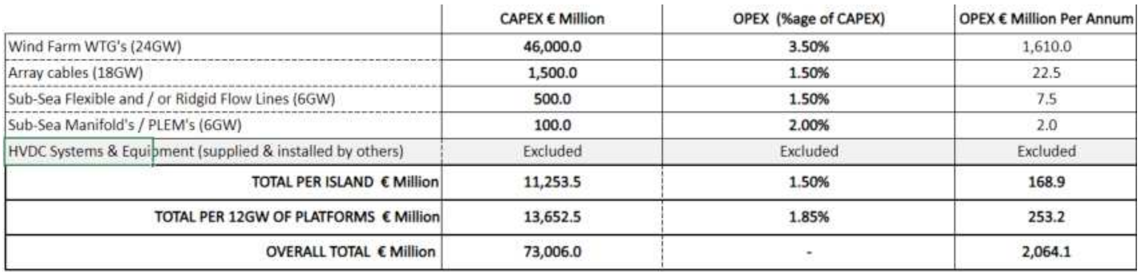
Table 6.17: Concept 1 – Cost Estimate of Island Based Energy Hub (Mott MacDonald analysis).



Concept 1 - Island Based Hub: Summary Breakdown

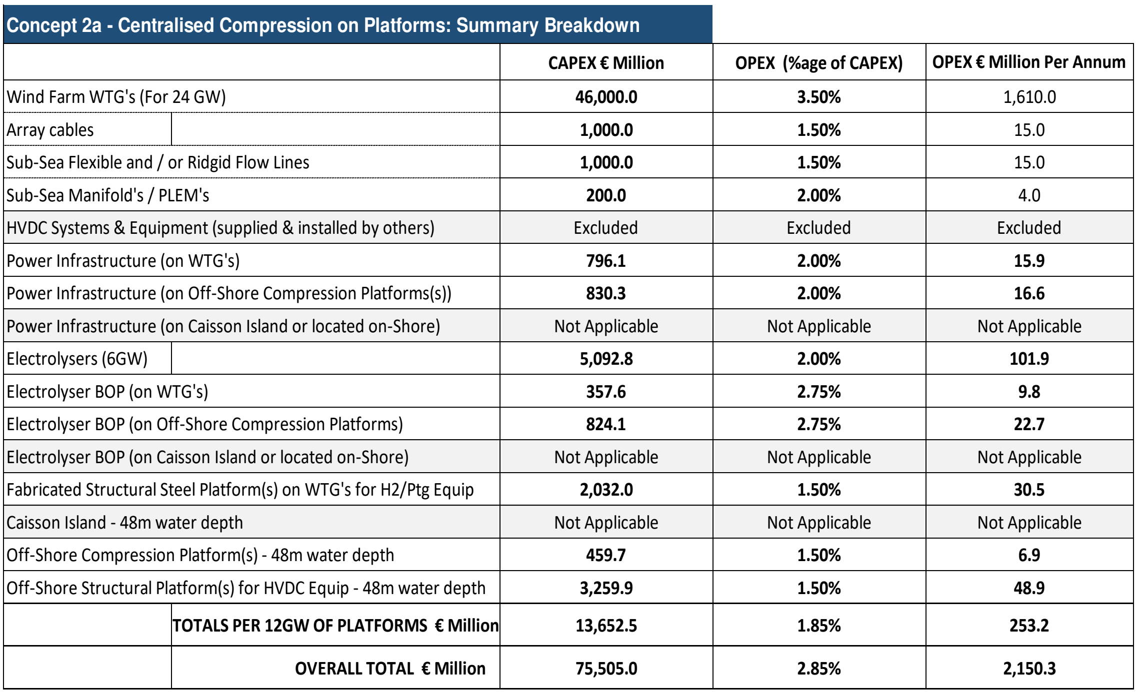
	CAPEX € Million	OPEX (%age of CAPEX)	OPEX € Million Per Annum
Wind Farm WTG's (For 24 GW)	**46,000.0**	**3.50%**	1,610.0
Array cables	**2,000.0**	**1.50%**	30.0
Sub-Sea Flexible and / or Ridgid Flow Lines	Not Applicable	**1.50%**	Not Applicable
Sub-Sea Manifold's / PLEM's	Not Applicable	**2.00%**	Not Applicable
HVDC Systems & Equipment (supplied & installed by others)	Excluded	Excluded	Excluded
Power Infrastructure (on WTG's)	Not Applicable	Not Applicable	Not Applicable
Power Infrastructure (on Off-Shore Compression Platforms(s))	Not Applicable	Not Applicable	Not Applicable
Power Infrastructure (on Caisson Island or located on-Shore)	**708.5**	**1.50%**	**10.6**
Electrolysers (6GW)	**4,285.8**	**2.50%**	**107.1**
Electrolyser BOP (on WTG's)	Not Applicable	Not Applicable	Not Applicable
Electrolyser BOP (on Off-Shore Compression Platforms)	Not Applicable	Not Applicable	Not Applicable
Electrolyser BOP (on Caisson Island or located on-Shore)	**991.5**	**2.50%**	**24.8**
Fabricated Structural Steel Platform(s) on WTG's for H2/Ptg Equip	Not Applicable	Not Applicable	Not Applicable
Caisson Island - 48m water depth	**5,267.7**	**0.50%**	**26.3**
Off-Shore Compression Platform(s) - 48m water depth	Not Applicable	Not Applicable	Not Applicable
Off-Shore Structural Platform(s) for HVDC Equip - 48m water depth	Not Applicable	Not Applicable	Not Applicable
TOTALS PER ISLAND € Million	**11,253.5**	**1.50%**	**168.9**
OVERALL TOTAL € Million	**70,506.9**	**2.81%**	**1,977.8**

Table 6.18: Hybrid Hub Cost Estimate (Mott MacDonald analysis).



	CAPEX € Million	OPEX (%age of CAPEX)	OPEX € Million Per Annum
Wind Farm WTG's (24GW)	**46,000.0**	**3.50%**	1,610.0
Array cables (18GW)	**1,500.0**	**1.50%**	22.5
Sub-Sea Flexible and / or Ridgid Flow Lines (6GW)	**500.0**	**1.50%**	7.5
Sub-Sea Manifold's / PLEM's (6GW)	**100.0**	**2.00%**	2.0
HVDC Systems & Equipment (supplied & installed by others)	Excluded	Excluded	Excluded
TOTAL PER ISLAND € Million	**11,253.5**	**1.50%**	**168.9**
TOTAL PER 12GW OF PLATFORMS € Million	**13,652.5**	**1.85%**	**253.2**
OVERALL TOTAL € Million	**73,006.0**	**-**	**2,064.1**

Table 6.19: Platform-based Hub (Concept 2a) Cost Estimate (Mott MacDonald analysis).



Concept 2a - Centralised Compression on Platforms: Summary Breakdown			
	CAPEX € Million	OPEX (%age of CAPEX)	OPEX € Million Per Annum
Wind Farm WTG's (For 24 GW)	**46,000.0**	**3.50%**	1,610.0
Array cables	**1,000.0**	**1.50%**	15.0
Sub-Sea Flexible and / or Ridgid Flow Lines	**1,000.0**	**1.50%**	15.0
Sub-Sea Manifold's / PLEM's	**200.0**	**2.00%**	4.0
HVDC Systems & Equipment (supplied & installed by others)	Excluded	Excluded	Excluded
Power Infrastructure (on WTG's)	**796.1**	**2.00%**	**15.9**
Power Infrastructure (on Off-Shore Compression Platforms(s))	**830.3**	**2.00%**	**16.6**
Power Infrastructure (on Caisson Island or located on-Shore)	Not Applicable	Not Applicable	Not Applicable
Electrolysers (6GW)	**5,092.8**	**2.00%**	**101.9**
Electrolyser BOP (on WTG's)	**357.6**	**2.75%**	**9.8**
Electrolyser BOP (on Off-Shore Compression Platforms)	**824.1**	**2.75%**	**22.7**
Electrolyser BOP (on Caisson Island or located on-Shore)	Not Applicable	Not Applicable	Not Applicable
Fabricated Structural Steel Platform(s) on WTG's for H2/Ptg Equip	**2,032.0**	**1.50%**	**30.5**
Caisson Island - 48m water depth	Not Applicable	Not Applicable	Not Applicable
Off-Shore Compression Platform(s) - 48m water depth	**459.7**	**1.50%**	**6.9**
Off-Shore Structural Platform(s) for HVDC Equip - 48m water depth	**3,259.9**	**1.50%**	**48.9**
TOTALS PER 12GW OF PLATFORMS € Million	**13,652.5**	**1.85%**	**253.2**
OVERALL TOTAL € Million	**75,505.0**	**2.85%**	**2,150.3**

6.1.6.3 Need for pre-investment

A direct comparison between the CapEx and OpEx of the concepts does not provide the full picture for their economic evaluation. Island construction needs very significant upfront investment as the island must be constructed at full capacity as the cost and complexity of extensions to it once constructed are prohibitive. To account for this investment which likely will have to be provided or facilitated by government the concepts have been scored on the need for pre-investment.

6.1.6.4 Economics Weighting

Table 6.20: Evaluation 1 – Economics Scoring & Weighting.

Criteria	Scale	Islands	Hybrid €billion	Platforms	Weighting
CapEx (€ billion)	Higher scores for higher cost, values based on € billion.	70.5	73	75.5	**80**
OpEx	Higher scores for higher cost, values based on € million/a	1,977.8	2,064.1	2,150.3	**80**
Need for pre-investment	Higher scores for higher need	High	Medium	Low	**100**
Normalised Results	**Highest score is best**	**88**	**94**	**100**	

6.1.7 Realisation & Technical Feasibility

6.1.7.1 Development Time to Operations

The development time to first power export and first offshore hydrogen production is dictated by the concepts selected. During the NSWPH programme schedules to first power export and first hydrogen were developed for combined onshore and offshore (platform based) hydrogen production and for combined onshore and caisson island-based hydrogen production. The approach during the programme assumed initial onshore hydrogen production which would then delay installation of offshore hydrogen production whether on platforms or islands.

For the search area 6 and 7 energy hub whilst it may be advisable to install onshore hydrogen production in line with the HVDC system capacity to bring power ashore and to avoid curtailment this should not be linked to the schedule to develop offshore hydrogen production which is already very challenging. Each of the schedules has been updated for this study, removing onshore hydrogen production, allowing for a proper comparison (Appendix C). The resulting timelines are:

- For a large offshore island
    - First power export and first hydrogen production in 2034. Both are interlinked due to the need to first construct the island in its entirety. As installation of HVDC equipment is on the critical path rather than hydrogen production equipment both can be realised at the same time.
- For hybrids
    - First hydrogen & power export on island in 2034 (only required in 2035).
    - First hydrogen on platform is based on platform schedule and thus 2031.
    - First power export via HVDC platforms is 2030.
- For platforms
    - First power export in 2030 as based on TenneT’s standardised 2 GW HVDC platforms.
    - First hydrogen in 2031.

These schedules have been developed based on a conceptual design and there may be scope for optimisation but equally the uncertainties associated with major offshore wind generation and hydrogen production may result in schedule slippage. The longer schedule for an island-based energy hub is driven by island construction and installation, and the fact that the island must be constructed in its entirety before any infrastructure or equipment may be installed. As initial island construction can only occur in the North Sea’s summer season extending the overall schedule and increasing the risk of delays whilst making it more difficult to recover schedule delays in following years.

For the island concept, therefore, the current schedule is not in line with optimal first hydrogen or direct power export. This along with the greater uncertainty in construction of large islands in 50m water depth compared to platforms as well as potential material supply constraints led to it being scored least favourably. For the hybrid concept, as the platforms could be used for initial development with the island only required once the initial 12 GW of wind generation capacity had been installed, the concerns are reduced. The risks associated with parallel engineering phases of both platforms and the island results in a higher score than the all platforms concept. The least risk is associated with a solution comprised solely of modular and scalable platforms. The concepts were scored quantitatively as the difference between hybrids and islands is expected to be relatively higher than the difference between hybrids and platforms. The scoring results are presented in Table 6.21 with higher numbers indicating longer development timelines with greater risk of slippage.

Table 6.21: Evaluation 1 Scoring – Development time to operations.

Criteria	Scale	Islands	Hybrid	Platforms
Development time to operations	Higher scores for longer development time (estimates in years)	8	3	2

6.1.7.2 Construction/Installation Constraints

The design of the platform topsides and substructure will impact construction and installation of the platforms. As an example, the pros and cons are provided in Table 6.22 for three types of platform substructures.

Table 6.22: Construction and Installation Pros and Cons for platforms designs (ref. 20).

Criteria	Concrete Gravity Base		XXL Piles		Jacket	
	Pros	**Cons**	**Pros**	**Cons**	**Pros**	**Cons**
Fabrication / construction	• A range of potential constructors available. • No requirements for skilled labour.	• Purpose built construction facility required. • Dry dock required?	• 10m dia. piles are within current WTG foundation experience and capabilities. • European fabrication yards tend to lead the way for XXL Piles. Good for local content. • Good supply chain and it is expected to continue growing.	• Currently there are very few vendors for 10m+ dia. piles.	• Many experienced fabricators in Europe and the World.	• Large dimensions will limit the available fabrication sites.
Transport	• These concepts use large geometric volumes and result in the production of self-buoyant structures, meaning tugboats can be used to transport to the offshore site	• Large and very heavy foundation to transport. • Permanent ballast (sand or aggregate) is required. • Planning and operations of transport and installation are constrained by the available weather windows. Limitatio	• 10m dia. piles are within current WTG foundation experience and capabilities. • Large number of vessels in the market and the fleet is expected to grow.	• The piles are longer and heavier than current WTG foundation examples.	• Well established market and a number of contractors who understand jacket installation and are willing to take responsibility for risks.	• Large plan dimensions limit load out capability and makes transport difficult

Table 6.22: Construction and Installation Pros and Cons for platforms designs (ref. 20).

Criteria	Concrete Gravity Base		XXL Piles		Jacket	
		ns could be restrictive. - Potential quayside draft limitations and in the towing route. A larger draft makes towing easier.				
Installation	- No heavy-lift vessel is required, low dependency on HLV & barge availability.	- Installation is limited by lower sea state than transport - Requires extensive seabed preparation. - Requires scour protection. - Grouting required to fill possible volumes between GBS and seafloor.	- Large number of vessels with experience and capability of installing XXL piles. Vessel fleet is expected to grow. - Conventional installation by hydraulic hammer. Vibration installation may also be possible.	- Possible noise issues although mitigation measures are available and continually being developed. - Scour protection is likely to be required although less extensive than the gravity base solution. - Installation tolerances could be an issue.	- Well established market and a number of contractors who understand jacket installation and are willing to take responsibility for risks.	- Possibly too large and heavy for a single hook lift. Use of two HLFV's is possible or it will require a larger vessel

Based on the NSWPH programme it is assumed that the HVDC and compression platforms are jacketed structures. Hydrogen production platforms are also assumed to be jacketed but if hydrogen production is local to the WTGs then it would be installed on platforms attached to the WTG itself and the entire construction would be installed on monopiles. For both monopiles (for WTGs) and jacketed platforms there is extensive experience of installing them in the North Sea.

For an offshore island or an offshore platform, multiple construction sites (shipyard, onshore pre-fabrication site, island or offshore platform locations) and both onshore and offshore activities are required:

- Islands:
  - Construction of island components onshore
  - Transportation of island components and raw materials offshore
  - Construction of the island offshore
  - Construction of the equipment onshore
  - Installation of the equipment on the island offshore
- Platforms
  - Construction of the substructure onshore
  - Construction of the topsides onshore
  - Construction and installation of the equipment onto the topsides onshore
  - Transportation and installation of substructure offshore
  - Transportation and mounting of topsides onto the substructure offshore
  - Minimal tie-ins of equipment offshore
- Hybrids:
  - Combination of both islands and platform sites and activities

The offshore nature of the concepts introduces a level of complexity for the construction and installation of the concepts. Equipment for the island would need to be modularised to minimise construction activities on the island and promoting tie-ins between modules only, with module sizes maximised (nominally 500 tonnes from the NSWPH programme) to reduce the number of transfers from onshore to the island. Although the design of the plant on the island would be modularised, there would still be a larger number of transport activities and a longer duration of offshore works required for the island compared with platforms which can mostly be constructed and installed onshore, and with complete topsides floated out and mounted onto the substructure in a much shorter period.

Weather patterns will need to be observed to avoid transportation and works offshore during extreme weather conditions. It is only possible during the summer season from April to September when sea conditions allow. This is more limiting for construction of an island, which has more offshore activities compared with platforms, although less weather downtime is achieved after the island supply port is completed.

The number of array cables which need to be connected to the artificial island is expected to be in excess of 130 based on the use of 66 kV cables. The necessary cable routing around caisson island needs to be developed in order to manage installation of this number of cable circuits at one location. When combined with the HVDC cables and flowlines, accommodating this amount of infrastructure in a single location could prove challenging. Routing of the cables on the island and installing sufficient switchgear for terminating the cables could also be an issue and de-rating factors would need to be considered for cables in close proximity. In order to achieve an element of mitigating in this respect, the NSWPH programme considered the use of offshore satellite collector substations. These would be used for stepping up the AC voltage from 66 kV to 275 kV, which would reduce the quantity of cables to around 20-30 275 kV AC submarine cables.

However, step down transformation to 66 kV voltage level would be required to be implemented on the island for hydrogen production plant equipment. While this approach would simplify cable installation around the caisson island it will introduce another voltage in the system and a requirement for offshore AC substation platforms. The approach should be selected based on techno economic analysis of proposed concepts.

For a solution which uses platforms as opposed to islands, it is expected that connection of 66 kV array cables would not be as complex as significantly fewer cables will need to be routed to each location. Considering that several new contracts have been signed for construction of offshore wind farms in the North Sea which use HVDC links for power export to the shore, experience and lessons learned from these projects could be used to optimise routing of cables.

The reactive power compensation requirements are associated also with the length of array cables. The reactive power generated by cables is proportional to the cable length. The total array cable length will be longer for an island compared to the platform concept. Therefore, it is expected that additional or larger reactive power compensation equipment will be required to be installed on the island for compensation of reactive power.

Overall, the offshore nature of the concepts introduces a level of complexity for the construction and installation of the concepts. While platforms are commonplace in the North Sea, an artificial island in 50 m water depth has never been done before. This combined with the higher number of offshore activities and duration of offshore activities to construct an island indicates a much higher level of complexity for construction of an offshore island versus platforms (Table 6.23). Therefore, islands are given a high score to indicate a high construction and installation complexity. Hybrid concepts are scored with a medium to indicate medium complexity, due to the decreased size of the island. Platforms are given a low complexity as they are seen to be much easier to construct and install, with a proven track record in the North Sea.

Table 6.23: Evaluation 1 Scoring – Construction & Installation Constraints.

Criteria	Scale	Islands	Hybrid	Platforms
Constructability & Installation Constraints	Higher scores for higher complexity	High	Medium	Low

6.1.7.3 Supply Chain Complexity

Supply chain complexity takes into consideration both materials of construction and technology/equipment.

Construction of the caisson island requires coordination of several supply streams complicated by considerations of weather and seasonal constraints. There is a schedule gap between the initial sand dredging and placing of the lower foundation mound and the infilling behind the revetment and caisson. The placing of quarry run is more tolerant of weather conditions than the subsequent placing of armouring to the upper slopes of the foundation mound. The placing of the caisson requires calm sea conditions. Once the caisson is in place the weather constraints on subsequent work are less onerous.

There are significant constraints on the supply of quarried rock materials, particularly the grades of selected stones required for the upper face armouring. The overall demand for the island is a significant proportion of the northern European annual production. This demand, and other known potential demands for rock products for coastal and marine works is likely to distort the market. New quarries, either supplying the market in general or supplying a particular project, may have to be opened, or existing quarries substantially extended, with associated lead times for environmental permitting. To supply quarry run and rip-rap to an offshore project several specific attributes are required of the quarry: an appropriate geology; proximity to a port or site for load out quay; manageable ecological constraints. It is expected that there will be a limited number of sites for quarries that meet these criteria.

Construction of caissons requires a dedicated casting yard with the facility to launch caissons. For the depth of caisson required for the caisson solution to be effective there are no existing facilities for their construction and preparatory work would be required near a deep-water port.

Regarding platforms, how much equipment can be installed on the topsides is heavily defined by the transport & installation limitations, which will restrict the size and weight of the platform and substructure. The NSWPH programme identified several barges capable of transporting 26,000 tonnes of topsides, for a platform size of 110 m x 70 m x 40 m (suitable for 500 MW of combined electrolysis and compression). This size of platform can instead support 2 GW of HVDC equipment or approximately 3 GW of hydrogen compression equipment. In addition to the barges, yards must be available to construct the platforms in. The NSWPH identified 3-4 yards suitable for this size of platform. Larger platforms are possible however the available yards for construction and barges for transportation would be very limited. There were no obvious supplier constraints for the various types of substructures, GBF, monopiles or jackets, and in general platforms are seen to be easier to construct than islands.

Equipment considerations differ depending on whether they are to be installed on an island or a platform, and whether the solution is for a centralised or decentralised concept. Electrolysers and compressors are seen to have the highest supply chain risk for the process equipment. Considerations for electrolysers include:

- Platforms have more space and weight constraints, therefore technologies that reduce weight and footprint are preferred. As PEM electrolysers are significantly smaller and lighter compared with alkaline electrolysers they are preferred for platforms, to maximise the amount of electrolysis that can be installed, although there is potential to move to alkaline for future platforms. This restricts the supply chain to a specific type of electrolyser vendor at least initially. In addition, pressurised electrolysis would be preferred to reduce compression requirements. As most PEM suppliers offer pressurised electrolysis, this is not seen to provide additional constraints, however any downstream equipment would need to have a higher-pressure rating to accommodate the pressurised gas from the electrolyser.
- Islands are not as constrained on footprint or weight and therefore either alkaline, PEM or a combination of both could be employed, having the benefit of using multiple suppliers and reducing bottlenecks in electrolyser supply chain due to the flexibility in technology. An island can also benefit from economies of scale, employing larger unit blocks than on a platform.
- Depending on logistics and module size limits centralised electrolysis would likely contain fewer, larger electrolysers compared with a decentralised solution that would likely use a containerised packaged solution (e.g. hydrogen production at individual WTGs). There is less need to select a containerised solution for hydrogen production on platforms compared to hydrogen production local to the WTGs. Containerised packages could reduce the complexity of the supply chain for process equipment as some Balance of Plant (BOP) items such as demineralisation, oxygen removal, dehydration and air coolers may be included in the packaged solution reducing requirement to engage with multiple suppliers, although at the same time a large number of small units could see cause bottlenecks in the supply chain. Electrolyser suppliers are currently scaling up production plants however it is unclear yet which direction they will expand in (containerised vs augmented) and therefore where the bottleneck may be. The more flexible the concept the lower the risk of electrolyser supply chain.
- Centralised electrolysis on a platform will need to have all the electrolysers installed on the platform prior to float-out, whereas installation at individual WTGs or on the island allows for phased roll-out of electrolysis. The phased roll-out is more favourable as it reduces the demand on an already strained supply chain.

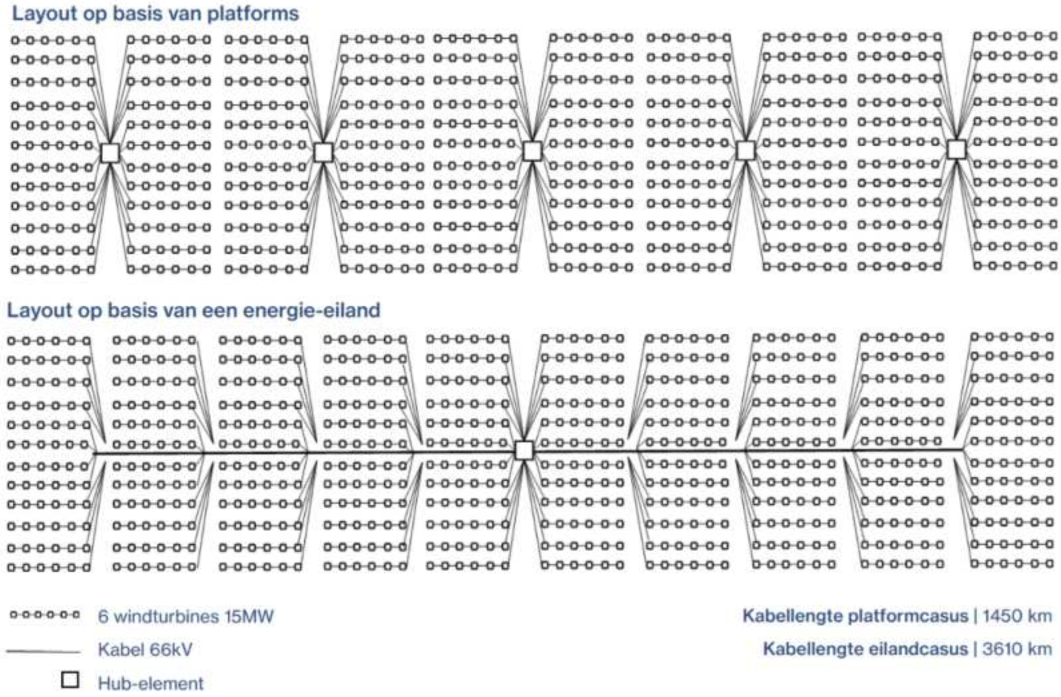
- Two potential technologies can be used for the rectifiers; thyristor based and IGBT based. The main advantages of IGBT based rectifiers compared to thyristor based are:
  - They do not typically require any harmonic or reactive power compensation,
  - They are better suited to “wind-following” and operating at part-loading, whilst maintaining a near unity power factor,
  - They are more suited for use with containerised packaged solution,
- However, thyristor-based rectifiers are the lower-cost solution. Both thyristor and IGBT based rectifiers can be used on the hydrogen production platforms and islands. The thyristor-based rectifiers are acceptable in this case as there is more space for installation of harmonic and reactive power compensation equipment. Also, considering that at the moment thyristor-based rectifiers are produced in larger units (20 MW) compared to the IGBT based rectifiers (limited to 10 MW), use of thyristor-based technology will allow large hydrogen production units to be installed.

Considerations for compression include:

- Reciprocating compressors are currently seen to be the industry standard for hydrogen compression. With many competing projects coming online, the supply chain for compression could be constrained. This could be a challenge for centralised compression on platforms, which would require all compressors to be installed on the platform prior to float-out and installation at sea. Decentralised compression on a platform, compression co-located with hydrogen on a platform or installation on an island could be phased and relax the demand on the supply chain.

All three concepts share a common 2 GW block. Therefore, they are putting equal pressures on the supply chains. In the case of islands, 66 kV AC cable lengths would be significantly higher than for the comparable 2 GW platforms, and availability of both material supply and competent installation contractors must be considered (Figure 6.17). However, it is foreseen that it will only lead to a small increase in pressure on the supply chain, as this type of cable is widely available and there is now a high level of familiarity in respect of its installation. Irrespective of this point, for each solution a large quantity of cable will be required with attention needed to be given to advanced planning and phased installation.

Figure 6.17: Array cable layout for a 10 GW concept (ref. 6).



A high, medium and low scoring was not seen as sufficient to differentiate the concepts, and therefore a scale of 0-10 has been employed, with a high value of 10 indicating a high complexity. Out of the discussed supply chain challenges, the complexities associated with the supply of material for the island is seen to overshadow the complexities associated with the supply of equipment. More than half the supply of quarry to Europe would be required for a water depth of 50m, and therefore a new quarry would need to be opened which would be a challenge as no one wants to open a new quarry. For this reason, a complexity rating of 10 has been assigned to the islands (Table 6.24). The hybrid concept still contains an island and for that reason still has a fairly high complexity however because the island is smaller and the quantity of materials to build the island is reduced, the score is reduced to 7. Platforms are given a supply chain complexity value of 3 as, while the complexity is low, there still needs to be considerations with respect to available yards and barges, and they have more restrictions on the equipment technology selection and rollout schedule. Higher scoring indicates greater complexity.

Table 6.24: Evaluation 1 Scoring – Supply Chain Complexity.

Criteria	Scale	Islands	Hybrid	Platforms
Supply chain complexity	Higher scores for higher complexity	10	7	3

6.1.7.4 Permitting

The permitting process for platforms is assumed to be relatively simple as multiple platforms have already been constructed in the North Sea. The novelty of island construction in the North Sea and the potential greater environmental impact will make permitting more challenging.

The relative scores are included in Table 6.25 with high representing greater complexity.

Table 6.25: Evaluation 1 Scoring – Permitting.

Criteria	Scale	Islands	Hybrid	Platforms
Permitting	Higher scores for higher complexity	High	High	Medium

6.1.7.5 Technology Readiness

In general, offshore platforms and caisson islands are highly developed technologies.

Platforms are well known and proven technology in the North Sea, with the most common substructure being jackets. While monopiles are also commonplace in the North Sea, this is more for WTGs and applications other than for WTGs would be novel although experience could be transferred. GBS substructures are also a well-established technology with experience in the North Sea, however an island in 50m water depth has not been done before. Based on this, platforms in general have a higher technology readiness level than islands in the North Sea.

Equipment considerations differ depending on whether they are to be installed on an island or a platform, and whether the solution is for a centralised or decentralised concept. Technology readiness is considered for the following process plant equipment:

- Electrolysers: Platforms have more space and weight constraints, therefore technologies that reduce weight and footprint are preferred. As PEM electrolysers are significantly smaller and lighter compared with alkaline electrolysers they are preferred for platforms to maximise the amount of electrolysis that can be installed, at least for the initial platforms. Islands are less spatially constrained and therefore either alkaline or PEM or a combination could be installed. In general, electrolysers are an emerging, innovative technology that is not yet produced or operated at scale. Considerations regarding technology readiness include:
  - Alkaline electrolyser plants have been in operation since 1927, whereas PEM electrolyser plants have only been operating since 1987, clearly marking alkaline electrolysers as the more mature technology. However, neither technology has been used offshore or at scale supplied by wind power.
  - The largest electrolyser plant currently has 150 MW of alkaline electrolysis installed, supplied by solar power. In comparison, the largest PEM electrolyser plant in operation is 20 MW, also supplied by solar power. Alkaline electrolyser plants therefore currently significantly exceed the size of any operational PEM electrolyser plants.
  - Larger stack sizes introduce economies of scale benefits, reducing CapEx and space requirements. This is relevant for an island design or centralised hydrogen production. While alkaline electrolysers are more mature, the NWSPH programme assumes stack sizes of up to 10 MW for both alkaline and PEM electrolysers are available within the project timelines (early 2030s). Alkaline stack sizes of 10 MW are already readily available, however the current maximum PEM electrolyser stack size is 2.5 MW, and so a 10 MW PEM stack may be ambitious depending on the market direction for technology developments. Alkaline electrolysers are seen to have a higher technology readiness level from this aspect.
  - Containerised PEM packages for hydrogen production are more likely to be installed at the individual WTG. Containerised PEM packages up to 5 MW are readily available in the market and are therefore also seen to have a high technology readiness level.
  - Small scale PEM electrolysis may be more suited to wind profiles than small scale alkaline electrolysis, due to the ramp rates and minimum load requirements. These differences can be mitigated at large scale through the control philosophy.
- BoP: Offshore desalination is a fairly new technology and not as commonly used as onshore desalination. Seawater Reverse Osmosis (SWRO) is currently practised offshore, however Multi-Effect Distillation (MED) is not currently practised offshore. MED has benefits of

utilising the waste heat from the electrolysers, particularly on an island this could be for heating accommodation. 500 MW platforms are expected bo be equiped with SWRO. The decision of which particular technology should be employed is the responsibility of the developer and is not a differentiating factor for technology readiness rating for islands vs platforms vs hybrids at this stage, however it should be understood that the decision of islands vs platforms vs hybrids could impact the desalination technology selection.

- Compressors: Several mechanical and non-mechanical compression technologies are available, including reciprocating, diaphragm, ionic liquid, cryogenic, adsorption and electrochemical compression.
  - Non-mechanical means of compression has a low level of technical maturity (research to prototype phase) and would not be suitable for large scale offshore hydrogen compression.
  - Ionic compression has advantages for offshore compression due to low vibration and minimal maintenance, however this technology is still in development and is currently used for high pressures and lower throughput and would not be suitable for large scale hydrogen compression.
  - Offshore compression is generally carried out using centrifugal compressors due to the reduced vibrational issues amongst factors, however, for hydrogen applications reciprocating compressors are generally more suitable. Reciprocating compressors exhibit vibrations during operations, which could be exacerbated by the number of units on a platform for centralised compression (refer Section 6.3.1).
- Optimized offshore 2 GW 525 kV HVDC VSC transmission: TenneT has developed a standard platform design for a 525 kV 2 GW HVDC off-shore to on-shore point to point link using voltage source converter (VSC) technology. Contracts have been awarded to several consortiums for the supply and installation of 14 such solutions, with deployment across Dutch and German waters. The first projects are expected to be energised in 2029 with all 14 projects operational by 2031 (ref. 44). Whilst HVDC VSC technology operating at 525 kV is considered well proven, projects which are currently operational do not generally operate at 2 GW, primarily due to limitations of current cable technology. As part of the 2 GW programme, TenneT has developed a design for a 2GW cable system using XLPE insulation and including a metallic return. Whilst several manufacturers have pre-qualified 525 kV XLPE cables, we are not aware of any having been put into service at the present time. However, given the timeframes expected for TenneT’s 2 GW programme, it is expected that the cable system, and use of 525 kV VSC at 2GW capacity will have been put into service prior to this project’s requirements. As the same technology is expected to be used for both platforms or islands, the HVDC and cable technology itself is not considered a key differentiator. On the other hand, TenneT has expended significant effort to have a packaged, highly integrated and compact 2 GW 525 kV HVDC package located on a platform. As such, the design of the HVDC system is more advanced for a platform solution as compared to an island solution, which has not yet been developed.
- The first versions of the platforms will not be supplied with HVDC circuit breakers, which are expected to be developed and used in the future. HVDC circuit breakers would allow operation of the assets as “multi-purpose interconnectors” (MPIs) or integration of multiple HVDC systems together (for example, connection of three platforms as opposed to point-to-point links). Space has been allocated on the HVDC platform for the required assets to allow operation as a multipurpose interconnector (MPI) as indicated in Figure 6.18 below. We understand that first versions of “MPI-ready” HVDC platforms are expected to be for hybrid connections, similar to that proposed for the LionLink project. This is a joint project between National Grid and TenneT which is designed as an interconnector between the Dutch and

British transmission systems, but also facilitates connection of a Dutch offshore windfarm[3]. Future generations of MPI HVDC platforms are expected to be equipped with HVDC circuit breakers which will require a partial redesign. However, HVDC circuit breakers are still under development with ENTSOE classifying them as technology readiness level (TRL) 6 for high voltage devices and TRL3 for extra high voltage devices (ref. 56). It is likely to be some years before these are fully developed.

Figure 6.18: Standard 2GW HVDC platform (ref. 44).

An alternative solution which can be used to develop multi-ended HVDC links is construction of a HVDC switching station such as that being deployed in the UK on the Caithness-Moray-Shetland HVDC link (ref. 55). However, the land-take required for such a solution would likely make it un-viable in an offshore environment, although it would likely be more easily achievable on an island as compared to a platform.

Overall, a platform solution is seen to have a higher technology readiness level than islands, due to the fact that there are many platforms in the North Sea, with many more on order through TenneT's 2 GW programme, and while islands in general are a mature and proven technology an island in 50 m water depth has not been previously built.

The selection of islands vs platforms vs hybrids will influence equipment technology selection, with expected technologies for the island to be more mature than for platforms except for the containerised PEM electrolyser packages which are available now. In any case, large scale offshore electrolysis supplied by wind power has never been done and there will be many complexities and challenges involved in any of the options. Therefore, platforms are given a high technology readiness rating, and islands and hybrids a medium technology readiness rating (Table 6.26).

Table 6.26: Evaluation 1 Scoring – Technology Readiness.

Concept	Scale	Islands	Hybrid	Platforms
Technology readiness	Higher scores for higher TRL	Medium	Medium	High

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[3] https://www.nationalgrid.com/national-grid-ventures/future-developments/lionlink

6.1.7.6 Water Depth

The 50m deep water at the island sites restricts the availability of jack up barges that might be useable for working on the armour placement on the upper slope of the foundation mound. However, the deep water makes it possible to place the sand bed layer easily from the dredger and the quarry run core from bottom dumping vessels. Once the caissons are placed work from the caissons and inside the island are not affected by the water depth. The protection to the supply port on the island is wide but no more complicated than the perimeter bund. The construction is practicable, and the complications covered by the cost.

Concept designs from the NSWPH programme platforms are based on a water depth of 35m, however it was concluded that a water depth of up to 45m is feasible for the three types of substructures identified: GBF, XXL piles and jackets. The XXL piles are installed all over the world and in ever increasing water depths, however, were seen to be the most sensitive to deep waters and were limited to a depth of 45 m. The GBF and jacket concept designs were considered adaptable to water depths of up to 50 m without significant modification, noting there will be added CapEx and added steel (which could limit the weight of the topsides). Jackets are installed all over the world in a range of water depths, although they are not cost effective at shallow water depths less than 20m. As the platforms are seen to be relatively adaptable to water depths compared with islands, they are scored with a “low” complexity (Table 6.27). Islands are more difficult in deep waters and are therefore scored with a “high” complexity. Hybrids being a combination of both islands and platforms are given a “medium” complexity.

Table 6.27: Evaluation 1 Scoring – Water Depth.

Concept	Scale	Islands	Hybrid	Platforms
Water depth	Higher scores for higher complexity	High	Medium	Low

6.1.7.7 System Integration

The system integration criteria is included to assess the complexities resulting from each energy hub concept in relation to the number of parties involved in its development and the number of required interfaces between them.

The energy hub in search areas 6 and 7 will be facilitated by a combination of the Dutch Government (EZK and IenW), Gasunie as potential HNO and TenneT as TSO as well as individual developers. EZK and IenW will set the framework under which the HNO and TSO will supervision the individual developers.

The energy hub will need to tie-in to the wider development of the Dutch Sector with potential interconnections to other energy hubs and internationally and hydrogen will be exported to shore either via conversion of the existing subsea natural gas pipelines or via new dedicated hydrogen pipelines. Each 2GW HVDC system whether installed on a standardised platform or on an island will link to the onshore grid via a 2 GW HVDC subsea cable. Depending on the level of complexity of future offshore networks, additional infrastructure might need to be constructed in order to facilitate interconnections between countries.

Search areas 6 and 7 is assumed to be parcelled up into blocks of approximately 2GW capacity for which licenses will be issued to individual developers. Hydrogen production will either be installed separate to compression within the blocks or on a large artificial island but either way will be the responsibility of the associated wind block developer.

Hydrogen compression system design will be developed by Gasunie and either installed on a large island or on platforms, responsibility for which will be assigned to a separate developer.

If a large artificial island or islands is selected for the whole or part of areas 6 and 7 then it is assumed that additional ancillary infrastructure will also be installed there creating additional scope boundaries and interfaces. The regulatory framework for the development of an offshore island is not yet finalised.

This criterion attempts to score each of the concepts based on the complexity of interfaces between different systems and developers. The large island inherently has many as yet not fully defined interfaces whilst platforms inherently have fewer as individual systems are geographically separated. The scoring between the concepts is indicated in Table 6.28 with high representing greater interface complexity than medium then low.

Table 6.28: Evaluation 1 Scoring – System Integration.

Concept	Scale	Islands	Hybrid	Platforms
System Integration	Higher scores for higher complexity	High	Medium	Low

6.1.7.8 Realisation & Technical Feasibility Weighting

The relative weightings of the realisation & technical feasibility criteria are listed in Table 6.29. To meet the government's plans for the development of offshore wind generation the development time to operations is key and is weighted 100. Ensuring that both HVDC and hydrogen production capacity is ready as early as possible allows for the optimal balance between power and hydrogen export for a grid-integrated solution.

Construction and Installation is weighted 80 as it is believed achievable for all concepts albeit that island construction in 50m water depth is novel. Supply chain complexity is weighted 100 due to the known concerns in the availability of materials for island construction and the massive expansion of hydrogen equipment capacity required.

Permitting complexity is weighted 50 as this constraint can be managed by government. Equipment TRL is weighted 80 to acknowledge concerns in the readiness of hydrogen production equipment and the concept infrastructure. Concerns on constructability in the water depth is weighted 60 as it considered feasible to construct both platforms and islands in 50m.

System integration is weighted 60 as although it will be potentially complex this can be mitigated through effective project management.

Table 6.29: Evaluation 1 Weighting – Realisation & Technical Feasibility.

Concept	Scale	Islands	Hybrid	Platforms	Weighting
Development time to operations	Higher scores for longer development time	8	3	2	**100**
Constructability & Installation	Higher scores for higher complexity	High	Medium	Low	**80**
Supply chain Complexity	Higher scores for higher complexity	10	7	3	**100**
Permitting complexity	Higher scores for higher complexity	High	High	Medium	**50**
TRL	Higher scores for higher technology readiness	Medium	Medium	High	**80**

Concept	Scale	Islands	Hybrid	Platforms	Weighting
Water Depth	Higher scores for higher compexity	High	Medium	Low	**60**
System integration	Higher scores for higher complexity	High	Medium	Low	**60**
Normalised Results	**Highest score is best**	**62**	**81**	**100**	

6.1.8 Operation and Maintenance

6.1.8.1 Operations Complexity

Large scale offshore electrolysis has never been done before so there will be steep learning curves for operations on islands and on platforms. A hybrid solution will require twice the amount of learning – first for island operation and second for platform operation.

Islands are expected to be fully manned, with the main operating and control room on the island. It is expected there will be increased/concentrated level of staff (hundreds) during phase build-out over the first years of production. Platforms are expected to be unmanned or have only a limited number of operators present. A local control room is expected to be on the platforms, to provide visibility and basic control to any operators or personnel during a manned/maintenance visits, however main operations and control will be remotely from an onshore base.

Compressor platforms will be stand-alone modularised units built onshore and floated out, with manning only expected to increase over summer for compressor maintenance. Hydrogen production platforms will be stand-alone modularised units built on shore and floated out, with manning temporarily increased in line with stack replacement regimes. On a manned island, operators will be permanently present and available to perform walk-throughs or check on any upset process easier than on an unmanned platform, which would rely solely on instrument readings or organised visits to platforms situated in multiple locations in the North Sea.

Chemicals may be required for water treatment and cooling, depending on the selected process and technologies (e.g. seawater cooling will require chemicals but air cooling will not, and air cooling may be easier to employ on an island than a compression platform due to size constraints). These chemicals will need to be topped-up as part of normal operations. Bulk chemicals deliveries will be easier for the island, as it will be a small number of locations with a functioning port. Chemicals top-ups for the platforms will need to be delivered to multiple locations within the North Sea and could be more frequent due to the size and weight constraints on a platform limiting the amount of storage. For hydrogen production at the WTGs, this could mean visits to hundreds of platforms, further increasing the complexity. Frequent visits to the platforms have an environmental and potentially ecological impact. Waste removal follows a similar philosophy, in that it is easier to remove waste from an island than from multiple platforms.

From electrical point of view, 2 GW HVDC converter stations installed either on a platform or an island are unmanned therefore the difference is not considered to be great in respect of operations. However, with respect to hydrogen production facilities there is a difference between platforms and island considering the fact that platforms will be unmanned, and islands will be fully manned. It is expected that electrical engineers/technicians will be included in the team stationed on the island that will support operation of the hydrogen production plant.

A high, medium and low scoring was not seen as sufficient to differentiate the concepts, and therefore a scale of 0-10 has been employed, with a high value of 10 indicating a high complexity (Table 6.30). While there will be some level of complexity involved in a first-of-its-kind offshore hydrogen production facility, islands are seen to be easier than platforms due to the presence of operators, having only a few operating locations and a functioning port for deliveries, therefore a rating of 3 has been applied. Platforms have a high complexity due to being unmanned and being located across many sites and have been given a rating of 5. The complexity of a hybrid solution of islands and platforms is viewed to exceed that of concepts solely based on islands or platforms.

Table 6.30: Evaluation 1 Scoring – Operations Complexity.

Concept	Scale	Islands	Hybrid	Platforms
Operations complexity	Higher scores for higher complexity	3	8	5

6.1.8.2 Maintenance Complexity

Maintenance will need to be carried on a periodic and annual basis, as well as long-term overhauls. Maintenance of the island and platforms themselves are not considered in this evaluation as their design life exceeds the project duration.

Equipment located on an island has the benefit of being more spaced out compared with platforms, which provides easier access for maintenance. It is likely that an island will include a warehouse for spares and a workshop to carry out any maintenance works on the island, and space for laydown areas can be more generous on an island than on a platform. Ships will be able to bring in spare equipment for the warehouse, loading them via a safe dock with cranes and heavy lift equipment. Islands will be permanently manned and have staff on site to perform frequent inspections or maintenance. Conversely, platforms will be unmanned, and periodic inspections and maintenance will require frequent visits to multiple platforms stationed throughout the North Sea, introducing a level of complexity with logistics that may be impacted by weather. There is likely to be only limited spares stored on a platform, with a main warehouse and workshop on an onshore base which would require transport of equipment to/from the platform for maintenance as well as personnel. Reduced spacing between equipment and more restricted laydown areas increases maintenance complexity compared with islands.

Major maintenance activities and overhauls identified at this stage include electrolyser stack replacements, annual compression maintenance, deoxy reactor catalyst replacement. Depending on the dehydration technology, the adsorbent may also need to be replaced after a time.

- Electrolyser stacks will need to be replaced/refurbished every 7-10 years, depending on the technology and operation. Considering the full wind park electrolyser capacity of 12 GW, this could mean hundreds or even thousands of stacks. A rolling stack replacement regime would need to be followed for all concepts. Stacks on an island will be easier to transport to shore for replacement with the availability of a permanent dock and heavy lift equipment. However, if alkaline stacks are selected (more likely for an island), the replacement is more challenging due to the size and weight of the alkaline stacks compared with PEM stacks. For hydrogen production at the WTGs, the entire WTG would need to be offline.
- Typical reciprocating compressor maintenance would include:
  - Minor overhaul every 11,000 hours of continuous operation, downtime lasting 2-7 days
  - Major overhaul every 72,000 hours of continuous operation, downtime lasting 4-18 days
  - Based on the NSWPH programme a compression platform could have up to 6 compressors on a single platform, which would require personnel on the platform for 2-6 weeks over 15 a month period. A floating SOV or similar would need required to achieve this. An island would have the personnel available on site to perform these activities.
- While it is for the developers to determine another factor to be considered is the pressure of the electrolysers, which influences the compression requirements. It is likely that electrolysis on platforms will be pressurised (circa 30 barg) and electrolysis on islands can be either

atmospheric or pressurised. Having atmospheric electrolysis requires more compression and therefore maintenance requirements will increase.

- Reactor catalyst replacement is expected to be needed every 5 years, depending on the design and operation of the reactor. On an island or for centralised hydrogen production, the deoxy reactor is likely to take advantage of economies of scale, with a lower number of large vessels. For hydrogen production at the WTGs, the deoxy reactor will likely be supplied within the containerised electrolyser package, across hundreds of platforms in the wind park. Replacement of catalyst on an island will be less complex as, although it will be in greater quantities, it will be in a single location which simplifies logistics.

From an electrical point of view, similarly to operations, 2 GW HVDC converter stations (both on a platform and an island) and hydrogen production platforms are foreseen as unmanned platforms. The focus would be made on preventive, predictive, and scheduled maintenance, to keep the blocks in good working condition and prevent emergency maintenance. The type of maintenance required for the HVDC system would not be significantly different for either solution. Since the blocks will be standardized, and the crews sufficiently trained and knowledgeable with their maintenance work, the complexity is classified as medium and is primarily driven by the location as opposed to the technology. Vessel and helicopter access is available for both the standard HVDC platform and islands for maintenance & emergency evacuation purposes. The major difference between HVDC platforms and HVDC converter stations installed on the island is that transport and replacement of a large equipment may be easier on an island compared to the platform.

With respect to the maintenance of electrical equipment that is part of hydrogen production facility, it is assumed that operational teams stationed on the island will consist of various disciplines including process, mechanical, electrical and control instrumentation. As electrical staff will be present on an island it is considered that repairs of minor faults as well as fault diagnostics could be undertaken by the team located in this area.

Further, a platform-based solution will necessitate the use of multiple platforms, requiring maintenance crews to visit several different locations including a number of HVDC platforms and compressor platform. This may make any maintenance operation more complex.

Overall, maintenance will be less complex on an island than on a platform, due to the available space, onsite warehouse and workshop, permanent manning, permanent dock and concentrated location of equipment reducing logistic challenges. A numerical score of 0-10 has been applied to the concept, with a high number indicating high maintenance complexity (less favourable). Islands has been given a low complexity score of 2 (as there still some challenges due to the offshore nature) and platforms are given a high complexity score of 8 (Table 6.31). Hybrid solutions would see warehouse/stores on the island, which could reduce transport to the platforms compares with an onshore warehouse/stores and would also have personnel closer to the platforms for routine inspections as well as overhauls, negating the need for an SOV. This reduces the complexity of a hybrid solution compared with platforms, therefore a lower score of 5 has been assigned.

Table 6.31: Evaluation 1 Scoring – Maintenance Complexity.

Concept	Scale	Islands	Hybrid	Platforms
Maintenance complexity	Higher scores for higher complexity	2	5	8

6.1.8.3 Availability / Reliability

Reliability, availability and maintainability is usually assessed via a RAM study at the FEED then detailed design stages of a project when information on equipment is available. In the absence of a RAM study, availability and reliability will be reviewed based on how easy or difficult it may be to keep equipment functioning. Reliability will depend very much on the equipment and the maintenance regime specified, with a better maintenance programme leading to better reliability and therefore availability. Availability is directly linked to planned and unplanned maintenance (downtime) and therefore any factors that may increase or decrease downtime are considered to impact availability.

Based on the NSWPH programme, islands will be permanently manned, while platforms will be unmanned. Therefore, any unplanned equipment shutdown on an island can be quickly and immediately investigated and attended to by available personnel on the island. A warehouse/workshop located on an island will also reduce any waiting time for equipment replacement. In comparison, personnel will need to travel to equipment on platforms and any replacement items will need to come from the onshore warehouse, or equipment may need to be transported to the onshore workshop to be worked on, increasing downtime. A hybrid solution will have the warehouse/workshop on an island which should be closer to the platform and reduce transport time, assuming a vessel is readily available. From this perspective, availability is higher on an island, followed by hybrids and lastly platforms.

In respect of an Island, there is a high concentration of HVDC equipment all located in one area. In the event of a catastrophic event impacting the island then there is potential for greater power loss (6GW) as compared to the platform arrangement (2GW), whereby a single catastrophic event may not impact multiple platforms. However, this is considered to be a low-likelihood scenario which, to an extent, would be expected to be mitigated through design measures. For example, using different cable routes for HVDC cables, and locating converter stations on different parts of the island, would provide physical separation between different HVDC systems, with a lower probability of a single catastrophic event impacting more than one converter station and HVDC cable circuit.

Availability of plant is also impacted by redundancy of plant equipment or system integration (inter-hub connectivity). Equipment sparing is easier on an island as there is more space available for additional equipment, for example an additional compressor. Platforms, which are more restrictive on the available space, are less likely to have sparing and instead be interconnected with neighbouring platforms which allows for flows to be re-routed in the case of any unplanned shutdowns. For planned shutdown, platforms will need to consider weather patterns and employ summer maintenance campaigns both for logistics purposes and in line with reduced hydrogen production. Islands will also benefit with summer maintenance campaigns when hydrogen production is more likely to be low.

For hydrogen production on platforms at the WTGs, due to the large number of platforms if one is out of service the impact on the overall system is minimal (i.e. 20 MW out of 12,000 MW or less than 0.2 %). On the other hand, if one of 4x compression platforms is down, then this could become a larger bottleneck. This can be mitigated by oversizing compression capacity.

Availability of the HVDC system will depend mainly on the equipment which is under outage (shutdown). The design of HVDC systems is not fully redundant, therefore the shutdown of major equipment such as a converter transformer, would lead to loss of 50 % of HVDC transmission capacity. The standard HVDC platform has been designed to have interconnection to another HVDC platform or different countries. Thus, if a HVDC cable is out of operation this would allow HVDC power to be rerouted.

Historically many HVDC systems have not incorporated a metallic return conductor. Thus, if a failure was to occur on either of the conductors then the HVDC system would be out of service. The standard design currently proposed by TenneT incorporates a metallic return conductor. Thus, in the event of a failure on any one of the main conductors, 50 % transmission capacity can be retained by using the metallic return.

Compared to the platform, an island could provide more redundancy, and consequently availability, as rerouting of power could be achieved on the 66kV side. Typically, onshore HVDC converter stations include a spare converter transformer which can be deployed quickly in the event of a failure of one of the in-service units. If sufficient space is available on the island to accommodate this then it would be expected to increase the availability of the HVDC system. Subject once again to space availability, a HVDC switching station could be constructed on the island which could be used as an interconnection node between multiple countries and the converter station in the energy hub. The HVDC switching station on an island is expected to be capable of higher power transfers to international connections as compared to the platforms which are limited by the 2GW HVDC cables. This could increase overall availability of the HVDC system and would lead to a DC hub with fewer constraints in respect of the possible connection options.

In respect of the AC cable systems, given the quantity of generation planned, a failure on an individual cable section would only be expected to have a low overall impact on output. However, it should still be considered as part of the overall assessment. Statistically speaking, the greater the quantity of cable, the higher the likelihood of a cable failure occurring. As such, in respect of AC cables, the design with the lowest quantity of AC cables (platforms) is likely to have a relatively higher reliability as compared to the design with a higher quantity of AC cables (islands).

A Low, Medium and High score has been applied to each of the concepts (Table 6.32), with “high” indicating high availability and reliability (more favourable). An inverted scoring scale has been used for consistent scoring convention (in this case higher availability is more desirable so lower scores have been allocated to higher rankings). Islands have been given a high availability and reliability due to permanent manning and access to onsite spares. Platforms have been scored with low availability due to being unmanned and having no spares on site. Hybrids are scored with medium availability, having elements of both.

Table 6.32: Evaluation 1 Scoring – Availability/ Reliability.

Concept	Scale	Islands	Hybrid	Platforms
Availability / Reliability	Higher scores for higher availability and reliability	High	Medium	Low

6.1.8.4 Flexibility

The flexibility criteria is included to assess the flexibility of each concept to bring energy ashore as direct power or hydrogen. This capacity is beneficial as it allows the flexibility to react to system faults but also to maximise revenues and avoid constrained power by directing power to hydrogen production even when capacity to export it to shore exists to account for constraints in the onshore grid, low onshore demand or in the case of power import from shore low cost of onshore renewable electricity.

For large offshore islands all infrastructure other than the WTGs is installed on the islands allowing for easy cross connection of power between the HVDC system and hydrogen production. This flexibility is at the total system level and does not allow power from an individual WTG to be directed.

For the platform-based concept hydrogen production can be local to the WTGs. As each string of WTGs would be able to either export power ashore or produce hydrogen this arrangement gives great flexibility in energy export. However, if hydrogen production is on 500MW platforms then the geographical separation of HVDC systems and hydrogen production would make these cross connections more impractical.

The concepts are scored in Table 6.33 with greater flexibility scoring high.

Table 6.33: Evaluation 1 Scoring – Flexibility

Concept	Scale	Islands	Hybrid	Platforms
Flexibility	Higher scores for higher flexibility (inverted scale)	Medium	High	High

6.1.8.5 Operation & Maintenance Weighting

Operations and maintenance are key criteria to ensure that the energy hub can deliver on its requirement to meet as much of the onshore base load demand for renewable electricity and green hydrogen as possible and therefore operations and maintenance complexity are both weighted 100. Availability/ Reliability is similarly weighted 100. Security of supply and the flexibility to maximise energy output and revenues is considered an upside to each concept and is weighted 50. All weightings are listed in Table 6.34.

Table 6.34: Evaluation 1 Weighting – Operations & Maintenance.

Concept	Scale	Islands	Hybrid	Platforms	Weighting
Operations complexity	Higher scores for higher risks	3	8	5	**100**
Maintenance complexity	Higher scores for higher risks	2	5	8	**100**
Availability / Reliability	Lower scores for higher risks	High	Medium	Low	**100**
Security of supply (flexibility)	Lower scores for higher risks	Medium	High	High	**50**
Normalised Results	**Highest score is best**	**100**	**78**	**71**	

6.1.9 Future Proofing

6.1.9.1 Modularity & Scalability

Modularity and scalability are key criteria in the selection of the energy hub concept. This criteria assesses the capacity of the concept to be modified throughout the project lifetime if the project basis changes. Large artificial islands supporting the energy hub infrastructure need to be fully constructed before any equipment is installed and their capacity needs to be predetermined during the design phase. It is not practical or economic to adjust the size of a constructed island. This ensures that concepts which are solely based on islands have very limited modularity or scalability. Due to their limited individual capacity and replicable design platform-based concepts allow for much greater modularity.

The expansion of offshore wind generation and associated energy hubs in search areas 6 and 7 is not planned to commence until 2032. This long timeline combined with the uncertainties in the development of offshore hydrogen production means that the final design of the energy hub is difficult to assess. Before the energy hub concept can be fully developed its location within areas 6 and 7 must be defined and the area available for wind generation specified. IenW are working on this, engaging with impacted parties but this process may be protracted. Even once the energy hub location is defined technology developments, equipment and material availability and other factors may influence the design. IenW emphasised the key benefits of modularity and scalability amongst other important factors in their discussions.

The optimal ratio of direct power export to hydrogen production will be impacted by factors including:

- Total offshore wind generation.
- Onshore demand for renewable electricity
- Degree of inter hub and international connectivity.
- Demand for hydrogen to decarbonise industry and other consumers.
- Supply of blue and other forms of hydrogen.
- Hydrogen imports.

Therefore, modularity and flexibility are not just beneficial in terms of adapting to changes in the overall energy hub capacity but also to allow for potential changes in the ratio of power export to offshore hydrogen production.

Table 6.35 provides the concepts' scoring with a higher value indicating greater modularity and flexibility. An inverted scoring scales has been used for consitent scoring convention (lower values allocated to higher ranking results).

Table 6.35: Evaluation 1 Scoring – Modularity & Scalability.

Concept	Scale	Islands	Hybrid	Platforms
Modularity & Scalability	Higher scores for higher modularity and scalability	4	5	8

6.1.9.2 Future Expansion Capacity

Future expansion capacity assesses the ability of each concept to be expanded beyond the original capacity if required.

The scope of search areas 6 and 7 is mainly focussed on the time period 2030-2040. It is also interesting to look further after 2040 and see what the expansion capabilities are for the concepts. As the surface area of both the island and platforms are fixed the expansion capabilities are limited. Assumed is that the area of the island is designed in such way that there is no area left for future expansions and all area is utilized to reduce costs. Future development of wind farms after 2040 in potential zones 9/10 have therefore low advantages of the available equipment.

Platforms are considered to have a higher expansion capacity since the construction of one platform is easier than the construction of an additional island (Table 6.36). Furthermore, specific areas of the islands are designed to withstand a specific weight or forces for specific equipment, therefore using a designated area for other uses is potentially not possible. Future expansion can be for transporting extra generated energy but also for creating extra flexibility with overplanting either HVDC capacity or PtG capacity. Both are easier for the platform concept.

In respect of future interconnection, it is important to consider that the present design of 2GW energy hubs does not incorporate HVDC circuit breakers (refer to section 6.1.7.5) as the technology has not yet been sufficiently developed. However, it is understood that space has been allocated to allow the platforms to operation in an interconnected manner in the future. It could be expected that the second generation 525kV DC hubs may be suitably equipped ready for interconnection and operation in meshed mode, enabling tighter integration and stability of operation, although the timescale by which this could be achieved is uncertain. Expected is that this technology is ready around 2040 and does therefore not differentiate between the concepts. An inverted scoring scales has been used for consitent scoring convention to account for the fact that higher expantion potential is more desirable.

Table 6.36: Evaluation 1 CScoring – Future Capacity Expansion Potential.

Concept	Scale	Islands	Hybrid	Platforms
Future expansion capacity	Higher scores for higher expansion potential	Low	Medium	High

6.1.9.3 Design Lifespan

Based on the NSWPH programme studies the typical design life of a platform is 50 years and the design life of an island is at least 100 years. This does not relate to the equipment installed on the platforms or island which will have a shorter specified design life which is typically 20-25 years. This criterion should be considered as a potential upside to the concepts rather than a key consideration as the development of the energy hubs will be within the equipment design life. The weighting of this criterion has been selected on this basis with the actual design life value included (Table 6.37). The hybrid concept is given the average design life of islands and platforms. An inverted scale is used to account for the fact that higher values are more desirable.

Table 6.37: Evaluation 1 Scoring – Design Life.

Concept	Scale	Islands	Hybrid	Platforms
Design Life	Higher design life gets a higher score	100	75	50

6.1.9.4 Connectivity

This criterion assesses the capacity for each energy hub concept to support connectivity between hubs and internationally. Interconnections between energy hubs bring benefits in increased flexibility improving revenues and total energy export which also improving fault resilience.

There are strong upsides to international interconnection to reach deep into the European demand for renewable energy and hydrogen to help to increase the base offshore wind generation capacity. Different regions will generate offshore wind at different time with weather fronts typically arriving from the Atlantic to the UK before reach the Netherlands.

The equipment required to support interconnection is not extensive compared to the overall energy hub and therefore can be included within an island at limited additional cost, subject to sufficient space being made available. However, as mentioned previously, the technology to facilitate full interconnection at DC (namely DC circuit breakers) is not yet sufficiently developed. An alternative method of interconnecting HVDC systems is available by constructing HVDC switching stations, which could be accommodated on an island and facilitate the connection of the HVDC converter station to multiple locations. It is unlikely that HVDC switching station could be accommodated on the standard HVDC platforms as they have limited space available. Whilst we understand space has been allocated to allow interconnection in the future, we would not expect this to accommodate a HVDC switching station. It is understood from TenneT that the current standard design for a MPI on a HVDC platform could facilitate interconnection between countries similarly to the LionLink project[4] where one HVDC platform is connected to two countries, namely the Netherlands and the UK. The standard design for HVDC platforms would need to be slightly modified to accommodate the installation of HVDC circuit breakers once the technology is suitably mature. It should also be checked whether in the future it will be possible to retrofit these to platforms which had already been constructed. An alternative solution could be to construct an additional platform to accommodate a HVDC switching station, but this would be a non-standard design and the addition of a separate platform would significantly increase costs. Standard HVDC platforms could be connected to a separate HVDC switching station which will

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[4] https://www.nationalgrid.com/national-grid-ventures/future-developments/lionlink

be then used for interconnections between multiple HVDC platforms and various onshore converter stations. As described in previous sections the interconnection from HVDC connection will have less constrains compared to the HVDC platform. We consider it to be more straightforward to implement a HVDC switching station on an island as compared to an offshore platform which is reflected in the scoring. The scoring is provided in Table 6.38 with high indicating greater connectivity. An inverted scoring scale has been used to account for the fact that higher connectivity is more desirable.

Table 6.38: Evaluation 1 Scoring – Connectivity.

Concept	Scale	Islands	Hybrid	Platforms
Connectivity	Higher scores for higher connectivity	High	High	Low

6.1.9.5 Future Proofing Weighting

Modularity and scalability is key to the energy hub as so many factors are not yet known. Selecting a concept that allows for the design to be updated as the context and requirements become clear is a big advantage which de-risks the whole development and therefore is weighted 100. Factors that are not yet fully understood and could impact the design include:

- Overall wind generation capacity in search areas 6 and 7.
- Spatial roll-out of the wind farm.
- Ratio of power export to offshore hydrogen production.
- Use of existing natural gas pipelines or installation of dedicated new pipelines.
- Availability of land and other constraints to construction of onshore hydrogen production.
- Availability of cable landing points and bottlenecks in the onshore electricity grid.
- Demand for renewable electricity and green hydrogen.
- Quantities of imported hydrogen and onshore blue hydrogen.

This criterion could be considered so critical as to determine the concept selection but that is ultimately a decision for government.

Future expansion capacity is weighted 50 as it is considered a potential upside rather than key to energy hub design. Similarly, the design life is weighted 20 as the initial project phase is within the design life of all concepts. Connectivity is weighted 100 as it is essential that the concept selection does not prevent inter-hub and international connectivity. The weightings of the future proofing criteria are provided in Table 6.39.

Table 6.39: Evaluation 1 Weighting – Future Proofing.

Concept	Scale	Islands	Hybrid	Platforms	Weighting
Modularity & Scalability	Higher scores for higher modularity and scalability	4	56	8	**100**
Future Expansion Capacity	Higher scores for higher expansion potential	Low	Medium	High	**50**
Design Life	Higher scores for longer design life	100	75	50	**20**
Connectivity	Higher scores for increased connectivity	High	High	Low	**80**

Concept	Scale	Islands	Hybrid	Platforms	Weighting
Normalised Results	**Highest score is best**	**90**	**100**	**98**	

6.2 Centralised versus Decentralised Compression

Centralised compression assumes the compression equipment is installed outside of the wind blocks and services multiple wind blocks. Whilst in theory this could mean multiple compression locations the assumption is that due to ease of operation and maintenance and to take advantage of sparing opportunities resulting from bridge linked platforms that the full hub compression capacity of 12 GW will be in one central location. The selection of a single central location does need to be checked to ensure that pressure drop in the flexible flowlines supplying hydrogen from the blocks is not excessive. Based on the work of the NSWPH programme this would require four platforms with 3 GW of compression capacity each.

Centralised compression is represented by Concept 2a see Section 6.4.

Decentralised compression assumes each block is provided with dedicated compression equipment; 1 GW per block, which is located on a single platform smaller in size to the centralised platform.

Decentralised compression is represented by Concept 2b see Section 6.4.

Selection between centralised and decentralised compression as a decision is only required if large offshore islands supporting the full energy hub are not selected. The base case assumption for this decision is that all or a portion of the energy hub will be installed on platforms and this applies to all HVDC and hydrogen production and compression equipment. There may be a requirement to install centralised compression on an island rather than platforms as described in Section 6.3 and should this be required a review of the overall energy hub concept to consider instead choosing a large offshore island or some degree of decentralisation of compression should also be considered.

Hydrogen production, if not on a large island, is assumed to be separate to hydrogen compression. This assumption is driven by Gasunie's capacity as the potential HNO to design equipment for hydrogen compression; they do not have the same capacity to design hydrogen production equipment which will be assigned to the individual developer. To avoid a messy and complicated scope split within an individual platform hydrogen production and compression will not be co-located. The roll-out of hydrogen production is intrinsically linked to offshore wind generation requiring the same developer to be responsible for both (whether hydrogen production is on a large island or platforms) and this is simplified if hydrogen production is decentralised within the individual wind farm blocks: it will be up to the developer whether hydrogen production is local to the WTGs or on separate platforms as this decision does not fundamentally impact the spatial layout of search areas 6 and 7. This final assumption is based on the approach of the NSWPH programme in not requiring the hydrogen production (or compression) platforms to have helicopter access with the associated exclusion zone and should be revisited if this changes.

The selection between centralised and decentralised compression platforms needs to consider the integration of these HNO designed platforms with the developers and the economies of scale and ease of operation and maintenance associated with a centralised compression location. A central location will also reduce the complexity of the tie ins to the existing or new subsea hydrogen export pipelines. All of these factors and others are included in the comparative evaluation of centralised and decentralised compression platforms represented by Concepts 2a and 2b as described in Section 6.6.

6.3 Centralised Compression on Platforms versus Artificial Islands

Due to the smaller size of platform, it is not considered credible for decentralised compression to be located on islands. Centralised compression can be installed on an island if there are advantages to doing so. Due to the economies of scale resulting from larger island size it is assumed that 6 GW of HVDC equipment would also be located on the island (6 GW is the upper limit for one location specified by TenneT). The remaining 6 GW of HVDC equipment would be installed on standard 2 GW HVDC platforms.

Centralised compression on platforms is represented by Concept 2a see Section 6.4.

Centralised compression on an island with HVDC is represented by Concept 3 see Section 6.4.

The base case assumption in the evaluation is that centralised compression will be installed on platforms, and this is the basis on which the platform solution in Evaluation 1 is assessed. However, this base case assumption is re-evaluated in Evaluation 2 with comparative evaluation between Concepts 2a and 3. However, there may be technical reasons why centralised compression cannot be installed on platforms as described in this Section. Should it not be possible then either an island solution is required or potential more, decentralised compression platforms.

6.3.1 Impact of Compressor Vibration on Platforms

Offshore compression is generally carried out using centrifugal compressors due to the reduced vibrational issues amongst factors, however, for hydrogen applications reciprocating compressors are generally more suitable. Reciprocating compressors exhibit vibrations during operations, which could be exacerbated by the number of units on the platform. The NSWPH programme found that a maximum of six ~15 MW compressors could be installed on a single compressor platform, with the intention of operating four during normal operation(N+2) philosophy to maximise availability. The design of the platform as well as the placement and orientation of the compressors should take into account the compressor vibrations, with a view to minimise the vibrations. The design will need to consider all six compressors operating simultaneously as there may be common sparing between the three to four bridge linked platforms that would be required to support areas 6 and 7.

Considerations include:

- All compressor systems are different, and specifics are required on a selected system to properly address vibration issues for the solution.
- Pulsation and vibration study as per API 618 should be carried out, as well as a dynamic analysis of the skid mounting on the deck structure (mechanical vibrations and unbalanced forces). Deck integrity must also be considered.
- Compressors should be mounted on strong points on the platform, near supports, where flexibility is limited.
- The base frame is important as the compressor, electric motor, lube oil skid and cooling system skid are all mounted on this frame.
- Vibration issues may also lead to noise issues.
- Fixed speed is preferable to reduce vibration issues, as the resonance from variable is harder to mitigate.
- Machines can be run at slightly different rpm to avoid interference.

6.3.2 Economics of Constructing a Smaller Island

The complicated perimeter of the island dominates the cost compared to the simple sand fill of the island interior. For a small island the perimeter is a larger portion of the cost than for a large island. For a small island the marginal cost of increasing size is estimated to be a 6 % cost increase for a 10 % functional area increase. Consequently, if an island is required for any of the equipment it becomes cost effective to put other equipment and facilities on the island.

6.4 Concept Comparison (Evaluation 2)

The decision funnelling process begins with the selection between islands, platforms and a hybrid solution, then considers centralised versus decentralised compression and the requirement for centralised compression to be located on an island or platforms. Progressing through these decisions will lead to one of the four concepts proposed by TenneT in Table 6.40. Similarly, the preceding decisions will eliminate some or all the concepts as they are made. Selection between these concepts is Evaluation 2 as shown in the decision funnelling schematic in Section 3:

- Concept 1 – Two large artificial islands supporting hydrogen production (equivalent to the island concept in Evaluation 1).
- Concept 2a – Platform based concept with centralised compression on platforms (equivalent to the platform concept in Evaluation 1).
- Concept 2b – Platform based concept with decentralised compression on platforms).
- Concept 3 – Platforms based concept but with centralised compression and 6GW of HVDC installed on an island.

Figure 6.19 to Figure 6.22 indicate how the energy hub in search areas 6 and 7 would be configured for each of the four concepts. These schematics are indicative to give a basis for comparison and do not necessarily represent what a final energy hub design based on the concepts would look like schematically. Spatial lay-out optimization has not been performed for figures below and is considered of significant relevance for both cost effective design and technical feasibility.

Figure 6.19: Illustrative Layout of Concept 1 – Large Island supporting Hydrogen Production.

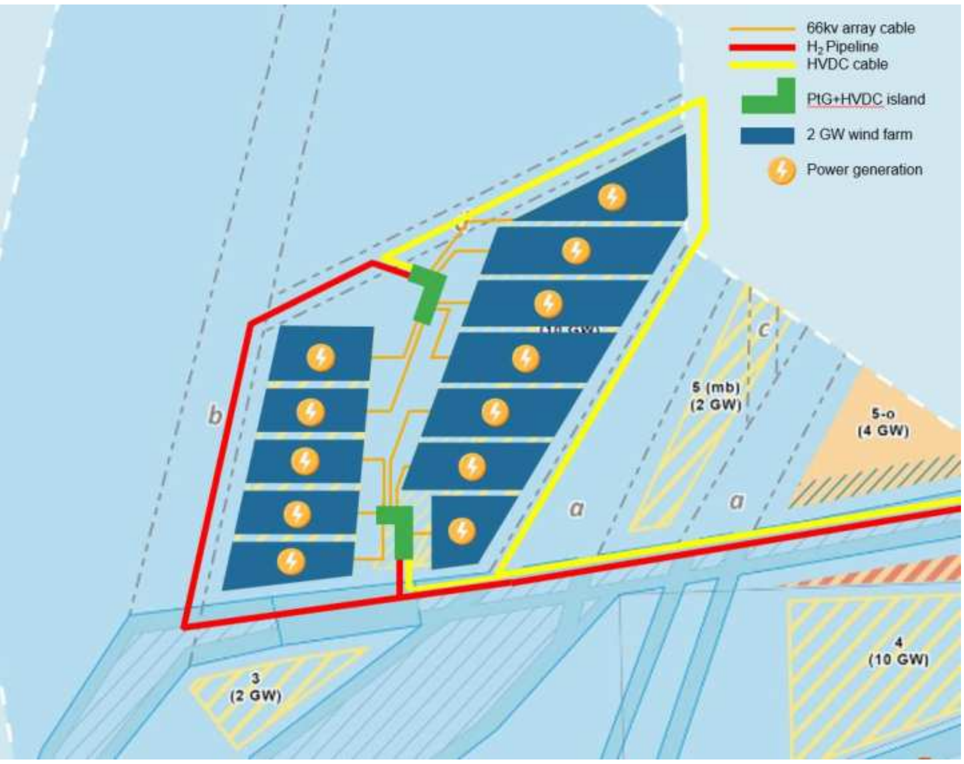


Figure 6.20: Illustrative Layout of Concept 2a – Platform-based Hub including Centralised Compression

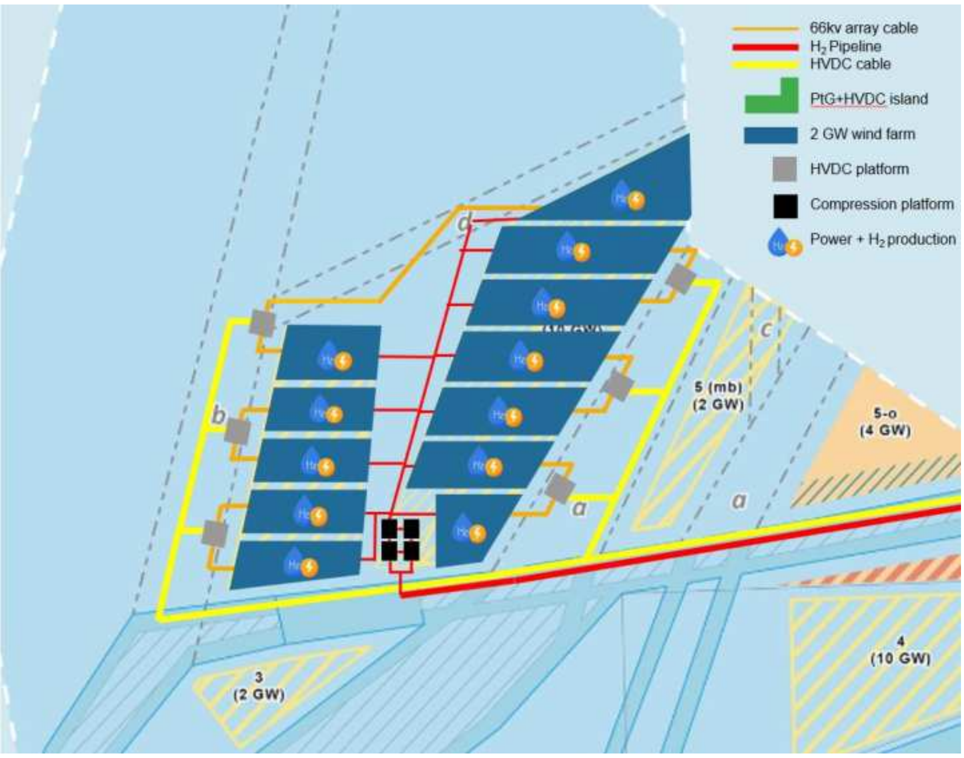


Figure 6.21: Illustrative Layout of Concept 2b – Platform-based Hub including Decentralised Compression

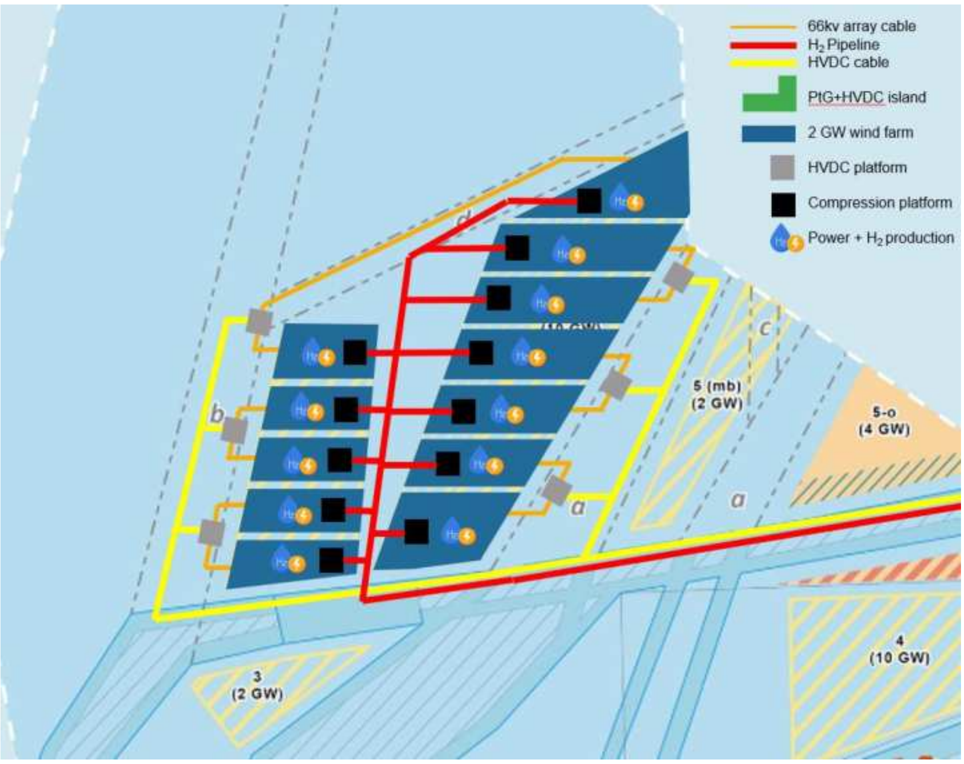
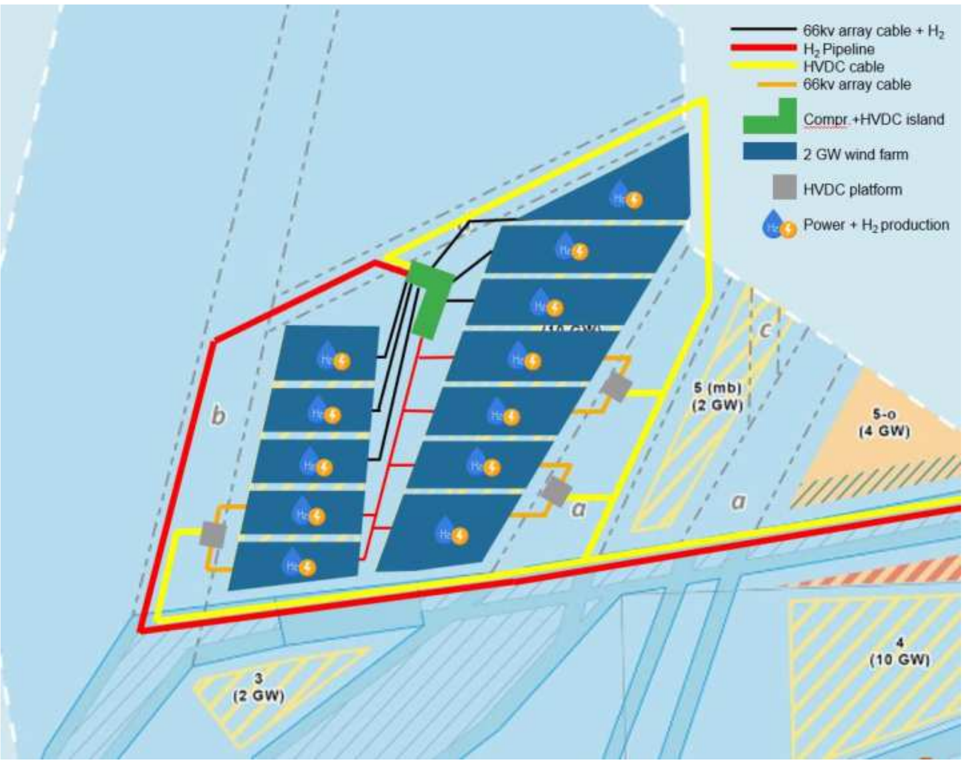


Figure 6.22: Illustrative Layout of Concept 3 – Platform-based Hub but with Centralised Compression/HVDC on an Island.



From the NSWPH programme a caisson island capable of supporting up to 6GW of HVDC equipment and 6GW of hydrogen production equipment has a total area of 100 ha (46 ha for

HVDC + 45 ha for hydrogen production + 9 ha for hydrogen compression). For Concept 3 there is a single island with hydrogen compression and 6GW of HVDC equipment but no hydrogen production equipment. As this island will support compression for the whole of areas 6 and 7 the compression capacity is 12GW. Scaling the equipment dimensions from the NSWPH island the estimated area of the island for Concept 3 is 64 ha.

Table 6.40: Concept Definition

Concept	Relation to Evaluation 1	WTGs	Array Cables	Flowlines (in case of PtG local to the WTG)	Hydrogen Production	Hydrogen Compression
Concept 1	Same as island concept	24GW across search areas 6 and 7	24GW connecting WTGs to islands	Not required	On islands	On islands
Concept 2a	Same as platform concept	24GW across search areas 6 and 7	12GW connecting WTGs to HVDC platforms 12GW connecting to PtG platforms (in case of PtG on 500MW platforms)	12GW connecting WTGs to compression platforms	12GW local to the WTGs or on 500MW platforms within wind blocks	12GW on centralised platforms outside wind blocks
Concept 2b	Platform concept but with decentralised compression platforms	24GW across search areas 6 and 7	12GW connecting WTGs to HVDC platforms 12GW connecting to PtG platforms (in case of PtG on 500MW platforms)	12GW connecting WTGs to compression platforms	12GW local to the WTGs or on 500MW platforms within wind blocks	12GW on decentralised 1GW platforms within wind blocks
Concept 3	Platform concept but with centralised compression on an island with 6GW of HVDC equipment added	24GW across search areas 6 and 7	6GW connecting WTGs to compression/HVDC island 6GW connecting WTGs to HVDC platforms 12GW connecting to PtG platforms (in case of PtG on 500MW platforms)	12GW connecting WTGs to compression/HVDC island	12GW local to the WTGs or on 500MW platforms within wind blocks	12GW on centralised island outside of wind blocks

This section of the report details the comparative evaluation between these concepts assuming that all are feasible selections. For the selection of platforms or islands there could be technical considerations such as the impact of compressor vibration on platforms that drive decision making as described in Section 6.3. Further studies developing on the work done in the NSWPH programme will be required.

In making the initial evaluation between islands, platforms and a hybrid configuration the island concept was assumed to be based on two islands of 12GW capacity. Therefore, there is no change to the Evaluation of concept 1 compared to the original island concept. Similarly, Concept 2a (platform based with central compression) is the basis on which the platform concept was assessed in the original evaluation (1). Therefore, the explanation of the scoring for Evaluation 2 will only focus on the differences between Concept 2b (platform based with decentralised compression) and Concept 3 (platform-based but with compression and 6GW of HVDC on an island) compared to concepts 1 (island based supporting hydrogen production) and 2a (platform based with centralised compression). In the decision funnelling process Concepts 2b and 3 are only selected if large offshore islands have not been selected and therefore the initial basis for their scoring was that of concept 2a with appropriate adjustments made.

6.4.1 Safety & Security

6.4.1.1 Safety during Construction & Installation

Concept 2b – Decentralised Compression Platforms

The construction and installation risks associated with multiple smaller compression platforms as required for decentralised compression is considered to increase the risk compared to centralised compression due to the larger number of operations that need to be carried out in a greater number of locations.

Concept 3 – Compression and HVDC on an artificial island

Whilst the size of the compression and HVDC island is smaller than the large 12 GW offshore islands considered in concept 1, its combination with the installation of multiple hydrogen production, compression and HVDC platforms results in a consideration that overall construction and installation risks is similar to concept 1.

To represent these comparative risks the four concepts are scored as shown in Table 6.41 with a higher score indicating greater safety risk.

Table 6.41: Evaluation 2 Scoring – Safety during Construction & Installation.

Criteria	Scale	1. Islands (12 GW island) (HVDC + PtG)	3. Island (HVDC + compression)	2a Central compression platform	2b Decentralized compression on platforms within
Safety during Construction & Installation	Higher scores for higher risks	8	7	5	6

6.4.1.2 Safety during Operation & Maintenance

Concept 2b – Decentralised Compression Platforms

In line with the approach taken in Evaluation 1 there is considered to be greater operations and maintenance safety risk associated with attendance at multiple normally unmanned platforms compared to permanently manned island with reduced space constraints which allow for greater exclusion zones. On this basis it is considered there are slightly greater safety risks for the decentralised compression concept due to the greater number of platforms that need to be visited, particularly given the compressors will need significantly greater maintenance than the hydrogen production equipment.

Concept 3 – Compression and HVDC on an artificial island

As for this concept there is a combination of islands and platforms the safety risks are assumed to be between those of concept 1 and concept 2a.

This approach has been applied to the concept scoring in Table 6.42 with higher scoring indicating greater safety risks (less favourable) during operations and maintenance.

Table 6.42: Evaluation 2 Scoring – Safety during Operations & Maintenance.

Criteria	Scale	1. Islands (12 GW island) (HVDC + PtG)	3. Island (HVDC + compression)	2a Central compression platform	2b Decentralized compression on platforms within
Safety during Operations and Maintenance	Higher scores for higher risks	6	7	9	10

6.4.1.3 Security

Whilst there are no major concerns relating to security for the offshore island and platforms, it is considered that security at major manned islands is easier to achieve than at remote platforms. Therefore, a larger number of platforms is seen to have a greater security risk than a lower number of platforms. The scoring for the four concepts, developed on this basis, is given in Table 6.43 with higher scoring indicating greater security risk.

Table 6.43: Evaluation 2 Scoring – Security.

Criteria	Scale	1. Islands (12 GW island) (HVDC + PtG)	3. Island (HVDC + compression)	2a Central compression platform	2b Decentralized compression on platforms within
Security	Higher scores for higher risks	4	6	7	8

6.4.1.4 Results Safety & Security

Table 6.44: Overall Scoring – Safety & Security

Criteria	Scale	Concept 1	Concept 3	Concept 2a	Concept 2b	Weighting
Safety during Construction & Installation	Higher scores for higher risks	8	7	5	6	**100**
Safety during Operations and Maintenance	Higher scores for higher risks	6	7	9	10	**100**
Security	Higher scores for higher risks	4	6	7	8	**30**
Normalised results	**Highest score is best**	**100**	**99**	**99**	**95**	

6.4.2 Environmental

6.4.2.1 Greenhouse Gas Emissions (Life Cycle Assessment)

Following a similar approach as to section 6.1.5.1, the carbon footprints of the four concepts have been calculated. In Table 6.45: Concept Summary, the concept information is provided. As can be seen, concept 1 is equal to the full island concept of the first comparison. Furthermore, concept 2a is similar to the platform only concept of the first comparison. Therefore, the calculated carbon footprints of the first comparison were used for concept 1 and 2a.

Table 6.45: Concept Summary.

Concept	**1**	**3**	**2a**	**2b**
Wind farm capacity (GW)	24	24	24	24
H2 capacity (GW)	12	12	12	12
HVDC transport (GW)	12	12	12	12
HVDC on platforms (GW)	0	6	12	12
Turbine capacity (MW)	15	15	15	15
H2 on platforms (GW)	0	12	12	12
Array-Cable length (km)	7000	5250	3500	3500
No of multi-purpose Islands	2	0	0	0
HVDC/HNO island	0	1	0	0
No of turbines	1600	1600	1600	1600
No of Compression platforms (3GW)	0	0	4	0
No of Compression platform (1GW)	0	0	0	12

Concept 2b – Decentralised Compression Platforms

The differences between concept 2a and concept 2b is the location of compression. In concept 2b compression is decentralised and located within the wind farm. As can be seen from table 6.14 above, concept 2b has a total of 12 compression platforms that can process the hydrogen produced by 1 GW of electrolyser capacity. From previous work in the NSPWH a 1 GW compression platform design was not available. Therefore, the structural steel requirements for this compression platform were scaled. In Table 6.46 the steel requirements are presented.

Table 6.46: Compression platforms steel requirements (ref. 22).

Item	**Steel weight [tonnes]**			
	1 GW	**3.2 GW**	**4 GW**	**5.34 GW**
Topsides steelwork	2508		4848	6353
Vent boom	100		1000	100
Topsides cladding	231		276	388
Sub-total: Topsides	**2839**	**4,017**	**6124**	**6841**
Jacket	1923		3556	3950
Piles	1189		2113	2113
Sub-total: Substructure	**3112**	**3339**	**5669**	**6063**
Total structural steel	**5951**	**7356**	**11793**	**12904**

Concept 3 – Compression and HVDC on an artificial island

Similar to the 1 GW compression platform, the material requirements for the compression & HVDC island have not been developed in the NSWPH programme. Therefore, the material requirements are scaled and estimated. From the NSWPH programme, a 10 GW island requires 100 ha, of which 36ha is for 4 GW of HVDC equipment. In the new island design, 6GW of HVDC equipment is required. Therefore, it can be estimated that the 6GW HVDC equipment requires a footprint of approximately 54 ha. The footprint required for compression is also estimated from the NSWPH caisson island concept to be approximately 10 ha for 12 GW of compression. The total surface area required for the compression and HVDC island is estimated to be 64 ha.

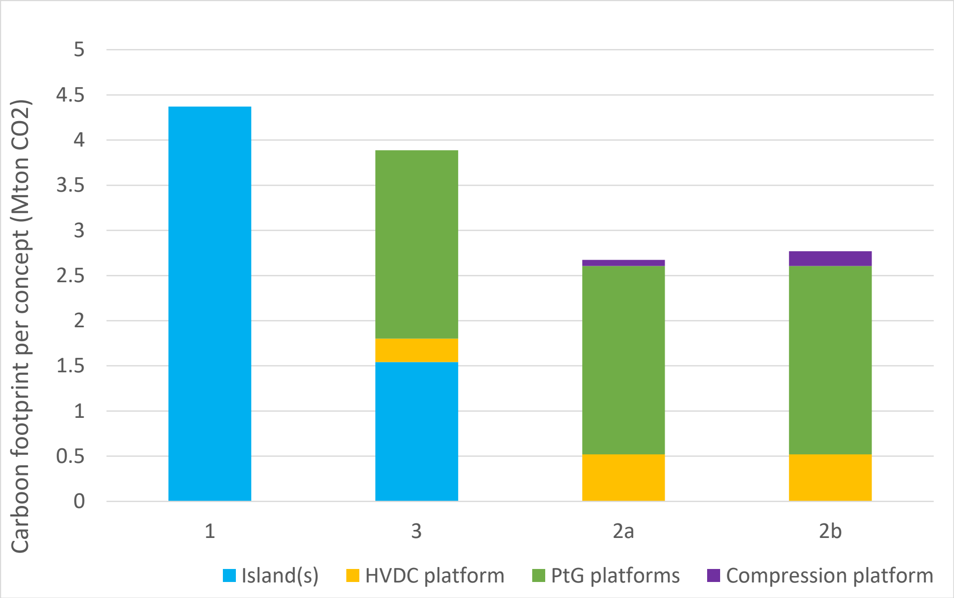
Subsequently, the material requirements for the 64ha have been developed in a similar way to the NSWPH estimates for the 13, 15 and 100 ha islands. The material breakdown for the 64 ha island is presented in Table 6.47.

Table 6.47: Life Cycle inventory 64 ha island.

Material	Substructure	Quantity	Unit	Source
Rock / Quarry	Quarry run 'Berm'	9,911,160	m^3	Mott MacDonald / NSWPH
	Core of Revetment:	180,201	m^3	Mott MacDonald / NSWPH
	Rock Fill behind Perimeter	200,000	m^3	Mott MacDonald / NSWPH
	Total	**10,291,361**	$\mathbf{m^3}$	Mott MacDonald / NSWPH
Sand	Sand Infill to perimeter	1,415,400	m^3	Mott MacDonald / NSWPH
	Island sand in-fill	32,754,561	m^3	Mott MacDonald / NSWPH
	Sand capping layer	116,981	m^3	Mott MacDonald / NSWPH
	Total	**34,286,942**	$\mathbf{m^3}$	Mott MacDonald / NSWPH
Concrete	Production Caissons	606,600	m^3	Mott MacDonald / NSWPH
	Cover	126,375	m^3	Mott MacDonald / NSWPH
	Nose Blocks	119,987	m^3	Mott MacDonald / NSWPH
	Port Basin	50,000	m^3	Mott MacDonald / NSWPH
	Compressor / Equipment Bases including Piling	75,000	m^3	Mott MacDonald / NSWPH
	Total	**977,962**	$\mathbf{m^3}$	Mott MacDonald / NSWPH

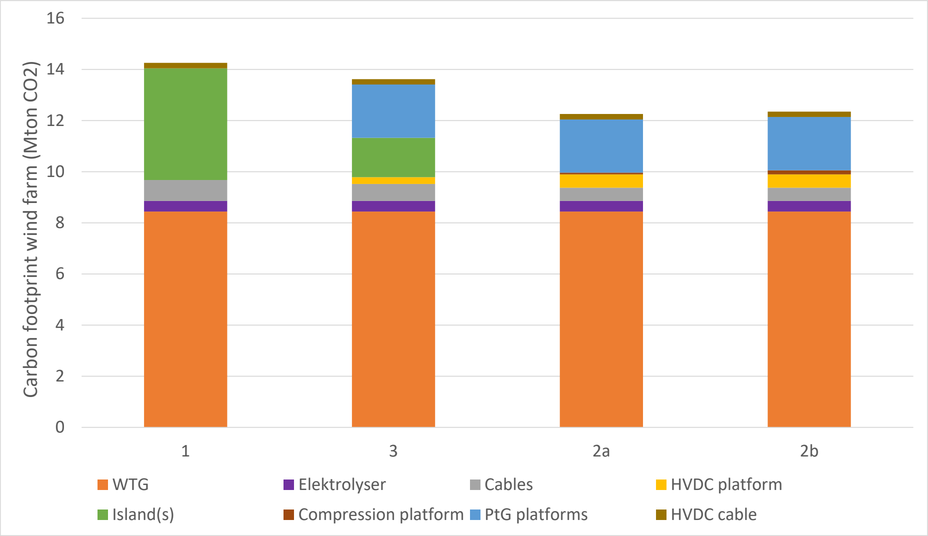
The results are presented in Figure 6.23. As discussed before the carbon footprints for concept 1 and 2a are copied from the first comparison. The results for concept 2b show that decentralizing compression increases the carbon footprint of the energy hub with around 5 %. This is caused by the fact that more than twice as much steel is required for compression in concept 2b than in 2a. The carbon footprint of the concept 3 is significantly higher than concept 2a. Compared to concept 1 the carbon footprint is lower but compared to surface area on the island it is relatively high. This is caused by the requirements for PtG platforms.

Figure 6.23: Carbon footprint per 24 GW energy hub concept (Mott MacDonald analysis).



Similar to the first comparison, the concepts have been compared to the full wind farm concepts. Results are presented in Figure 6.24. It can be seen that the difference between concept 2a and 2b are now almost negligible. The differences between concept 1, 2 and 3 are still significant.

Figure 6.24: Carbon footprint per 24 GW wind farm concept (Mott MacDonald analysis)



The results from Figure 6.23 have been transferred into scorings. The scorings for each concept are presented in Table 6.48, representing the total carbon footprint of the energy hub concept in Mton of CO_2.

Table 6.48: Evaluation 2 Scoring – Climate Change.

Criteria	Scale	1. Islands (12 GW island) (HVDC + PtG)	3. Island (HVDC + compression)	2a Central compression platform	2b Decentralized compression on platforms within
Greenhouse Gas Emissio	Higher scores for higher impact, values based on Mton CO_2	4.4	3.9	2.6	2.7

Criteri a	Scale	1. Islands (12 GW island) (HVDC + PtG)	3. Island (HVDC + compression)	2a Central compression platform	2b Decentralized compression on platforms within
ns (Life Cycle Assess ment)	per 24 GW energy hub				

6.4.2.2 Ecological Impact During Construction

There are now four concepts to compare. Therefore, it was chosen to move scoring as high, medium and low to a qualitative numerical approach (Table 6.49). The full island concept 1 was scored with a 9 comparing to a 3 for concept 2a. This is in line with the Belgian environmental studies, explaining the high ecological impact of the island.

Concept 2b – Decentralised Compression Platforms

In this concept more platforms are to be installed than in concept 2a, therefore more locations and thus ecosystems will be disturbed. As in this concept no islands are installed it was decided to score concept 2b with a 4.

Concept 3 – Compression and HVDC on an artificial island

Lastly, the compression and HVDC island has been scored with a 6. The surface area of this island is significantly less than two 12GW islands. Therefore, it was chosen to give the step from concept 1 to 3 higher than between concept 2b and 3.

Table 6.49: Evaluation 2 Scoring – Ecological impact during construction.

Criteria	Scale	1. Islands (12 GW island) (HVDC + PtG)	3. Island (HVDC + compression)	2a Central compression platform	2b Decentralized compression on platforms within
Ecological impact during construction	Higher scores for higher risks and impact	9	6	3	4

6.4.2.3 Ecological Impact During Operation

The scores for the ecological impact during operation are provided in Table 6.50.

Concept 2b – Decentralised Compression Platforms

The hydrogen production location and capacity does not differentiate with concept 2a and therefore gets the same scoring.

Concept 3 – Compression and HVDC on an artificial island

The hydrogen production location and capacity does not differentiate with concept 2a and therefore gets the same scoring.

Table 6.50: Evaluation 2 Scoring – Ecological impact during operation.

Criteria	Scale	1. Islands (12 GW island) (HVDC + PtG)	3. Island (HVDC + compression)	2a Central compression platform	2b Decentralized compression on platforms within
Ecological impact during operation	Higher scores for higher risks and impact	9	7	7	7

6.4.2.4 Results Environmental

Table 6.51: Overall scoring – Environmental

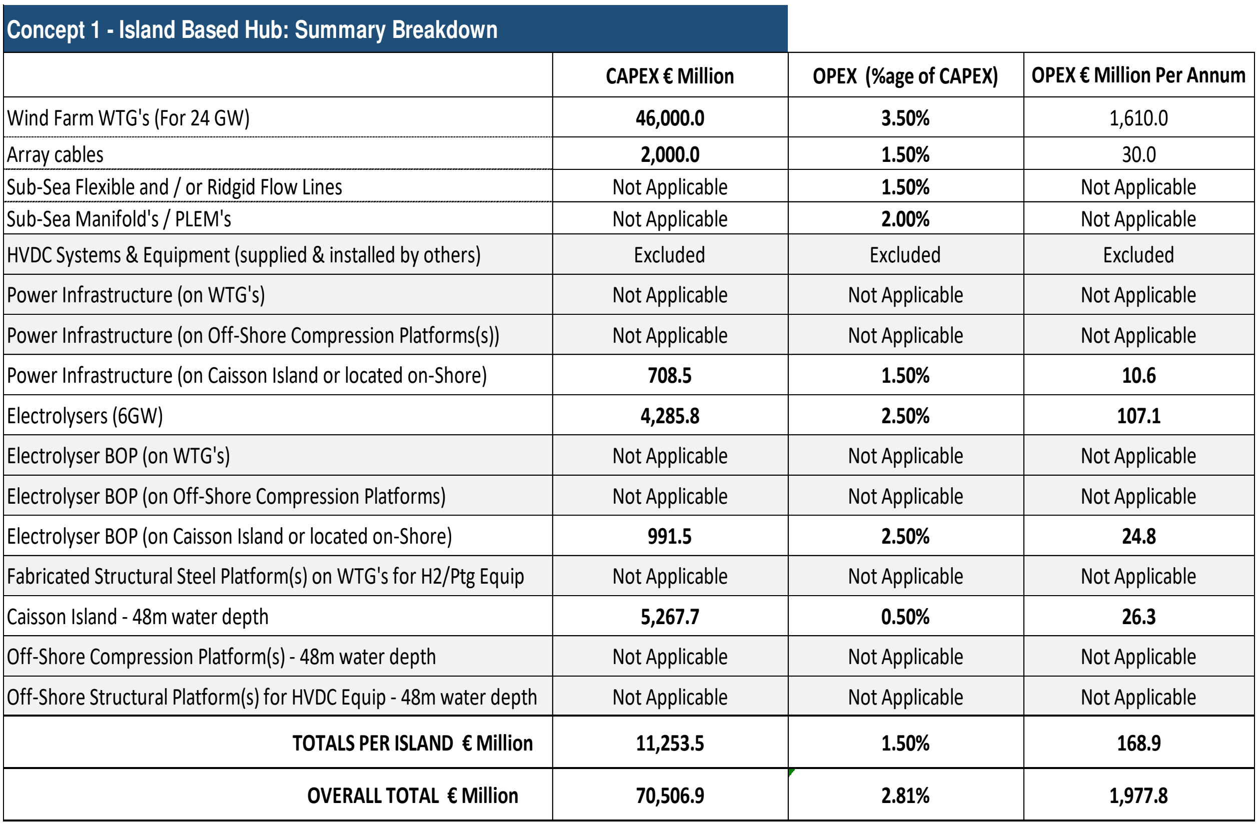
Criteria	Scale	Concept 1	Concept 3	Concept 2a	Concept 2b	Weighting
Greenhouse Gas Emissions (Life Cycle Assessment)	Higher scores for higher impact, values based on Mton CO_2 per 24 GW energy hub	4.4	3.9	2.6	2.7	**100**
Greenhouse Gas Emissions (Life Cycle Assessment)	Higher scores for higher impact, values based on Mton CO_2 per 24 GW energy hub	4.4	3.9	2.6	2.7	**0**
Ecological impact during operation	Higher scores for higher risks and impact	9	7	7	7	**20**
Normalised Results	**Highest score is best**	**85**	**90**	**100**	**100**	

6.4.3 Economics

A summary of the CapEx & OpEx cost estimates and analysis of the key cost drivers including supply chain opportunities are provided below.

6.4.3.1 CapEx & OpEx Summaries

Table 6.52: *C*oncept 1 – Island Based Hub supporting hydrogen production (Mott MacDonald analysis).



Concept 1 - Island Based Hub: Summary Breakdown

	CAPEX € Million	OPEX (%age of CAPEX)	OPEX € Million Per Annum
Wind Farm WTG's (For 24 GW)	**46,000.0**	**3.50%**	1,610.0
Array cables	**2,000.0**	**1.50%**	30.0
Sub-Sea Flexible and / or Ridgid Flow Lines	Not Applicable	**1.50%**	Not Applicable
Sub-Sea Manifold's / PLEM's	Not Applicable	**2.00%**	Not Applicable
HVDC Systems & Equipment (supplied & installed by others)	Excluded	Excluded	Excluded
Power Infrastructure (on WTG's)	Not Applicable	Not Applicable	Not Applicable
Power Infrastructure (on Off-Shore Compression Platforms(s))	Not Applicable	Not Applicable	Not Applicable
Power Infrastructure (on Caisson Island or located on-Shore)	**708.5**	**1.50%**	**10.6**
Electrolysers (6GW)	**4,285.8**	**2.50%**	**107.1**
Electrolyser BOP (on WTG's)	Not Applicable	Not Applicable	Not Applicable
Electrolyser BOP (on Off-Shore Compression Platforms)	Not Applicable	Not Applicable	Not Applicable
Electrolyser BOP (on Caisson Island or located on-Shore)	**991.5**	**2.50%**	**24.8**
Fabricated Structural Steel Platform(s) on WTG's for H2/Ptg Equip	Not Applicable	Not Applicable	Not Applicable
Caisson Island - 48m water depth	**5,267.7**	**0.50%**	**26.3**
Off-Shore Compression Platform(s) - 48m water depth	Not Applicable	Not Applicable	Not Applicable
Off-Shore Structural Platform(s) for HVDC Equip - 48m water depth	Not Applicable	Not Applicable	Not Applicable
TOTALS PER ISLAND € Million	**11,253.5**	**1.50%**	**168.9**
OVERALL TOTAL € Million	**70,506.9**	**2.81%**	**1,977.8**

Table 6.53: Concept 2a – Centralised Compression on Platforms (Mott MacDonald analysis).

Concept 2a - Centralised Compression on Platforms: Summary Breakdown

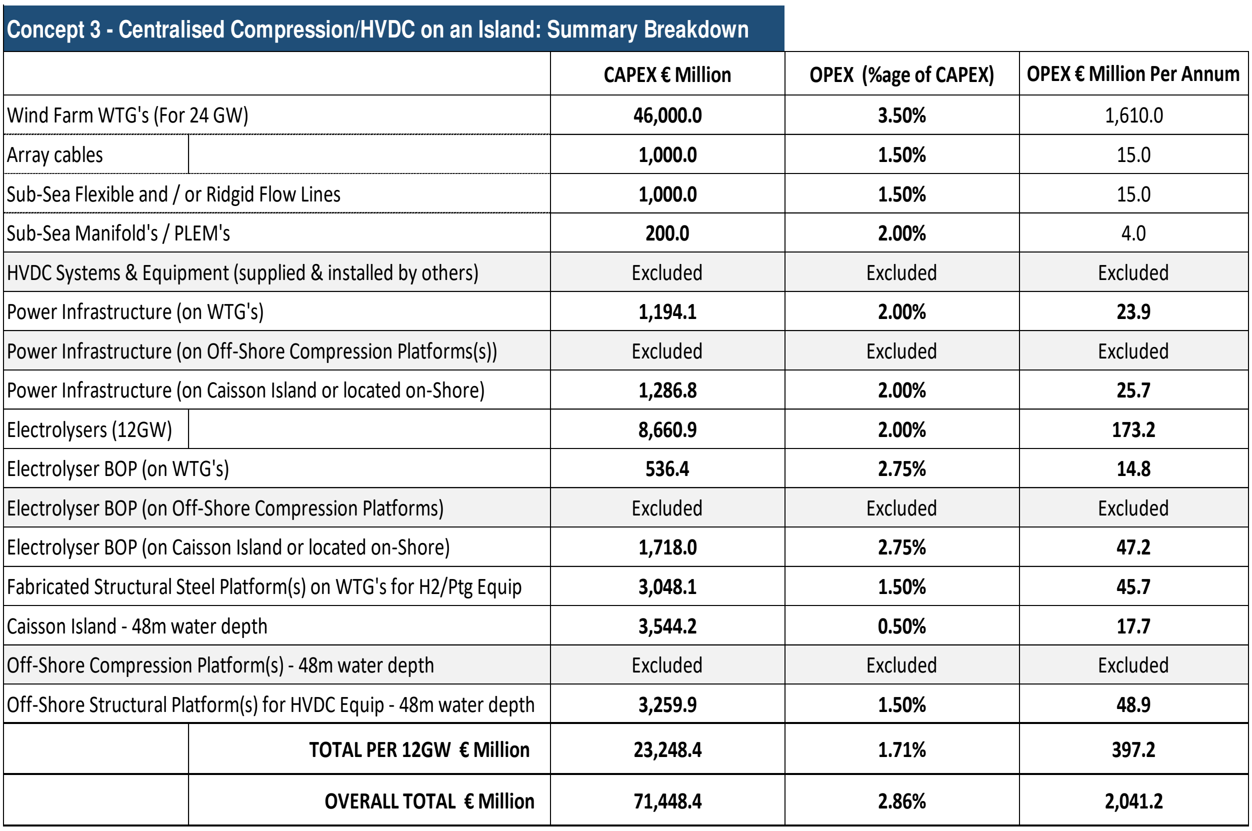
	CAPEX € Million	OPEX (%age of CAPEX)	OPEX € Million Per Annum
Wind Farm WTG's (For 24 GW)	**46,000.0**	**3.50%**	1,610.0
Array cables	**1,000.0**	**1.50%**	15.0
Sub-Sea Flexible and / or Ridgid Flow Lines	**1,000.0**	**1.50%**	15.0
Sub-Sea Manifold's / PLEM's	**200.0**	**2.00%**	4.0
HVDC Systems & Equipment (supplied & installed by others)	Excluded	Excluded	Excluded
Power Infrastructure (on WTG's)	**796.1**	**2.00%**	**15.9**
Power Infrastructure (on Off-Shore Compression Platforms(s))	**830.3**	**2.00%**	**16.6**
Power Infrastructure (on Caisson Island or located on-Shore)	Not Applicable	Not Applicable	Not Applicable
Electrolysers (6GW)	**5,092.8**	**2.00%**	**101.9**
Electrolyser BOP (on WTG's)	**357.6**	**2.75%**	**9.8**
Electrolyser BOP (on Off-Shore Compression Platforms)	**824.1**	**2.75%**	**22.7**
Electrolyser BOP (on Caisson Island or located on-Shore)	Not Applicable	Not Applicable	Not Applicable
Fabricated Structural Steel Platform(s) on WTG's for H2/Ptg Equip	**2,032.0**	**1.50%**	**30.5**
Caisson Island - 48m water depth	Not Applicable	Not Applicable	Not Applicable
Off-Shore Compression Platform(s) - 48m water depth	**459.7**	**1.50%**	**6.9**
Off-Shore Structural Platform(s) for HVDC Equip - 48m water depth	**3,259.9**	**1.50%**	**48.9**
TOTALS PER 12GW OF PLATFORMS € Million	**13,652.5**	**1.85%**	**253.2**
OVERALL TOTAL € Million	**75,505.0**	**2.85%**	**2,150.3**

Table 6.54: Concept 2b – Decentralised Compression on Platforms (Mott MacDonald Analysis).

Concept 2b - Decentralsied Compression on Platforms: Summary Breakdown

	CAPEX € Million	OPEX (%age of CAPEX)	OPEX € Million Per Annum
Wind Farm WTG's (For 24 GW)	**46,000.0**	**3.50%**	1,610.0
Array cables	**1,000.0**	**1.50%**	15.0
Sub-Sea Flexible and / or Ridgid Flow Lines	**1,000.0**	**1.50%**	15.0
Sub-Sea Manifold's / PLEM's	**200.0**	**2.00%**	4.0
HVDC Systems & Equipment (supplied & installed by others)	Excluded	Excluded	Excluded
Power Infrastructure (on WTG's)	**796.1**	**2.00%**	**15.9**
Power Infrastructure (on Off-Shore Compression Platforms(s))	**830.3**	**2.00%**	**16.6**
Power Infrastructure (on Caisson Island or located on-Shore)	Not Applicable	Not Applicable	Not Applicable
Electrolysers (6GW)	**5,092.8**	**2.00%**	**101.9**
Electrolyser BOP (on WTG's)	**357.6**	**2.75%**	**9.8**
Electrolyser BOP (on Off-Shore Compression Platforms)	**859.1**	**2.75%**	**23.6**
Electrolyser BOP (on Caisson Island or located on-Shore)	Not Applicable	Not Applicable	Not Applicable
Fabricated Structural Steel Platform(s) on WTG's for H2/Ptg Equip	**2,032.0**	**1.50%**	**30.5**
Caisson Island - 48m water depth	Not Applicable	Not Applicable	Not Applicable
Off-Shore Compression Platform(s) - 48m water depth	**1,056.4**	**1.50%**	**15.8**
Off-Shore Structural Platform(s) for HVDC Equip - 48m water depth	**3,259.9**	**1.50%**	**48.9**
TOTAL PER 12GW OF PLATFORMS € Million	**14,284.3**	**1.84%**	**263.1**
OVERALL TOTAL € Million	**76,768.5**	**2.83%**	**2,170.1**

Table 6.55: Concept 3 – Centralised Compression and HVDC on an island (Mott MacDonald analysis).



Concept 3 - Centralised Compression/HVDC on an Island: Summary Breakdown

	CAPEX € Million	OPEX (%age of CAPEX)	OPEX € Million Per Annum
Wind Farm WTG's (For 24 GW)	46,000.0	3.50%	1,610.0
Array cables	1,000.0	1.50%	15.0
Sub-Sea Flexible and / or Ridgid Flow Lines	1,000.0	1.50%	15.0
Sub-Sea Manifold's / PLEM's	200.0	2.00%	4.0
HVDC Systems & Equipment (supplied & installed by others)	Excluded	Excluded	Excluded
Power Infrastructure (on WTG's)	1,194.1	2.00%	23.9
Power Infrastructure (on Off-Shore Compression Platforms(s))	Excluded	Excluded	Excluded
Power Infrastructure (on Caisson Island or located on-Shore)	1,286.8	2.00%	25.7
Electrolysers (12GW)	8,660.9	2.00%	173.2
Electrolyser BOP (on WTG's)	536.4	2.75%	14.8
Electrolyser BOP (on Off-Shore Compression Platforms)	Excluded	Excluded	Excluded
Electrolyser BOP (on Caisson Island or located on-Shore)	1,718.0	2.75%	47.2
Fabricated Structural Steel Platform(s) on WTG's for H2/Ptg Equip	3,048.1	1.50%	45.7
Caisson Island - 48m water depth	3,544.2	0.50%	17.7
Off-Shore Compression Platform(s) - 48m water depth	Excluded	Excluded	Excluded
Off-Shore Structural Platform(s) for HVDC Equip - 48m water depth	3,259.9	1.50%	48.9
TOTAL PER 12GW € Million	23,248.4	1.71%	397.2
OVERALL TOTAL € Million	71,448.4	2.86%	2,041.2

Table 6.56: Evaluation 2 Scoring – CapEx.

Criteria	Scale	1. Islands (12 GW island) (HVDC + PtG)	3. Island (HVDC + compression)	2a Central compression platform	2b Decentralized compression on platforms within
CapEx	Higher scores for higher risks, values based on €billion per 24 GW wind farm concept	70.5	71.5	75.5	76.8

Table 6.57: Evaluation 2 Scoring – OpEx.

Criteria	Scale	1. Islands (12 GW island) (HVDC + PtG)	3. Island (HVDC + compression)	2a Central compression platform	2b Decentralized compression on platforms within
OpEx	Higher scores for higher risks, values based on €million/a per 24 GW wind farm concept	1977.8	2041.2	2150.3	2170.1

6.4.3.2 Need for Pre-investment

Concept 2b – Decentralised Compression Platforms

Concept 2b is even more modular than Concept 2a as it includes smaller de-centralised compression platforms and therefore it also has a limited need for pre-investment and is scored low.

Concept 3 – Compression and HVDC on an artificial island

As Concept 3 combines a large island – approximately 60 % of the capacity of the Concept 1 islands - with multiple platforms the need for pre-investment is considered to be between Concept 1 and Concepts 2a and 2b and is scored medium.

Table 6.58: Evaluation 2 Scoring – Need for Pre-Investment.

Criteria	**Scale**	**1. Islands (12 GW island) (HVDC + PtG)**	**3. Island (HVDC + compression)**	**2a Central compression platform**	**2b Decentralized compression on platforms within**
Need for pre-investment	Higher scores for higher pre-investment need	High	Medium	Low	Low

6.4.3.3 Results Economics

Table 6.59: Overall scoring – Economics

Criteria	**Scale**	**Concept 1**	**Concept 3**	**Concept 2a**	**Concept 2b**	**Weighting**
CapEx	Higher scores for higher risks, values based on €billion per 24 GW wind farm concept	70.5	71.5	75.5	76.8	**80**
OpEx	Higher scores for higher risks, values based on €million/a per 24 GW wind farm concept	1977.8	2041.2	2150.3	2170.1	**80**
Need for pre-investment	Higher scores for higher pre-investment need	High	Medium	Low	Low	**100**
Normalised Results	**Highest score is best**	**92**	**96**	**100**	**100**	

6.4.4 Realisation and Technical Feasibility

6.4.4.1 Development Time to Operations

The schedule for first hydrogen and HVDC on large artificial results in first power export and offshore hydrogen production in approximately 2034 with platform-based concepts resulting in first power export possible in 2030 with hydrogen production following in 2031 ahead of the schedules roll-out of infrastructure in search areas 6 and 7 in 2032.

Concept 2b – Decentralised Compression Platforms

To comparatively score the four concepts it was considered that multiple smaller compression platforms as in concept 2b are easier to construct and install than larger platforms where the number of yards for construction and vessels for installation may be more limited. Furthermore, in concept 2b more platforms are to be constructed and the timeline will speed up when learnings from the first platforms can be applied. This could result in a shorter schedule and lower schedule risk for concept 2b compared to Concept 2a.

Concept 3 – Compression and HVDC on an artificial island

The smaller artificial island supporting compression and HVDC within concept 3 is easier to construct than the larger islands in concept 1. However, it is still a major island in water depths of up to 50m with the associated risks and materials constraints as well as the need to use summer weather windows for initial island construction.

Based on these considerations the four concepts are comparatively scored as shown in Table 6.60 with higher scores indicating a longer development schedule.

Table 6.60: Evaluation 2 Scoring – Development time to operations.

Criteria	Scale	1. Islands (12 GW island) (HVDC + PtG)	3. Island (HVDC + compression)	2a Central compression platform	2b Decentralized compression on platforms
Development time to operations	Higher scores for longer development times	8	7	3	2

6.4.4.2 Construction/Installation Constraints

Previous scoring for construction / installation constraints considered islands to be more complex than platforms as an island in 50m water depth has never been done before, whereas platforms are commonplace in the North Sea. The island option was scored with a high complexity and platform option was scored with a low complexity. All the scores are provided in Table 6.61.

Concept 2b – Decentralised Compression Platforms

Decentralised compression (2b) introduces a greater number of smaller compression platforms spread throughout the North Sea, compared with centralised compression (2a). There will be more offshore activities as more platforms will need to be transported offshore, although the size of the platforms being transported will be much smaller. The build-out of subsequent platforms can be streamlined as construction progresses, and learnings from earlier builds can be brought to improve construction and installation activities for later platforms. The increased complexity of having more offshore activities is seen to have a greater impact than the decreased size of the platforms and lessons learnt. Therefore, decentralised compression is seen to be more complex than centralised compression and is given a medium complexity rating.

Concept 3 – Compression and HVDC on an artificial island

In line with the previous scoring, an island results in a high complexity for construction and installation as an island has not previously been constructed in 50m water depth. Although the size of the Compression and HVDC island is smaller than the fully integrated island (~36 % smaller), platforms also must be constructed and shipped out for hydrogen production. Therefore Concept 3 also has a high complexity for construction and installation.

Table 6.61: Evaluation 2 Scoring – Construction/Installation Constraints.

Criteria	Scale	1. Islands (12 GW island) (HVDC + PtG)	3. Island (HVDC + compression)	2a Central compression platform	2b Decentralized compression on platforms within
Construction /installation constraints	Higher scores for higher complexity	High	High	Low	Medium

6.4.4.3 Supply Chain Complexity

Previous scoring for supply chain complexity considered islands to be more complex than platforms due to the complexities associated with the supply of material for the island. These challenges were seen to overshadow the complexities associated with the supply of material for platforms, transport and build options for platforms, and supply of equipment. A scoring of 0-10 (10 being more complex and less favourable) was applied to sufficiently differentiate the island concept (Concept 1) from the platforms concept (Concept 2a). The island concept was scored with a 10 and platform concept was scored with a 3.

Concept 2b – Decentralised Compression Platforms

Decentralised compression (2b) introduces a greater number of smaller compression platforms spread throughout the North Sea, compared with centralised compression (2a). Having smaller platforms may open up options for more construction yards and platform transport options (less restrictive on size), although overall there will be an increase in the quantity of materials used to construct the platform structure. An advantage that decentralised compression has over centralised compression is that there will be less compression on decentralised compression platforms and therefore the supply chain for the compression equipment will be less restrictive (as all the machines would need to be installed on the platform prior to float-out). The impact of these changes on supply chain complexity for decentralised compression platforms compared with centralised platforms cannot be differentiated at this stage, and the complexity remains at a 3.

Concept 3 – Compression and HVDC on an artificial island

A compression and HVDC island will be smaller than a fully integrated island (approx. 36 % smaller), therefore less material will need to be sourced to build the island. This reduces the constraints on the supply chain and the complexity for the smaller island is reduced. However, there will now also need to be platforms constructed for the hydrogen production, which introduces the need for materials for platforms as well as yards to construct the platforms in. Therefore, the complexity for the island build is reduced, but the added element of platforms somewhat increase complexity as well. A score of 7 is given as the platforms and smaller island are still seen to be less complex than a larger island, but significantly more complex than a pure platform solution (Table 6.62).

Table 6.62: Evaluation 2 Scoring – Supply Chain Complexity.

Criteria	Scale	1. Islands (12 GW island) (HVDC + PtG)	3. Island (HVDC + compression)	2a Central compression platform	2b Decentralized compression on platforms within
Supply chain complexity	Higher scores for higher complexity	10	7	3	3

6.4.4.4 Permitting

The scores for the permitting of Evaluation 2 are provided in Table 6.63.

Concept 2b – Decentralised Compression Platforms

In line with the platform-based concept in Evaluation 1 Concept 2b is considered to have lower permitting complexity as multiple platforms have already been installed in the North Sea.

Concept 3 – Compression and HVDC on an artificial island

As Concept 3 comprises both a large island and platforms its complexity is considered to be between Concept 1 and Concept 2a,

Table 6.63: Evaluation 2 Scoring – Permitting.

Criteria	Scale	1. Islands (12 GW island) (HVDC + PtG)	3. Island (HVDC + compression)	2a Central compression platform	2b Decentralized compression on platforms within
Permitting	Higher scores for higher complexity	High	High	Medium	Medium

6.4.4.5 Technology Readiness

Platforms were assumed to have a high technology readiness level in the previous scoring, as they are common in the North Sea and an island in 50m water depth has not yet been built to date. The technology readiness level for equipment on islands was seen to be higher than on platforms, particularly for modularised electrolysis and compression, aside from containerised PEM electrolyser packages which are readily available. A high score indicated a high technology readiness level, with platforms being seen to have a high technology readiness and islands to have a medium technology readiness, as the low readiness for a novel island in 50m water depth is seen to outweigh the equipment readiness (Table 6.64).

Concept 2b – Decentralised Compression Platforms

Decentralised compression (2b) limits the amount of compression on a single platform to a maximum of 1 GW, compared with centralised compression (2a) which could have up to 3-4 GW on a single platform. Whilst the impact of compressor vibration on the platforms cannot be neglected it is expected to be less severe than for larger platforms with up to 6 compressor per platform. The decentralised compression platform solution is therefore seen to have the same high technology readiness score as the centralised solution.

Concept 3 – Compression and HVDC on an artificial island

A compression and HVDC island means that hydrogen production is carried out on platforms. It is assumed that hydrogen production on platforms is at the individual WTGs rather than a centralised solution (this is constant across all concepts with hydrogen on platforms). While modularised large scale alkaline electrolysis on an island is more mature than modularised PEM electrolysis, electrolysis at the individual WTGs is likely to be a containerised PEM package which is readily available.

Moving hydrogen production off the island and onto platforms reduces the size of the island and the complexity of the island construction, however the depth of the water that the island is being constructed in remains at 50m and therefore the technology readiness level of the compression and HVDC island is seen to have the same medium technology readiness score as the large integrated island.

Table 6.64: Evaluation 2 Scoring – Technology Readiness.

Criteria	**Scale**	**1. Islands (12 GW island) (HVDC + PtG)**	**3. Island (HVDC + compression)**	**2a Central compression platform**	**2b Decentralized compression on platforms within**
Technology readiness	Higher scores for higher technology readiness	Medium	Medium	High	High

6.4.4.6 Water Depth

Concept 2b – Decentralised Compression Platforms

As with Concept 2a, Concept 2b comprises platforms with a proven history of construction and installation in the North Sea in water depths of 50m Therefore their associated risk and complexity is considered low.

Concept 3 – Compression and HVDC on an artificial island

For Concept 3 HVDC and compression equipment are installed on a large island with has not been done before in water depths of 50m. Therefore, in line with Concept 1 the associated risks and complexity are considered high.

Table 6.65: Evaluation 2 Scoring – Water Depth.

Criteria	**Scale**	**1. Islands (12 GW island) (HVDC + PtG)**	**3. Island (HVDC + compression)**	**2a Central compression platform**	**2b Decentralized compression on platforms within**
Water depth	Higher scores for higher complexity	High	High	Low	Low

6.4.4.7 System Integration

The system integration criteria is included to assess the complexities resulting from each energy hub concept in relation to the number of parties involved in its development and the number of required interfaces between them.

During Evaluation 1 it was considered that the multiple developers working on the large artificial islands in Concept 1 increased the complexity of system integration compared to geographically distributed platforms where scope such as hydrogen compression and production is separated.

Concept 2b – Decentralised Compression Platforms

Concept 2b was considered to be slightly more complex than Concept 2a as the decentralised compression platforms located within the individual wind blocks would be designed by HNO whilst the rest of the block infrastructure would be designed by the developer.

Concept 3 – Compression and HVDC on an artificial island

Concept 3 is considered to be less complex than Concept 1 but more complex than Concept 2a as the co-location of HVDC equipment and hydrogen compression equipment on the same island requires integration between HNO and TSO.

Based on these considerations the four concepts are comparatively scored as shown in Table 6.66, with high indicating increased complexity in system integration.

Table 6.66: Evaluation 2 Scoring – System Integration.

Criteria	Scale	1. Islands (12 GW island) (HVDC + PtG)	3. Island (HVDC + compression)	2a Central compression platform	2b Decentralized compression on platforms
System Integration	Higher scores for higher complexity	High	Medium	Low	Medium

6.4.4.8 Results Realisation and Technical Feasibility

Table 6.67: Overall Scoring – Realisation and Technical Feasibility

Criteria	Scale	Concept 1	Concept 3	Concept 2a	Concept 2b	Weighting
Development time to operations	Higher scores for longer development times	8	7	3	2	**100**
Construction /installation constraints	Higher scores for higher complexity	High	High	Low	Medium	**80**
Supply chain complexity	Higher scores for higher complexity	10	7	3	3	**100**
Permitting	Higher scores for higher complexity	High	High	Medium	Medium	**50**
Technology readiness	Higher scores for higher technology readiness	Medium	Medium	High	High	**80**
Water depth	Higher scores for higher complexity	High	High	Low	Low	**60**
System Integration	Higher scores for higher complexity	High	Medium	Low	Medium	**60**
Normalised results	**Highest scores is best**	**74**	**79**	**100**	**97**	

6.4.5 Operation and Maintenance

6.4.5.1 Operations Complexity

Previously islands were seen to have a lower operational complexity than platforms, due to the presence of operators, having only a few operating locations and a protected quay for equipment and personnel transfer. Islands were given a low complexity score of 3 and platforms were given a high complexity score of 8 (Table 6.68: Evaluation 2 Scoring – Operations Complexity.).

Concept 2b – Decentralised Compression Platforms

Decentralised compression simply sees more of the same (but smaller) compression platforms as centralised compression, across more locations in the North Sea. Therefore, the complexity is slightly increased compared with centralised compression.

Concept 3 – Compression and HVDC on an artificial island

The operations complexity of a compression and HVDC island (3) is increased compared with the large integrated island (1) as there is now the combination of islands and platforms. Introduction of platforms introduces the same logistical challenges as any of the platform options, but also combined with an island. Operator checks and chemical top-ups will need to be carried out across hundreds of platforms compared with a single island location, which will increase the complexity of operations. Therefore, the complexity is higher than both a large island and platform based concepts.

Table 6.68: Evaluation 2 Scoring – Operations Complexity.

Criteria	Scale	1. Islands (12 GW island) (HVDC + PtG)	3. Island (HVDC + compression)	2a Central compression platform	2b Decentralized compression on platforms within
Operations complexity	Higher scores for higher complexity	3	8	5	7

6.4.5.2 Maintenance Complexity

Overall, maintenance will be less complex on an island than on a platform, due to the available space, onsite warehouse and workshop, permanent manning, permanent, protected quay, and concentrated location of equipment reducing logistic challenges. Islands were given a low complexity score of 2 (as there still some challenges due to the offshore nature) and platforms were given a high complexity score of 8.

Concept 2b – Decentralised Compression Platforms

Decentralised compression simply sees more of the same (but smaller) compression platforms as centralised compression, across more locations in the North Sea. Therefore, the complexity is slightly increased compared with centralised compression and a rating of 9 has been assigned.

Concept 3 – Compression and HVDC on an artificial island

The maintenance complexity of a compression and HVDC island (3) is increased compared with the large integrated island (1) as there is now the added element of hydrogen platforms. Introduction of unmanned platforms introduces the same logistical challenges as any of the platform options, but with the advantage of an island base at sea rather than onshore (similar to the hybrid concept discussed in Section 6.1 which would see warehouse/stores on the island and personnel closer to the platforms for any maintenance activities). Hydrogen production at the WTGs (as assumed in this evaluation) will likely be containerised PEM electrolysis, which will be smaller and lighter and therefore easier to replace compared with alkaline (likely choice on an island), although it will be across many locations and require the WTG to be offline. Based on the NSWPH programme, WTGs with capacity 15-20 MW could be installed, and a single WTG offline is not seen to greatly impact overall production (each 2GW block will have between 100 and 200 WTGs). Maintenance activities will need to be carried out across hundreds of platforms compared with a single island location, which will increase the complexity of maintenance. Therefore, the complexity is higher than a large island but less than a pure platform solution and a score of 4 has been applied. Scores are provided in Table 6.69.

Table 6.69: Evaluation 2 Scoring – Maintenance Complexity.

Criteria	Scale	1. Islands (12 GW island) (HVDC + PtG)	3. Island (HVDC + compression)	2a Central compression platform	2b Decentralized compression on platforms within
Maintenance complexity	Higher scores for higher complexity	2	4	8	10

6.4.5.3 Availability / Reliability

A Low, Medium and High score has been applied to each of the concepts, with "high" indicating high availability and reliability (more favourable). Previously, islands have been given a high availability and reliability rating due to permanent manning and access to onsite spares. Platforms were scored with low availability and reliability due to being unmanned and having no spares on site.

Concept 2b – Decentralised Compression Platforms

In general, sparing on platforms is minimised compared with islands to keep the size and weight of the equipment down. To get around this and still provide appropriate levels of sparing and redundancy, the NSWPH programme suggests to bridge-link and interconnect platforms so that redundancy can be provided in neighbouring platforms. This is possible for centralised compression, which would be interlinked and include 1-2 spare compressors for the whole block. For decentralised solutions, there would need to be more spares (as there are more blocks), which inherently results in a more robust and reliable system due to the number of available spares. A single point of failure is removed, which might be the case for centralised compression, and having smaller systems (as you would for decentralised compared with centralised) will be easier to start again than larger systems, decreasing downtime. For these reasons, decentralised compression is seen have a higher availability and reliability compared with centralised compression and is assigned a medium availability and reliability rating. Decentralised compression also removes a single point of failure (e.g. power supply to the platforms) which could result in complete loss of hydrogen export for the whole energy hub.

Concept 3 – Compression and HVDC on an artificial island

As previously explored, sparing on an island is much easier than sparing on platforms due to the centralised location and available space. Moving hydrogen production to platforms (assumed to be at the WTG for this evaluation) locates hydrogen production across hundreds of different locations. It is not practical to install spare electrolyser capacity at each of the WTGs, however the WTGs are likely to be connected by array cable strings for power and flexible flowlines for hydrogen and in the case of electrolyser failure at one WTG, power generated at that WTG can be redirected to electrolysers at other WTGs. For any maintenance activity, the WTG would need to be offline, however a single offline WTG (15-20 MW out of a block wind generation capacity of 2GW) will have only a small impact on overall availability and production. The duration of downtime will be longer than on an island due to logistics and overall the reliability and availability for Concept 3 is lower than Concept 1 (large integrated island).

Availability and reliability for Concept 3 is still better than for any of the pure platform concepts, and a scoring of Low, Medium and High is no longer sufficient to differentiate the concepts. Instead, a numerical scoring of 0-10 is now applied, with a high number indicating high availability and reliability (favourable). Using this scale and the rationale above the concepts are scored as shown in Table 6.70.

Table 6.70: Evaluation 2 Scoring – Availability/ Reliability.

Criteria	Scale	1. Islands (12 GW island) (HVDC + PtG)	3. Island (HVDC + compression)	2a Central compression platform	2b Decentralized compression on platforms within
Availability / Reliability	Higher scores for higher availability and realiability	6	5	3	4

6.4.5.4 Flexibility

Whilst the large energy island allows for cross connections to supply power to either the HVDC system or to produce hydrogen, it is assumed for Concepts 2a, 2b and 3 that hydrogen production is local to the WTGs which provides for the maximum flexibility by allowing power from each WTG to be directed to either the HVDC system or to hydrogen production (Table 6.71).

Table 6.71: Evaluation 2 Scoring – Flexibility

Criteria	Scale	1. Islands (12 GW island) (HVDC + PtG)	3. Island (HVDC + compression)	2a Central compression platform	2b Decentralized compression on platforms
Flexibility	Higher scores for higher flexibility	Medium	High	High	High

6.4.5.5 Results Operation and Maintenance

Table 6.72: Overall Scores – Operation and Management

Criteria	Scale	Concept 1	Concept 3	Concept 2a	Concept 2b	Weighting
Operations complexity	Higher scores for higher complexity	3	8	5	7	**100**
Maintenance complexity	Higher scores for higher complexity	2	4	8	10	**100**
Availability / Reliability	Higher scores for higher availability and realiability	6	5	3	4	**100**
Flexibility	Higher scores for higher flexibility	Medium	High	High	High	**50**
Normalised results	**Highest scores is best**	**100**	**87**	**81**	**76**	

6.4.6 Future Proofing

6.4.6.1 Modularity & Scalability

This key criterion is largely defined by the difference in the modularity between islands and platforms as indicated in Evaluation 1.

Concept 3 – Compression and HVDC on an artificial island

Concept 3 includes a single island on which all the hydrogen compression equipment and half the HVDC equipment is installed (6GW). The island is therefore key to development of the energy hub and without it no hydrogen export can take place. It is therefore scored similarly to Concept 1 but an allowance is made for the 6GW of HVDC capacity which is installed on platforms.

Based on the island developed during the NSWPH programme a large island of 12GW (6GW of HVDC and 6GW of hydrogen production and compression) requires a buildable area of approximately one million m^2 (100ha). Of this total area 360,000m^2 is required to support hydrogen production. In order to determine the area required to support the full 12GW of hydrogen compression equipment and 6GW of HVDC equipment the areas dedicated to each are scaled resulting in an island size of 640,000m^2 (64ha) to support hydrogen compression and 6GW of HVDC equipment. Therefore, although the Concept 3 island is smaller it still a very large island that will be challenging to construct in 50m water depth and will need significant pre-investment.

Concept 2b – Decentralised Compression Platforms

Concept 2b with its decentralised platforms is considered to be even more modular and scalable than Concept 2a.

This assessment has been captured in the scoring in Table 6.73 with a higher number indicating greater modularity and scalability.

Table 6.73: Evaluation 2 Scoring – Modularity/Scalability.

Criteria	Scale	1. Islands (12 GW island) (HVDC + PtG)	3. Island (HVDC + compression)	2a Central compression platform	2b Decentralized compression on platforms
Modularity & Scalability	Higher scores for higher modularity and scalability	4	5	8	10

6.4.6.2 Future Expansion Capacity

This assessment has been captured in the scoring in Table 6.74.

Concept 2b – Decentralised Compression Platforms

In terms of future expansion capacity, it was estimated that there are no significant differences in concept 2a and 2b. In theory compression capacity can be expanded more easily than for Concept 2a but the impact is considered limited.

Concept 3 – Compression and HVDC on an artificial island

As concept 3 has hydrogen production and HVDC on platforms, the future expansion capacity of concept 3 is higher than concept 1 and therefore scored “medium”.

Table 6.74: Evaluation 2 Scoring – Future Expansion Capacity.

Criteria	Scale	1. Islands (12 GW island) (HVDC + PtG)	3. Island (HVDC + compression)	2a Central compression platform	2b Decentralized compression on platforms within
Future expansion capacity	Higher scores for higher future expansion potential	Low	Medium	High	High

6.4.6.3 Design Life

Based on the NSWPH programme the design life of platforms is 50 years whilst the design life of artificial islands is at least 100 years. The four concepts have been scored with their actual design life based on their combination of islands and platforms with Concept 3 assumed to have an average design life between island and platforms (Table 6.75).

Table 6.75: Evaluation 2 Scoring – Design Life.

Criteria	Scale	1. Islands (12 GW island) (HVDC + PtG)	3. Island (HVDC + compression)	2a Central compression platform	2b Decentralized compression on platforms
Design Life	Higher scores for longer design life	100	75	50	50

6.4.6.4 Connectivity

Concept 2b – Decentralised Compression Platforms

A centralised compression platform (Concept 2a) would have an electrical connection to the two nearest HVDC platforms or hydrogen production platform in order to have security of supply for exporting of hydrogen to the shore. The centralised platform will be located outside blocks and therefore access will be possible to other platforms.

Based on the NSWPH programme the power supply for a compression platform is provided by connecting it via submarine cables to the AC switchgear at the HVDC platform. A decentralised platform is expected to be connected to the nearest HVDC platform or to the hydrogen production platform. Concept 2b requires more cable connections and is therefore scored lower on connectivity as compared to concept 2a.

As explained in section 6.1.9.4 full interconnection require circuit breakers or HVDC switching station. Circuit breakers are the only expected possibility for platforms. Decentralised compression adds extra complexity in a already limited area. Therefore, concept 2b is scored lower than concept 2a.

Concept 3 – Compression and HVDC on an artificial island

Concept 3 and Concept 1 are similar in respect of connection to the system. Compressors are co-located next to the HVDC system, and a power supply will be obtained from multiple blocks with minimum cable routing between HVDC and compression platforms.

Overall, concepts 1 and 3 are expected to perform equally as the HVDC equipment is similar. Concept 2a is awarded a lower score as explained in section 6.1.9.4, with concept 2b scoring slightly worse due to the additional cable connections required.

Table 6.76 provides the concepts' scoring with a higher value indicating greater connectivity.

Table 6.76: Evaluation 2 Scoring – Connectivity.

Criteria	Scale	1. Islands (12 GW island) (HVDC + PtG)	3. Island (HVDC + compression)	2a Central compression platform	2b Decentralized compression on platforms within
Connectivity	Higher scores for higher connectivity	8	8	3	2

6.4.6.5 Results Future Proofing

Table 6.77: Overall Scores – Future Proofing

Criteria	Scale	Concept 1	Concept 3	Concept 2a	Concept 2b	Weighting
Modularity & Scalability	Higher scores for higher modularity and scalability	4	5	8	10	**100**
Future expansion capacity	Higher scores for higher future expansion potential	Low	Medium	High	High	**50**
Design Life	Higher scores for longer design life	100	75	50	50	**20**
Connectivity	Higher scores for higher connectivity	8	8	3	2	**80**
Normalised results	**Highest scores is best**	**92**	**99**	**97**	**100**	

7 Hydrogen Production Concepts

If a large offshore island is selected, then all energy hub infrastructure (including hydrogen production equipment), other than the WTGs and array cables to transmit power, will be installed on the island. For other concepts the assumption is that hydrogen production will be located within the individual wind farm blocks and will be separate from compression (see Section 3).

The development of the individual wind blocks is the responsibility of the developers who will choose between hydrogen production local to the WTGs or on separate platforms. This decision will not impact the overall layout of the search areas and therefore does not need to be part of the initial design making from government. Given the technical immaturity of both options it makes sense to delay this decision to see how the sector develops. The drivers for selection between these options may differ between developers. What will be of interest to both individual developers and the government is the lowest cost of hydrogen which will be the best achieved by allowing flexibility in decision making.

Each wind farm block of approximately 2 GW capacity is assumed to produce up to 1 GW of hydrogen (see Section 3). As part of the NSWPH programme, 500 MW hydrogen production platforms designs were developed selecting the largest platforms that could be practically constructed and then installed in line with the approach to TenneT’s standardised 2 GW HVDC platform. This design incorporated compression equipment and therefore it is assumed that more than 500 MW of hydrogen production equipment can be installed on a single platform, but a reasonable approach is to assume that each 2 GW block requires two hydrogen production platforms.

If hydrogen production is local to the WTGs, then the developer will need to make decisions as to how to develop the block. Individual WTGs can be either dedicated to hydrogen production or hybrids including the capacity to also export power directly. The capacity of each WTG will depend on developments in the market and the approach taken by the developer. From the work done in the NSWPH programme the current maximum commercially available WTG capacity is 15 MW but it was considered credible that 20 MW WTGs will be available in time for the schedule roll-out within search areas 6 and 7.

The approach to the parcelling up of search areas 6 and 7 into licensed blocks is to be determined. Based on discussions with stakeholders, two options are to either allocate licenses for 2 GW of wind generation capacity or to allocate similar areas to the developers to incentivise them to maximise wind generation capacity. This can be achieved by increasing WTG capacity and by overplanting where the spread of WTGs is selected to maximise overall generation whilst balancing this against increasing wake losses. Given these drivers, a reasonable assumption is that developers will roll-out overplanted (installed closely enough to result in wake losses but which increases overall wind generation) 20 MW WTGs within search areas 6 and 7. Installing larger 20 MW WTGs can also minimise the impact on ecology and other users.

There are economic benefits in selecting a combination of standard and hybrid WTGs within a block and increasing the hydrogen production capacity per hybrid WTG. From the NSWPH programme 20 MW WTGs in up to 50 m water depth could be installed on monopiles rather than more costly platforms and it is estimated that up to 20 MW of hydrogen production equipment could be installed per WTG. Power from the standard WTGs can be transferred to the hybrid WTGs via array cable strings. This approach would result in approximately 100 WTGs per block of which approximately 50 would be hybrid supporting hydrogen production and 50 standard WTGs (Table 7.1).

Table 7.1: Hydrogen Production Option Comparison.

Concept	No. of WTGs	No. of hydrogen production platforms	Export Architecture
Hydrogen Production local to WTGs	50 Standard WTGs and 50 Hybrid WTGsthis	None	Hydrogen exported to compression via flexible flowlines.
Hydrogen production on platforms	100 Standard WTGs	Two	Power transmitted to hydrogen production platforms via array cables. Hydrogen transferred to compression via flexible flowlines.

7.1.1 Potential Impact of Hydrogen Production Concepts

Irrespective of the hydrogen production concept ultimately selected, both involve significant decentralisation compared to the large island concept (Concept 1) where all hydrogen production equipment is centrally located. For each of the other concepts (Concepts 2a, 2b and 3) either hydrogen production concept could be selected and in both cases pressurised electrolysis would be needed to transport the hydrogen, given compression will be separate. Therefore, when considering between the concepts the hydrogen production concept is not expected to materially affect the decision taken but rather would impact the degree of variation compared to the island concept.

The final phase of the NSWPH programme developed an overall energy hub concept based on hydrogen production local to the WTGs. Each hybrid WTG included 20 MW of hydrogen production capacity; due to the small scale, 5 MW containerised hydrogen production units were selected. It is assumed that for any capacity of hydrogen production local to the WTGs, a scaled containerised solution would be developed. The following hydrogen production equipment would be installed local to the WTGs which already have the capacity for direct power export:

- Electrolyser module (5 MW) including:
  - Electrolyser stacks (pressurised PEM although alkaline alternatives exist)
  - Transformer-rectifiers
  - Demineralisation (RO/EDI)
  - Gas-liquid separators
  - Gas purification (dehydration)
  - Control system.
- Water treatment
  - Seawater pre-treatment
  - Desalination (RO)
- Utilities/Support
  - Bulk chemicals for desalination/ demineralisation/ seawater pre-treatment
  - Nitrogen package
  - Wastewater treatment.

The operating pressure of the electrolyser is assumed as 30 barg – currently electrolyser with operating pressures up to 40 barg are available – to provide sufficient pressure for the hydrogen to be routed via flexible flowlines to the separate hydrogen compression location. The hydrogen must be dehydrated to avoid liquid drop-out in the flowlines. Deoxygenation is not required as PEM electrolysers produce hydrogen which already meets the subsea and onshore pipeline oxygen specifications. If an alkaline electrolyser is used then an electrolyte system would be needed and deoxygenation may be required.

If, alternatively, developers select hydrogen production on platforms, then the same equipment would be required but the overall hydrogen production capacity is assumed to be 1 GW per block, either installed on one or two platforms. Due to the significant increase in capacity the design would likely move from a containerised solution to electrolyser modules of 80 MW capacity, comprised of 10 MW stacks. While 5 MW containerised PEM solutions are readily available, only 2.5 MW PEM stacks are currently available and 10 MW PEM stack availability is highly dependent on the market direction for technology advancement.

The move from a containerised solution to electrolyser modules would also see the balance of plant be centralised within that platform. There will be technology considerations alongside economies of scale benefits – e.g., a certain dehydration technology may be more favourable at scale. An estimated 420-550 m^3/h seawater is needed for 1 GW of electrolyser based on the NSWPH programme, and environmental studies will need to be undertaken to review the impacts of the water consumption and discharge for a centralised solution versus smaller consumption and discharges in different locations throughout the North Sea.

An intricate network of flowlines would be required for hydrogen local to the WTGs, to transport the hydrogen from each WTG to compression, considering flow paths and pressure profiles and maintenance (pigging and dewatering). For centralised hydrogen production, fewer pipelines would be needed to transport the hydrogen and construction and installation would be less complex (while lower cost barges could be used for flowline installation if they are flexible / plastic type, they would still need many tie-ins).

Using power direct from the WTG for local hydrogen production avoids further electrical losses (conversion and transmission) that would be incurred while routing the power from the WTG to a hydrogen production platform. This advantage would be seen during peak loads when all the power generated at the WTG is sent to the local electrolyser. At lower loads the power from standard or neighbouring WTGs could be routed to electrolysers and therefore have similar losses. Another consideration is stack operation, which could be maximised through control of the distribution of the power to the stacks and which could be easier for a centralised location.

Reducing the number of hydrogen production locations will make construction and operations and maintenance easier. For example, within a 2 GW block,

- Less platforms (i.e. 2 centralised platforms vs platforms at 50 WTGs) naturally means less offshore activities for construction and installation, from transport to tie-ins.
- Operators will need to visit 2 platforms rather than 50 WTGs for routine inspection and maintenance activities.
- Chemicals (e.g. for demineralisation) will need to be topped up at 2 platforms rather than 50 WTGs.
- Catalyst replacement (for deoxy reactor) will need to be at 2 platforms rather than 50 locations.
- Waste which cannot be discharged to sea will need to be removed from 2 platforms rather than 50 locations.
- For hydrogen production at the WTGs, the entire WTG would need to be offline for stack replacement, although this would only be small portion of the entire block capacity.

However, availability and reliability would be greater for hydrogen production at the WTGs as, although there are more points of failure, there is less of an impact if only a single WTG platform is down compared with the entire hydrogen production platform.

It was concluded in the NSWPH that retrofitting hydrogen production at the WTGs is not favourable. Therefore, for both options it is assumed that all equipment is installed on the platform prior to float-out to sea. Electrolysis at a WTG requires only 40 MW (maximum) of electrolysis for jacketed substructures and 20 MW (maximum) for monopiles to be installed prior to float-out. Whereas a platform could have at least 500 MW installed. This could impact project timelines and supply chain risks depending on competing projects and whether bulk fabrication of the modules is ready for offshore installation in line with the project schedule.

The greatest benefits identified for hydrogen production local to the WTG are in terms of flexibility to maximise total energy export. The placement of hydrogen production equipment local to each WTG gives complete flexibility to direct power as desired (either for hydrogen production or as electrical power export via HVDC platform) limited by only the capacity of the downstream infrastructure to bring power or hydrogen ashore. This flexibility also allows for power to be imported from shore to generate hydrogen. Therefore, the scoring given to Concepts 2a, 2b and 3 for security of supply is affected by selection between hydrogen production local to the WTGs and on platforms.

This arrangement also increases fault resilience as the loss of any individual WTG or array capable is likely to have limited overall impact (loss of separate hydrogen production will still prevent hydrogen export). Hydrogen production local to the WTGs requires space optimisation which would need to be achieved through selection of rectifying technology. Two potential technologies can be used for the rectifiers; thyristor based and IGBT based. The IGBT based rectifiers as part of containerised hydrogen production units were preferred solution to be used on hybrid WTGs due to its advantages compared to the thyristor-based solution. Consequently, this could impact supply chain options as solely one technology will be used.

Impact of hydrogen turbines on total carbon footprint

Furthermore, the carbon footprint of a wind farm with hydrogen production local to the WTGs was assessed. From previous work on the NSWPH it is known that a platform supporting 7.5 MW of electrolyser capacity adds around 438 tonnes of construction steel. For a platform supporting 20 MW of electrolyser capacity a total of 580 tonnes of steel is added. A fourth concept was added to the first life cycle assessment of the island vs. hybrid vs platform, where all of the WTGs support 7.5 MW of PtG.

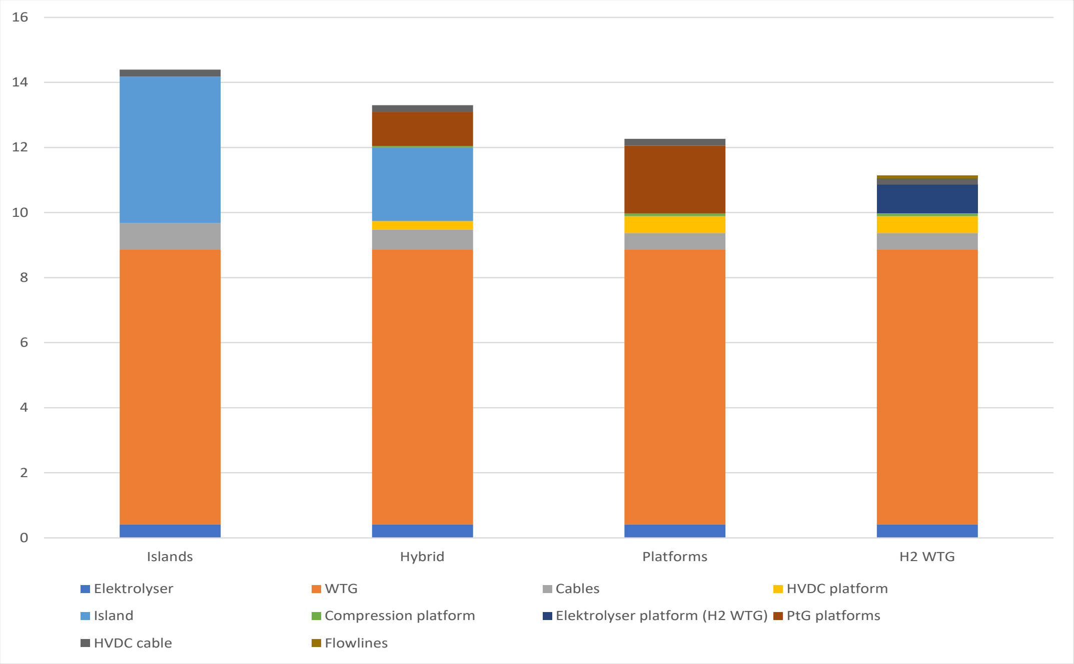
As additional transport of hydrogen now has to take place, additional infrastructure is required. From the NSWPH programme’s developed flowline architectures it is known that a 4 GW wind farm with 15 MW WTGs supporting 7.5 MW of PtG has a total of 356 km of 5” flowlines. Therefore, a total of 2,136 km of 5” flowlines was added to the calculations. In Table 7.2 the total materials for 1 km of flowline is presented.

Table 7.2: Flexible Flowline materials per km.

Material	Amount	Unit
PE	16.80	tonne/km
EGF	1.69	tonne/km
Magnetite	28.39	tonne/km
Steel	15.37	tonne/km
PP	0.57	tonne/km

The results of the calculations are presented in Figure 7.1. As can be seen, the carbon footprint of the hydrogen turbine concept is significantly lower than the other concepts. This is explained by the fact that the foundations for the wind turbines at 50 m water depth already require a significant quantity of steel. The additional steel requirement to support the process equipment on the WTGs is relatively low. Carbon footprints for a concept with 20 MW WTGs and 20 MW PtG platforms are expected to be even lower. Lastly, it should be noted that this analysis doesn't include BoP, which is expected to be relatively more for hydrogen turbines.

Figure 7.1: Life Cycle Assessment including PtG local to the WTG at a 50:50 split for 15 MW WTGs.



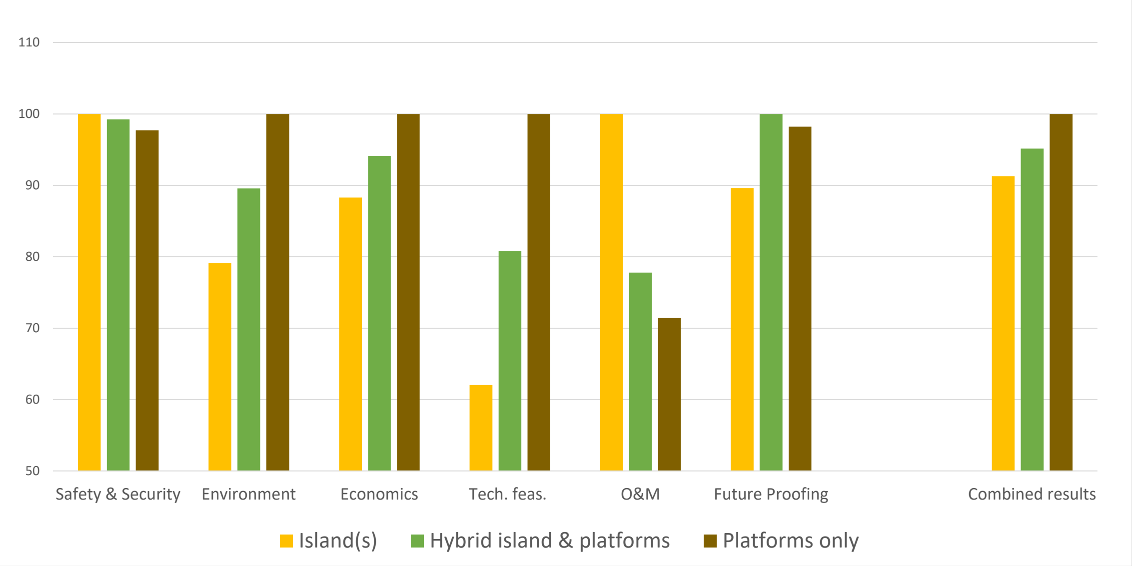
8 Results of Evaluation

8.1 Evaluation 1 – Islands vs Platforms vs Hybrid Configuration

Due to the large number of considerations, with many conflicting advantages and disadvantages a systematic approach was adopted to rank the options being compared and aggregate the cumulative contributions to support the selection of a preferred option.

Figure 8.1 presents the results of the rankings for the first evaluation indicating that platforms are the preferred solution followed by a hybrid solution and then an island solution. Although the scoring convention described in Section 5.4.1 and used in Section 6 is based on the highest scores being least desirable (e.g. high cost, high risk, high complexity) the results were transformed into a "highest score is best" basis for ease of visualisation and interpretation. Furthermore, the data has also been normalised to 100 to standardise the visualisation of relative differences. The way in which the scoring and the data transformations was done is described in the sample calculation presented in Appendix A.

Figure 8.1: Evaluation 1 normalised results per criteria (Highest score is best)



A summary of all the ranking data in matrix format is presented in Appendix A for both evaluations.

8.1.1 Weightings

All level 1 criteria were designated an equal contribution to the ranking evaluation. The weightings for second level criteria were moderated according to our multi-disciplinary team's opinion of the relative impact and importance of the decision-making process. The summary of weightings and justifications for the level 2 criteria is presented in Table 8.1.

Table 8.1: Summary of Level 2 weightings and justifications

Safety and Security

Safety (construction)	100	Safety during construction and installation is weighted at the maximum score of 100 due to the known concerns and uncertainties associated with offshore island construction in water depths of 50m. The scale of the development and the number of platforms and resulting SIMOPs also increases the risks
Safety (O&M)	80	Safety during operation is also a key concern and is weighted 80 out of 100. Its weighting is lowered as operation of platforms is a known concept and once constructed operation on the island is similar to operations onshore except for transfer to and from the island.
Security	30	Security is weighted at only 30 due to the limited risk of intruders at this distance from shore.
Environment		
Life cycle assessment (Climate change)	100	As the impact of climate change is very significant and noticeable all around the world, climate change is weighted 100 out of 100.
Ecology (Quickscan) 'construction impact	0	The ecology impact during construction is expected to have a significant impact on the local ecosystems and should therefore be rated as 100 out of 100. Since the results of the quick scan are yet to be received, it was chosen to put ecology on hold, so results can be added or adjusted at a later stage.
Ecology O&M impact (waste management /pollution)	20	The ecology impact due to operation processes is expected to have a low impact on ecosystems since toxicity of the pollutants is low. Most chemicals that are worked with are abundant in nature and consist mainly of brine, water, H_2 and O_2. Furthermore, there are available mitigation measures that can be set in place. Therefore, the weighting for pollution is advised to be 20 out of 100.
Economics		
CapEx	80	Capex estimates are based on a level of detail that is not highly defined (concept development stage) corresponding to a Class 4/5 AACE estimate with an uncertainty level of plus or minus 50 per cent. The team felt that although cost estimates are important they are less important than the impact of the need for significant pre-investment that will place a fiscal burden on government.
OpEx	80	Similar to Capex, Opex estimates are based on a conceptual level of development with a relatively high degree of uncertainty in the estimate accuracy. Ocer the investment horizon the impact of Opex is considered to be similar in importance to Capex, but slightly less than the impact of pre-investment.
Need for pre-investment	100	Based on feedback from some of the stakeholders and our insights gained from the experience of the Danish Island initiative, the impact of pre-investment was given a full weighting of 100.
Technical Feasibility & Realisation		
Development time to operations	100	To meet the government's plans for the development of offshore wind generation the development time to operations is key and is weighted 100. Ensuring that both HVDC and hydrogen production capacity is ready as early as possible allows for the optimal balance between power and hydrogen export for a grid-integrated solution
Constructability & installation	80	Construction and Installation is weighted 80 as it is believed achievable for all concepts albeit that island construction in 50m water depth is novel.

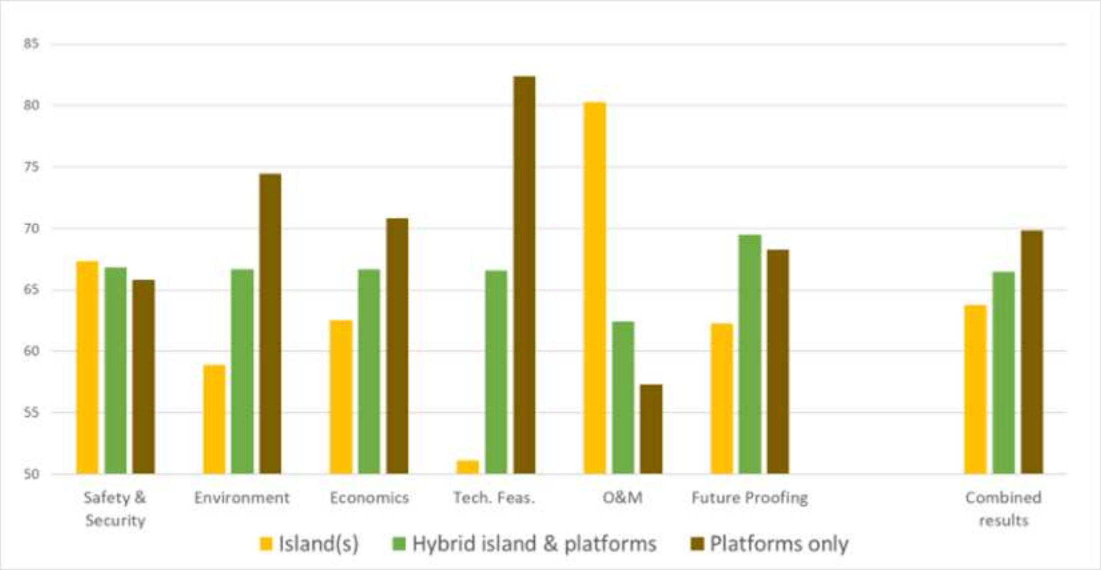
Supply chain complexity	100	Supply chain complexity is weighted 100 due to the known concerns in the availability of materials for island construction and the massive expansion of hydrogen equipment capacity required.
Permitting complexity	50	Permitting complexity is weighted 50 as this constraint can be managed by government.
Technology curve (readiness /TRL)	80	Equipment TRL is weighted 80 to acknowledge concerns in the readiness of hydrogen production equipment and the concept infrastructure.
Water depth	60	Concerns on constructability in the water depth is weighted 60 as it considered feasible to construct both platforms and islands in 50m.
System integration	60	System integration is weighted 60 as although it will be potentially complex this can be mitigated through effective project management.
Operations and maintenance		
Operability	100	Operations and maintenance are key criteria to ensure that the energy hub can deliver on its requirement to meet as much of the onshore base load demand for renewable electricity and green hydrogen as possible and therefore operations and maintenance complexity are both weighted 100.
Maintainability	100	
Availability & Reliability	100	Availability/ Reliability is similarly weighted 100
Security (of supply)	50	Security of supply and the flexibility to maximise energy output and revenues is considered an upside to each concept and is weighted 50
Future Proofing		
Modularity & Scalability	100	Modularity and scalability is key to the energy hub as so many factors are not yet known. Selecting a concept that allows for the design to be updated as the context and requirements become clear is a big advantage which de-risks the whole development and therefore is weighted 100
Future expansion capacity	50	Future expansion capacity is weighted 50 as it is considered a potential upside rather than key to energy hub design
Design life / longevity/robustness	20	Similarly, the design life is weighted 20 as the initial project phase is within the design life of all concepts
Connectivity (other hubs and internationally)	80	Connectivity is weighted 80 as it is essential that the concept selection does not prevent inter-hub and international connectivity

8.1.2 Weighting Sensitivity Analysis

Figure 8.2 indicates that some criteria, when considered in isolation, have the potential to change the rankings of the preferred options (for example the operations and maintenance considerations). A sensitivity analysis has been performed by evaluating each criterion's individual impact on the rankings while the contribution of all the other criteria is incrementally increased (from zero and 100). This demonstrates the increasing impact and contribution of the other criteria as they become progressively more important in the decision-making progress, up to the point where they carry the same weight as the focus criterion.

The sensitivity analysis is performed on the data presented in Figure 8.2, which has not been normailised to 100.

Figure 8.2: Non-normalised ranking results for Evaluation 1



The sensitivity starts with the relative ranking results for a single criterion (an example is presented in Figure 8.3 using the Environmental criterion). As the weight of the other criteria are systematically increased from zero to 100, the ranking results get progressively closer to the combined ranking results as presented in Table 8.2: Example of a sensitivity analysis.

Figure 8.3: Sensitivity analysis illustration for environmental criteria

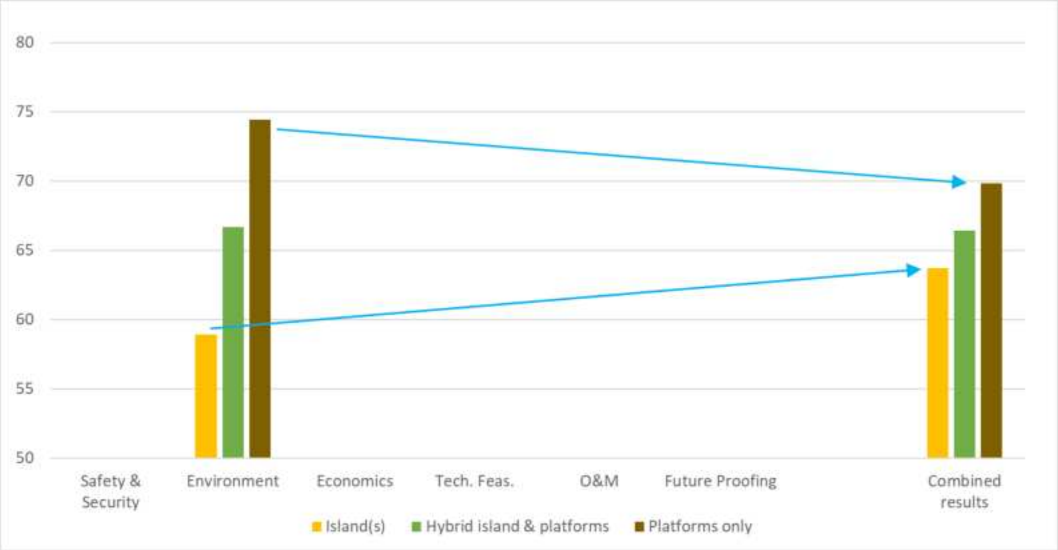
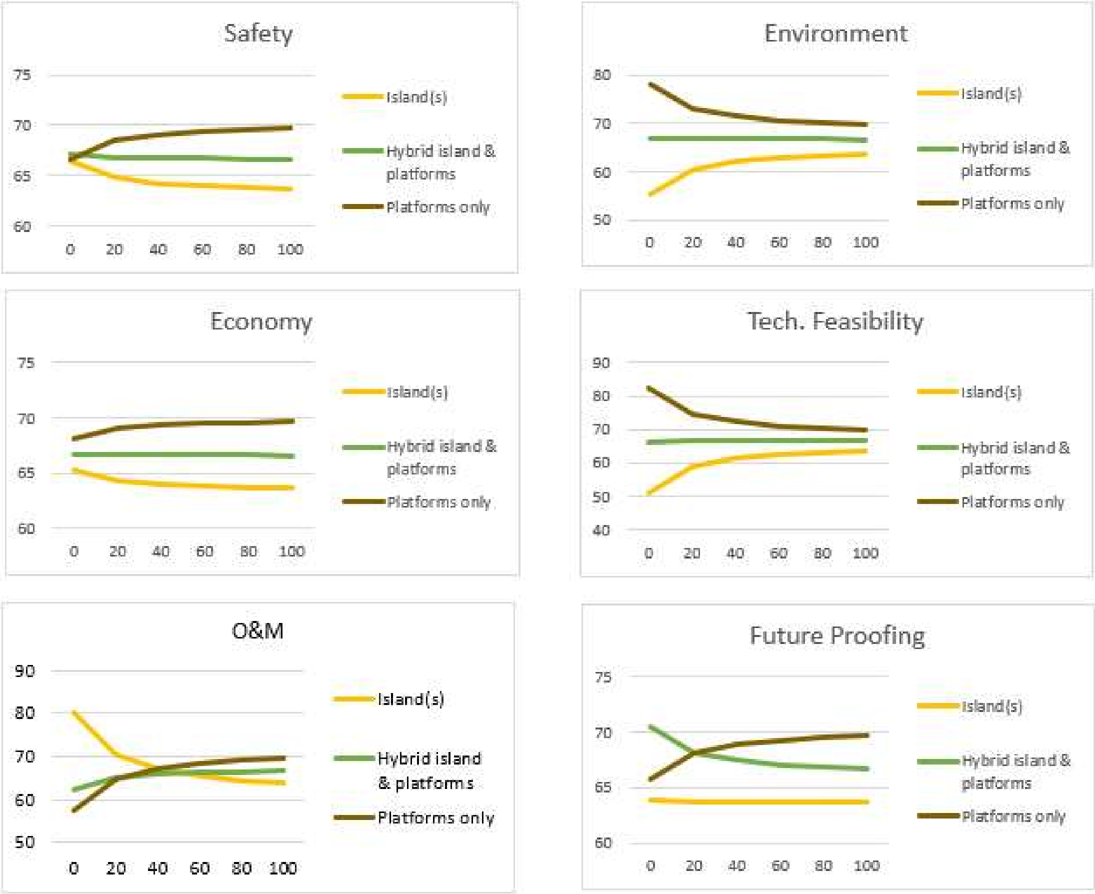


Table 8.2: Example of a sensitivity analysis

Environment weight	100	100	100	100	100	100
Other criteria weights combined	0	20	40	60	80	100
Island(s)	55	60	62	63	63	64
Hybrid island & platforms	67	67	67	67	67	67
Platforms only	78	73	71	71	70	70

This sensitivity analysis methodology has been applied to each of the criteria and the trends have been graphically represented in Figure 8.4.

Figure 8.4: Sensitivity analysis of criteria weightings for Evaluation 1



Each of these graphics represents the relative ranking of the options being evaluated on the y-axis, with the highest scores being most preferable according to the scoring convention we have used for presenting results visually. Options that lie at the top of the plot with high values are the most preferred options. The x-axis scale represents the contribution of all the other criteria combined that gradually contribute more weight to the decision-making process progressing from zero contribution on the left to 100 per cent on the right. The graphic essentially reflects how the relative rankings change as the decision-making process migrates from a single-criterion evaluation (on the left, zero contribution of all the other criteria) to a multi-criteria evaluation with all criteria having the same weight in the end (on the right-hand side at 100).

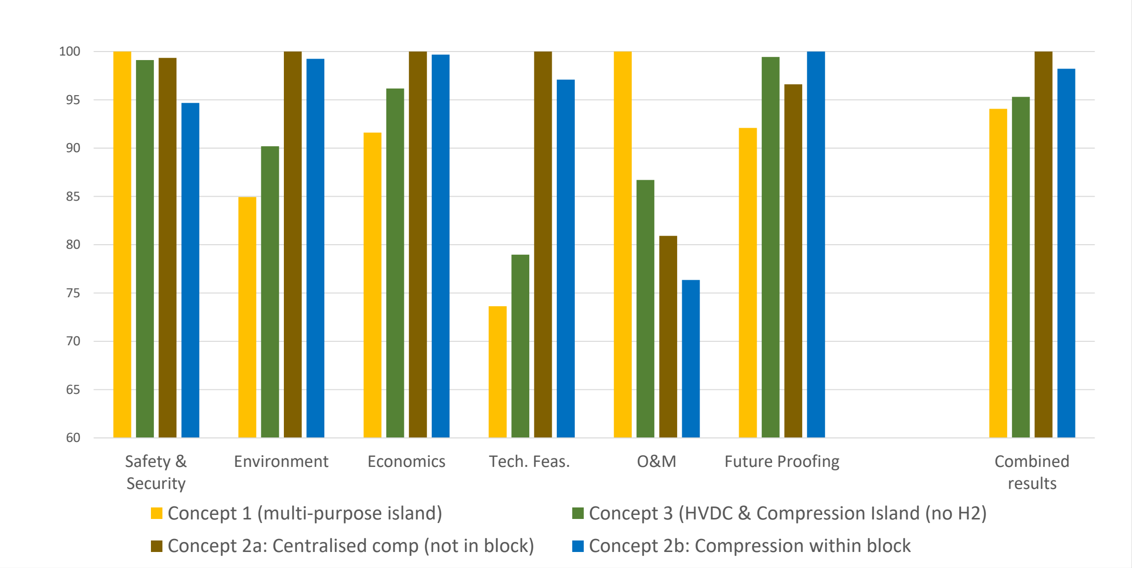
With the exception of operations and maintenance, and future proofing, changes in the relative weightings do not appear to have a significant impact on the ranking results. This indicates that the ranking results are largely insensitive to safety, environment, economics, and technical feasibility considerations. When considering future proofing requirements there is a weak impact at very low contribution levels where hybrid solutions are ranking slightly ahead of platforms. The most significant impact is reflected by the significance of the contribution made by operations and maintenance considerations, in which island solutions are strongly preferred up to the point where the other criteria are considered to be about half as important to the decision-making process, at which point platforms start to dominate the ranking preference.

Our overall interpretation of the sensitivity analysis is that platforms appear to be a robust choice as the highest ranking and preferred option regardless of how much the weightings are adjusted unless individual criteria (specifically O&M and Future Proofing) are considered almost exclusively in isolation.

8.2 Evaluation 2 – Concept Comparison

Figure 8.5 presents the results of the rankings for the second evaluation indicating that a platform solution with compression centralised to one location within the proposed search area (Concept 2a) is the preferred solution followed by the platform option with decentralised compression (Concept 2b), followed by Concept 3 (a hybrid design) and then finally Concept 1 (an island-based design).

Figure 8.5: Evaluation 2 normalised results per criteria (Highest score is best)



A summary of all the ranking data in matrix format is presented in Aappendix A for both evaluations.

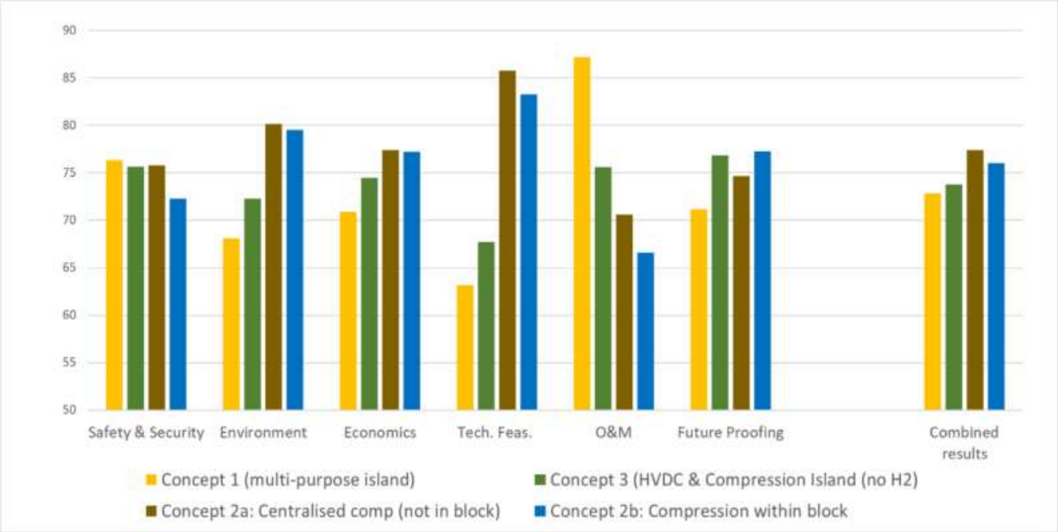
8.2.1 Weightings

The same weightings have been used in the level 2 criteria evaluations for the same reasons as those selected for the first evaluation decision.

8.2.2 Weighting Sensitivity Analysis

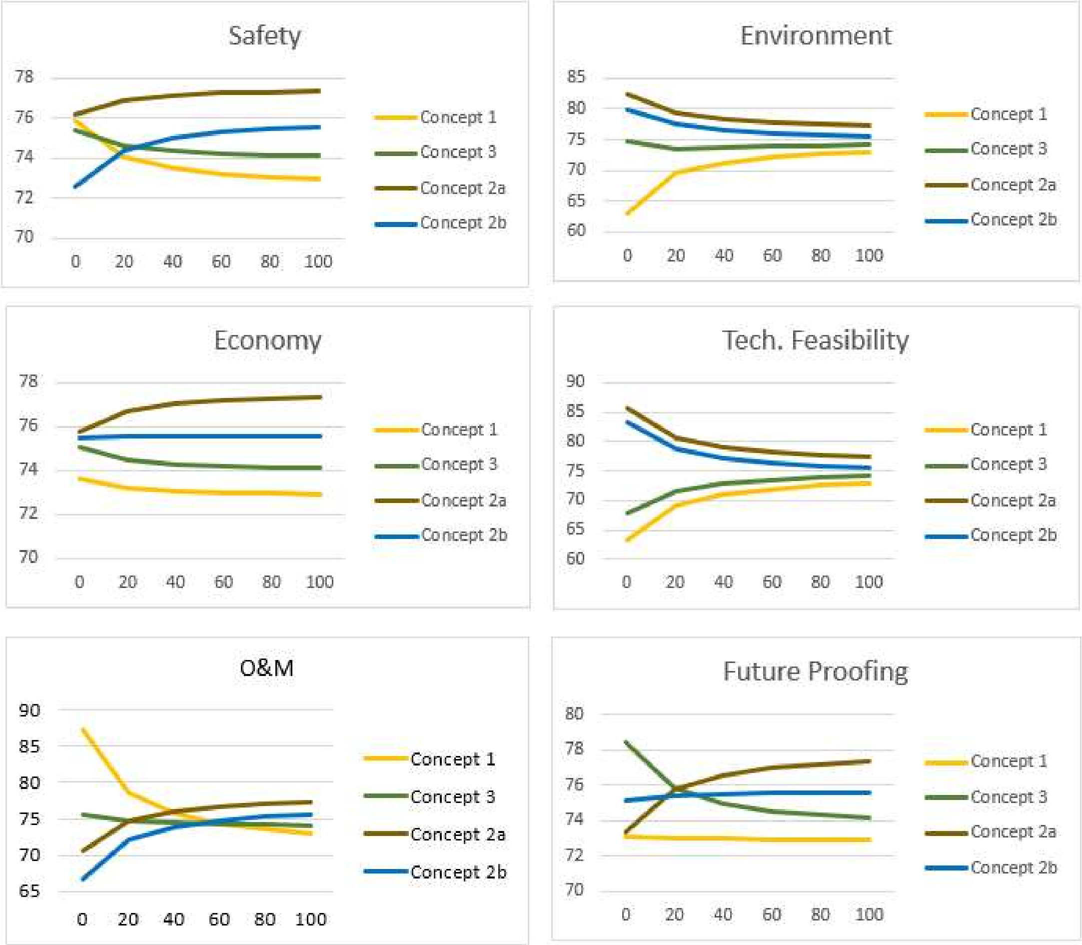
Figure 8.6 indicates that most of the criteria appear to indicate that the platform solutions, and specifically Concept 2a is the preferred choice. When considered in isolation, operations and maintenance considerations indicate that the multi-purpose island is the preferred choice. The same type of sensitivity analysis described before in Section 8.1.2 has been performed to test the impact of changing the weights of the level 1 criteria for Evaluation 2. The analysis is based on the data presented in non-normalised format as presented in Figure 8.6.

Figure 8.6: Non-normalised ranking results for Evaluation 2



This sensitivity analysis results are represented as trends in Figure 8.7.

Figure 8.7: Sensitivity analysis of criteria weightings for Evaluation 2



With the exception of operations and maintenance, and to a small degree future proofing, changes in the relative Level 1 weightings do not appear to have a significant impact on the ranking results.

This indicates that the ranking results are largely insensitive to safety, environment, economics and technical feasibility considerations. When considering future proofing requirements there is a weak impact at very low contribution levels where Concept 3 (the hybrid design) and 2b (the platform-based design with centralised compression) switch places in the rankings, but we note that the difference isn't significant and are of the opinion that future proofing doesn't dominate the decision-making process in any significant way. The most significant impact is reflected by the contribution made by operations and maintenance considerations, in which Concept 1 (an island design) initially dominates the ranking preference. This ranking changes in favour of the two platform-based concepts (specifically Concept 2a, the platform based design with centralised compression) when the other criteria start contributing more than a third of the weight allocated to the O&M criterion.

Our overall interpretation of the sensitivity analysis is that the two platform-based concepts appear to be a robust choice as the highest ranking and preferred options regardless of how much the weightings are adjusted unless individual criteria (specifically O&M and Future Proofing) are considered almost exclusively in isolation. Furthermore, Concept 2a (platforms with centralised compression) consistently outperforming Concept 2b (platforms with decentralised compression) by a small margin.

8.3 Scenarios

Several assumptions have been made about the rate of development in search areas 6 and 7, the demand for electricity and hydrogen, the ratio of production between these two, the availability of materials and resources in supply chains and the potential limits to production and construction capacity. It's practically impossible to perform a multi-criteria analysis on all the potential permutations of assumptions that have been made. This creates some degree of uncertainty in the decision-making process. The best way to deal with uncertainty is to consider how the decision-making process, the evaluations and the results might change under different scenarios. The cornerstone of a scenarios analysis is to identify the most important uncertainties and to consider how these may change from one scenario to the next. In our discussion with multiple stakeholders and our involvement in many studies over the past few years that have been focused on onshore and offshore hydrogen production in combination with wind electricity generation, we have ascertained that the key uncertainties are related to:

- Hydrogen demand growth over time and a change in the ratio of hydrogen to electricity production
- Potential challenges associated with technology scale-up
- The evolution of system solutions as learning is applied to new development phases

In all of these cases the value of adaptability and flexibility is essential.

In our evaluation criteria we considered several different values associated with future-proofing. We initially included a level 2 sub-category of adaptability and flexibility but discovered that the characteristics associated with scalability and modularity included the same principles and ideas for evaluation. For this reason, we considered scalability and modularity to include the attributes of flexibility and adaptability.

In a scenario in which there is a high degree of uncertainty about the timing, phasing, and evolution of solutions for the North Sea we would consider the requirement for adaptability and flexibility to outrank all other considerations in terms of relative importance. Looking at the ranking on options considered when evaluating modularity and scalability we ranked the platform-based solutions much higher than any of the island-containing solutions. Given that this ranking is consistent with the ranking results taking all the other criteria into account, we felt that it wasn't necessary to perform a separate formal scenario analysis. We are of the opinion that platforms represent the most robust and flexible choice as a construction form in the North Sea.

9 Conclusions & Next Steps

9.1 Conclusions

Concept definition for the energy hub in search areas 6 and 7 considers selection of the supporting infrastructure and other key decisions impacting on spatial development. The energy hub can be supported by platforms or artificial islands or a combination of the two and further decisions are required to select whether hydrogen compression should be located centrally or within the individual wind farm blocks, as well as whether centrally located compression should be installed on an island instead of platforms.

These factors lead to selection between the following infrastructure options:

- Large islands supporting the whole energy hub including hydrogen production.
- Platforms supporting HVDC equipment, hydrogen production and hydrogen compression.
- A combination of a large island and platforms, with initial expansion on platforms and later infrastructure including hydrogen production installed on the island.

The analysis carefully considered whether there are any hard constraints to the selection of either islands or platforms with a focus on the known challenges of large island construction in water depths up to 50m. The conclusion was that both islands and platforms are viable concepts and that their relative merits need to be assessed to determine the optimal concept. This decision does not depend on whether hydrogen production is on platforms or local to the WTGs which is a decision that can be left for later as it does not affect the overall layout of the energy hub within areas 6 and 7.

In evaluation the concepts the following criteria are considered:

- Safety & Security
- Environment
- Economics
- Realisation & technical feasibility
- Operability, maintainability, and flexibility in energy export
- Future proofing

Safety & Security

Whilst the construction and operation of either islands or platforms is considered feasible a key concern was safety during construction particularly for islands. The large islands need to be constructed during summer weather windows placing large numbers of construction personnel into a challenging offshore environment for prolonged periods over several years. Platform construction and installation is less challenging as platforms including their topsides equipment can be constructed in onshore fabrication yards and then transported offshore to be lifted onto their pre-installed substructures limiting offshore operations. This ensures the period of platform installation is much more limited than island construction reducing the time personnel must be in the hostile offshore environment.

Safety during operations was considered manageable for both concepts; there is extensive experience of operation of offshore platforms in the oil and gas industry and operations on an island would be similar to onshore once constructed. However, due to the larger size of islands which allow design decisions to be driven more by safety considerations and less by space constraints and as the islands are permanently manned with operators only leaving the safe areas close to accommodation to carry out essential activities safety risks during operation are considered higher for platforms than for islands. No significant security issues are identified for either concept due to their locations over a 100km offshore. Balancing the safety risks during construction with those during operations, overall island concepts would be slightly favoured for safety and security with the hybrid combination in between them.

Environment

The environmental ranking was based on an assessment of the Life Cycle Analysis (LCA) of embedded carbon in the construction materials and consideration of the potential operational and maintenance impact on local ecology. The LCA results indicated that the construction of an island has a significantly higher CO_2 footprint than the platform concept. This is mainly driven by the large quantities of sand and rock that are required for the island.

Furthermore, the ecological impact is expected to be higher for the island concept for both the construction and operational phases. The impact from construction is driven by the high impact from sand dredging and the higher subsurface area and habitat changes. As this is currently being investigated by IenW in a quickscan, the impact of construction on ecology was not considered in the overall scoring. Lastly, the ecological impact of operations is expected to be higher for the island concepts due to more concentrated disposal of waste streams. The impact of the waste streams is not expected to be very significant due to the nature of their composition (mainly brine), furthermore the impact can be easily mitigated.

From an environmental point of view, due to the impact on both GHG emissions and the local ecology of island construction, platforms are significantly favoured compared to islands with the hybrid concept in between them.

Economics

Cost estimates are developed for each of the concepts based on assumed configurations developed through the understanding gained in the NSWPH programme. These costs indicated little difference between the overall CAPEX and OPEX for the concepts with a relatively high degree of uncertainty in the accuracy of the estimates (+/- 50 per cent) due to limits in the level of detailed engineering available at this conceptual stage of development. The island-based concept has the lowest CAPEX and OPEX followed by the hybrid concept then the platform-based concept. It should be noted that similar analysis by Gasunie produced the opposite result again within the level of accuracy of the estimate highlighting that cost is not a clear driver for selection between the concepts.

Island based concepts require more significant pre-investment than platform-based concepts which was a factor in the rejection of the Danish Energy Island. The hybrid concept ranked between islands and platforms.

Realisation & Technical Feasibility

The conclusion of the analysis suggests that selecting only islands would make it very challenging to meet the target date for initial roll-out of direct power export and hydrogen production by 2032. The idealised schedule for island construction which considers no technical or other constraints to development achieves island-based first power export and hydrogen production in 2034 but given the novelty of island construction in the 50m water depths in areas 6 and 7 there is significant risk of this schedule slipping.

In addition to the concerns around the longer timeline for island construction there are greater concerns about the constructability of islands than platforms in 50m water depth. Platforms operate widely in the North Sea with several options for substructure design including GBS, jackets and monopiles proven in these depths. Island construction of the size required by any of the energy hub concepts has never been done at this depth. Our assessment is that construction is possible based on analysis of island design in shallower water depths. Caisson islands can be installed up to approximately 20m water depth; for deeper water the seabed needs to be build up using quarry run (large boulders) to a depth below the impact of wave action (around 30m). Below this the seabed can be built up using locally dredged sand. Island construction will need very large quantities of quarry run (and dredged sand) potentially requiring a new European quarry to be opened and the locally dredged sand and wide seabed footprint of the island widens the ecological impact.

The readiness of equipment to be installed on either the islands or platforms are similar with significant developments required to realise large scale offshore hydrogen production. Integrating the multiple parties involved in energy hub development may be more complex if all infrastructure is installed centrally on islands, making islands less attaractive.

Overall both island and platform concepts can be realised and are technically feasible but significantly greater challenges exist for islands particularly during construction.

Operability, Maintainability, and Flexibility in Energy Export

As islands are assumed to be permanently manned and have warehouse space for tools spares, and workshop space, they are considered less complex in terms of operability and maintainability in comparison to platforms that are expected to be unmanned and not to have sufficient space for any of these services. Operation of platforms are further complicated by personnel unfamiliarity with differing platform designs and by space constraints. For the hybrid configuration the combination of both platforms and an island is considered to further complicate operations.

Flexibility in energy export is considered to be good for both islands and platforms. For island concepts the co-location of HVDC and hydrogen production equipment on the island allows power to be directed as required between them. This can also be achieved for platform based concepts as hydrogen production local to the WTGs or on local platforms allows for power to be directed via array cables either to direct power export or hydrogen production.

Overall, the island-based concepts are considered to have significant advantages over platform based concepts for operability, maintainability and flexibility in energy export.

Future Proofing

The development of search areas 6 and 7 is uncertain with multiple factors which could impact the energy hub design including:

- Overall wind generation capacity.
- Ratio of power export to hydrogen production influenced.
- Spatial development of search areas 6 and 7.

Given these uncertainties the ability of a concept to adapt to changing conditions is key. Once the island has been designed then its area is fixed and whilst there is flexibility to alter the infrastructure constructed on it, its location and size cannot be changed. Platform concepts are inherently more flexible with modular designs developed that can be rolled-out in line with the project requirements and schedule and adapted to changing hub design over time both in terms of concept and location. Overall platforms-based concepts are considered significantly more adaptable than island based concepts. When considering all factors influencing future proofing the hybrid concept is slightly favoured over the platform-based concept.

Combined Results

When all criteria are considered together platform-based concepts are slightly favoured over island-based concepts with the hybrid concept in between them.

Compression

Once the infrastructure supporting the energy hub has been selected consideration should be given to the selection between centralised and decentralised compression and whether centralised compression should be on an island.

The evaluation has shown that preference lies with one of the two platform concepts (2a and 2b). Overall, the analysis favoured centralized compression over decentralized compression, but the differences are limited. This preference is mainly due to the advantages in ease of use, scalability, schedule and environmental impact. Chapters 6 and 8 provide a full explanation of the differences between centralized and decentralized compression concepts.

The choice of an island for centralized compression would probably only be made if there are technical limitations in the installation of compressors on platforms. The main concern is the impact of compressor vibration on platforms. The work of the NSWPH program suggests that these risks can be mitigated, but further research is needed to confirm feasibility. A compression island that would also support HVDC equipment is about two-thirds the size of the 12 GW islands that support hydrogen production. Given the challenges of island building, several smaller compression platforms could be chosen as an alternative.

Overall, taking into account all criteria, platform-based concepts are preferred over the other concepts, followed by centralized compression island, decentralized compression and the compression and HVDC island concept and lastly the large island concept.

9.2 Next Steps

The most important aspect of the initial decision that needs more insight, is the choice between platforms and islands for centralized compression. Although this report is partly a comparative evaluation, there are also technical factors that can determine the choice of an island, mainly the impact of compressor vibrations on platforms. This has been studied as part of the NSWPH programme, with potential measures identified. However, complete assurance that a compression platform design can be practically developed can only be obtained by further developing the platform design and conducting a pulsation and vibration study according to API 618, as well as a dynamic analysis of the skid attachment to the deck structure.

The results of the ecological Quickscan study and the sabotage risk assessment for the energy hub should be further evaluated.

9.3 Summary and Recommendation

The Government is the one that needs to decide of the energy hub construction form. This report intends to provide background information and analysis to support the decision-making process. In general, based on the assessment of workstream 3, platform-based concepts are slightly preferred over islands, mainly due to the greater risks involved in island construction, the greater need for pre-investments to realize island construction and due to the greater adaptability of platform-based concepts.

The longer development time of islands compared to platforms may cause too many restrictions on the island-only concept. Since the initial construction of the hybrid concept will take place on platforms, the timeline for island construction is longer. Even when taking the ideal assumption of island construction planning, the first energy exports and hydrogen production will not occur until 2034. Given the risks inherent in island construction, there is a real risk that this timescale will not be met, meaning that even for a hybrid concept, an island would not be ready when needed. The concept with the least risks is the platform concept.

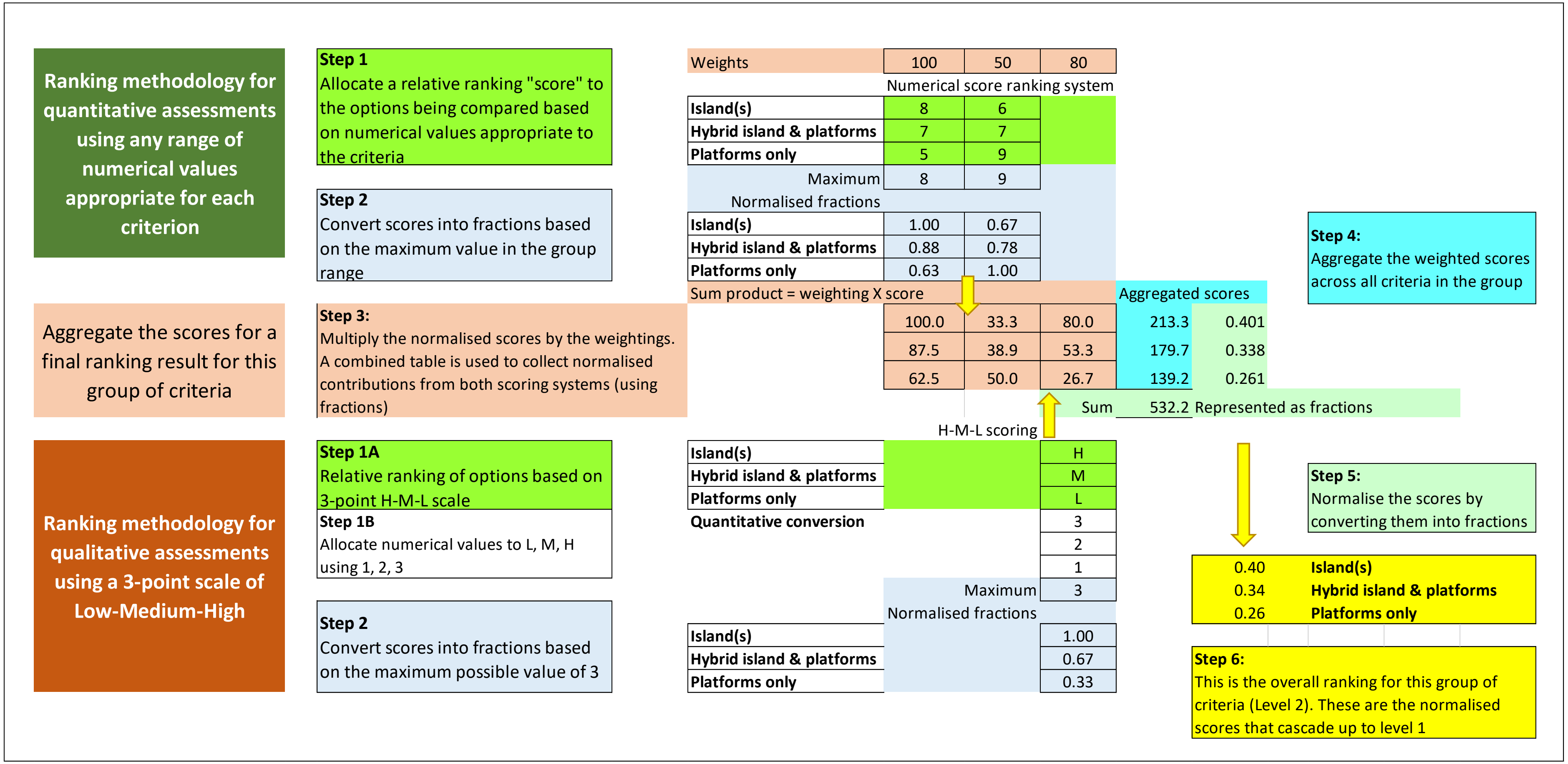
In general, based on the assessment of workstream 3, energy hubs on platform concepts are preferred over islands, largely due to the greater risks in the lead time of developing an island in relation to target, the greater need for pre-investments to realize the construction of islands. While based on our study energy hubs on platform has greater adaptability and lower environmental impact. Furthermore, a comparison was made of decentralized and central compression. Of all the concepts that have been evaluated, preference is given to concept 2a: an energy hub on platforms with central compression.

Within the (electrolysis) platform concepts there is a choice between standardized electrolysis platforms and hydrogen turbines. The choice between these two concepts can be made in consultation between the developer and the government and is not a choice that needs to be made at this time. It is expected that part of the electrolysis in area 6/7 will take place on standardized platforms and part on hydrogen turbines. The development of hydrogen turbines to a high TRL will be taken up by market parties, in contrast to the standardized electrolysis platforms. The advice is therefore to stimulate the development of these standardized electrolysis platforms from the government, separately from Demo 2.

Due to the time required to develop either concept, the government is recommended to make a decision on the energy hub construction form and compression location in 2024. This is essential for the development of areas 6 and 7 and achieving the 2032 targets.

A. Score Ranking Summaries and Sample Calculations

Figure A.1: Score ranking summaries and sample calculations.



Ranking methodology for quantitative assessments using any range of numerical values appropriate for each criterion

Step 1
Allocate a relative ranking "score" to the options being compared based on numerical values appropriate to the criteria

Step 2
Convert scores into fractions based on the maximum value in the group range

Weights	100	50	80
	Numerical score ranking system		
Island(s)	8	6	
Hybrid island & platforms	7	7	
Platforms only	5	9	
Maximum	8	9	
Normalised fractions			
Island(s)	1.00	0.67	
Hybrid island & platforms	0.88	0.78	
Platforms only	0.63	1.00	

Aggregate the scores for a final ranking result for this group of criteria

Step 3:
Multiply the normalised scores by the weightings. A combined table is used to collect normalised contributions from both scoring systems (using fractions)

Sum product = weighting X score

			Aggregated scores	
100.0	33.3	80.0	213.3	0.401
87.5	38.9	53.3	179.7	0.338
62.5	50.0	26.7	139.2	0.261
		Sum	532.2	Represented as fractions

Step 4:
Aggregate the weighted scores across all criteria in the group

Ranking methodology for qualitative assessments using a 3-point scale of Low-Medium-High

Step 1A
Relative ranking of options based on 3-point H-M-L scale

Step 1B
Allocate numerical values to L, M, H using 1, 2, 3

Step 2
Convert scores into fractions based on the maximum possible value of 3

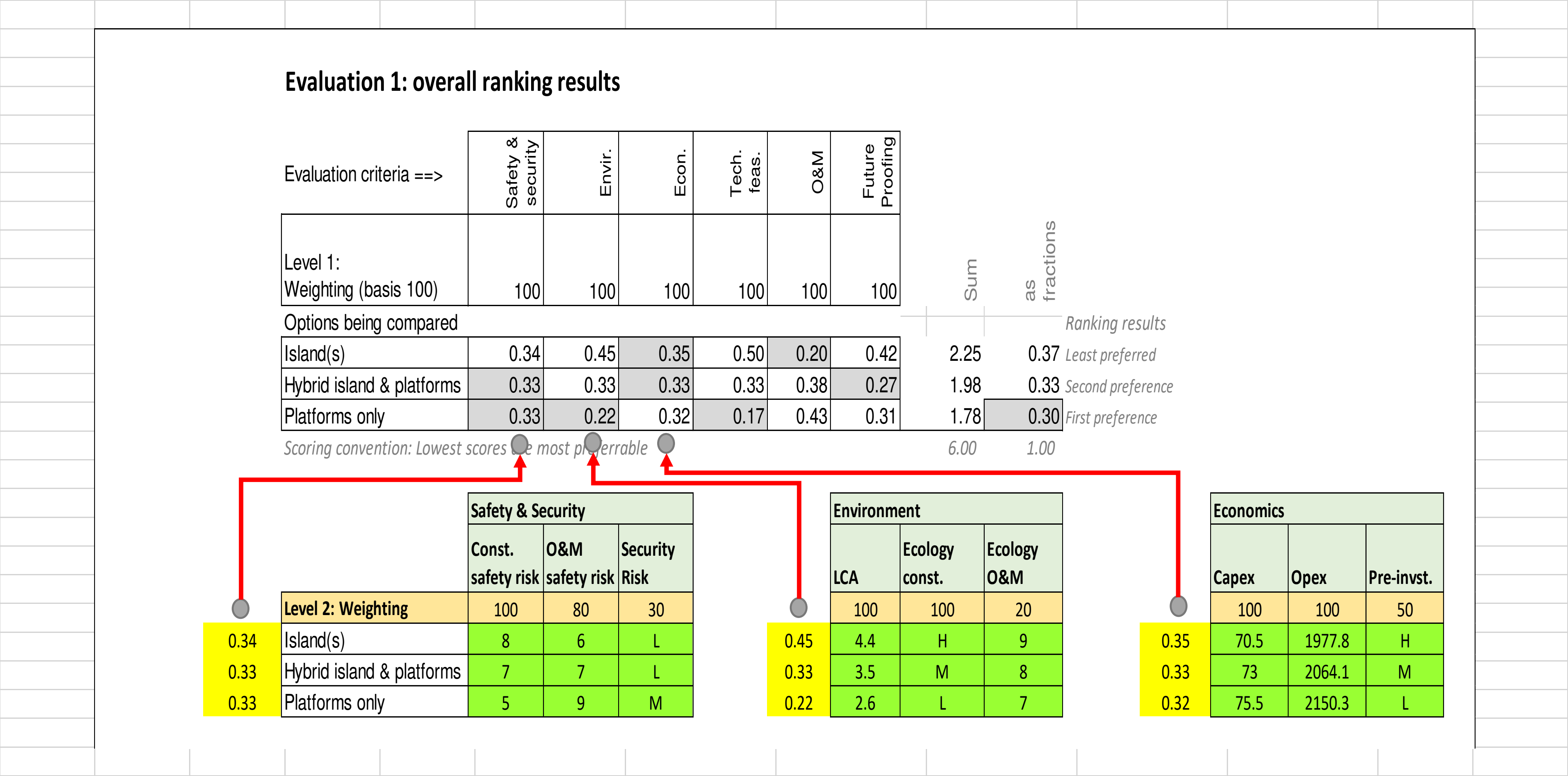
	H-M-L scoring
Island(s)	H
Hybrid island & platforms	M
Platforms only	L
Quantitative conversion	3
	2
	1
Maximum	3
Normalised fractions	
Island(s)	1.00
Hybrid island & platforms	0.67
Platforms only	0.33

Step 5:
Normalise the scores by converting them into fractions

0.40	**Island(s)**
0.34	**Hybrid island & platforms**
0.26	**Platforms only**

Step 6:
This is the overall ranking for this group of criteria (Level 2). These are the normalised scores that cascade up to level 1

Figure A.2: Score cascading from level 2 criteria up to level 1.



Evaluation 1: overall ranking results

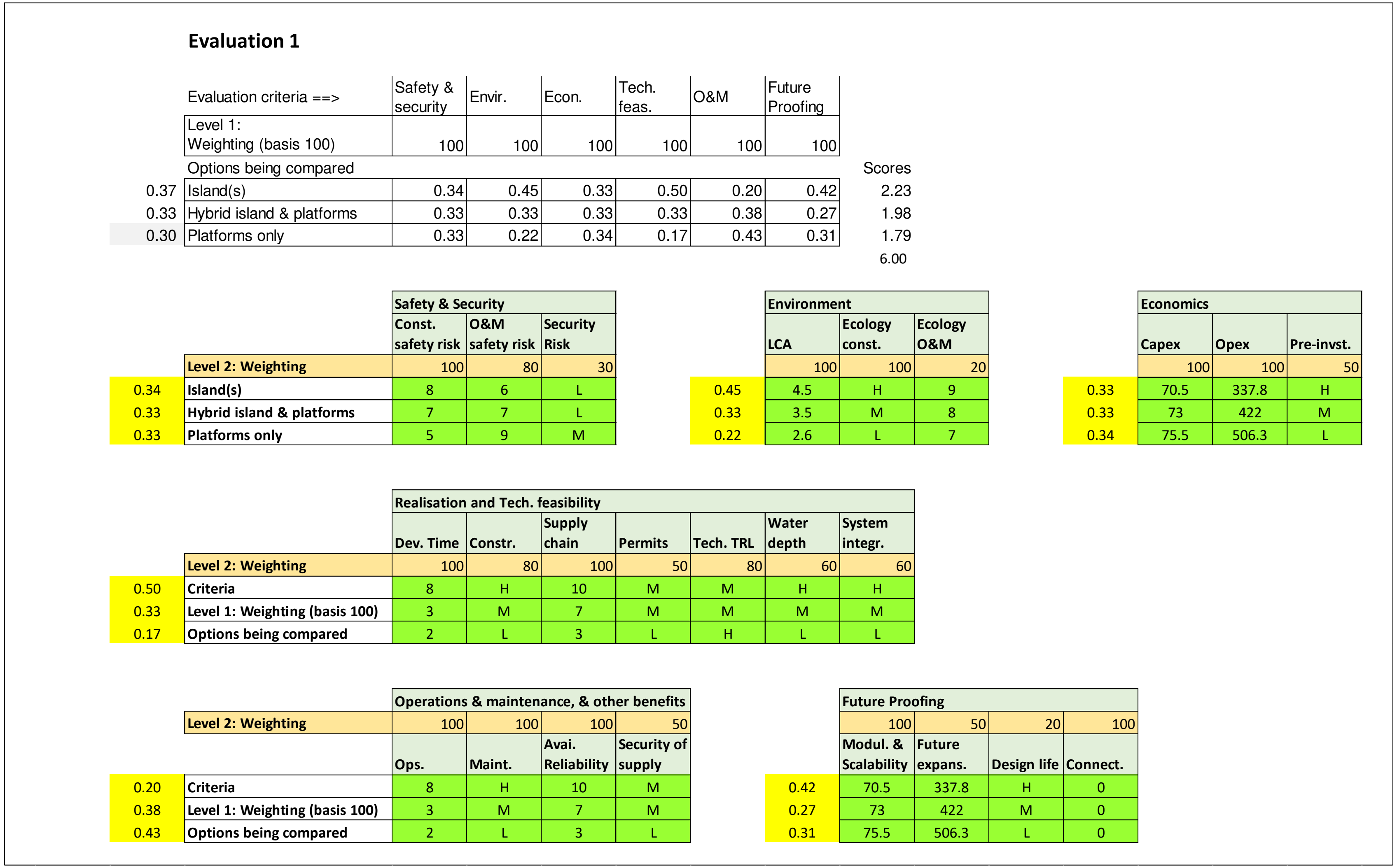
Evaluation criteria ==>	Safety & security	Envir.	Econ.	Tech. feas.	O&M	Future Proofing	Sum	as fractions	
Level 1: Weighting (basis 100)	100	100	100	100	100	100			
Options being compared									*Ranking results*
Island(s)	0.34	0.45	0.35	0.50	0.20	0.42	2.25	0.37	*Least preferred*
Hybrid island & platforms	0.33	0.33	0.33	0.33	0.38	0.27	1.98	0.33	*Second preference*
Platforms only	0.33	0.22	0.32	0.17	0.43	0.31	1.78	0.30	*First preference*
Scoring convention: Lowest scores are most preferrable							*6.00*	*1.00*	

		Safety & Security		
		Const. safety risk	**O&M safety risk**	**Security Risk**
	Level 2: Weighting	100	80	30
0.34	Island(s)	8	6	L
0.33	Hybrid island & platforms	7	7	L
0.33	Platforms only	5	9	M

		Environment		
		LCA	**Ecology const.**	**Ecology O&M**
	Level 2: Weighting	100	100	20
0.45	Island(s)	4.4	H	9
0.33	Hybrid island & platforms	3.5	M	8
0.22	Platforms only	2.6	L	7

		Economics		
		Capex	**Opex**	**Pre-invst.**
	Level 2: Weighting	100	100	50
0.35	Island(s)	70.5	1977.8	H
0.33	Hybrid island & platforms	73	2064.1	M
0.32	Platforms only	75.5	2150.3	L

Figure A.3: Evaluation 1 – Summary of ranking score results.



Evaluation 1

	Evaluation criteria ==>	Safety & security	Envir.	Econ.	Tech. feas.	O&M	Future Proofing	
	Level 1: Weighting (basis 100)	100	100	100	100	100	100	
	Options being compared							Scores
0.37	Island(s)	0.34	0.45	0.33	0.50	0.20	0.42	2.23
0.33	Hybrid island & platforms	0.33	0.33	0.33	0.33	0.38	0.27	1.98
0.30	Platforms only	0.33	0.22	0.34	0.17	0.43	0.31	1.79
								6.00

		Safety & Security		
		Const. safety risk	**O&M safety risk**	**Security Risk**
	Level 2: Weighting	100	80	30
0.34	**Island(s)**	8	6	L
0.33	**Hybrid island & platforms**	7	7	L
0.33	**Platforms only**	5	9	M

	Environment		
	LCA	**Ecology const.**	**Ecology O&M**
	100	100	20
0.45	4.5	H	9
0.33	3.5	M	8
0.22	2.6	L	7

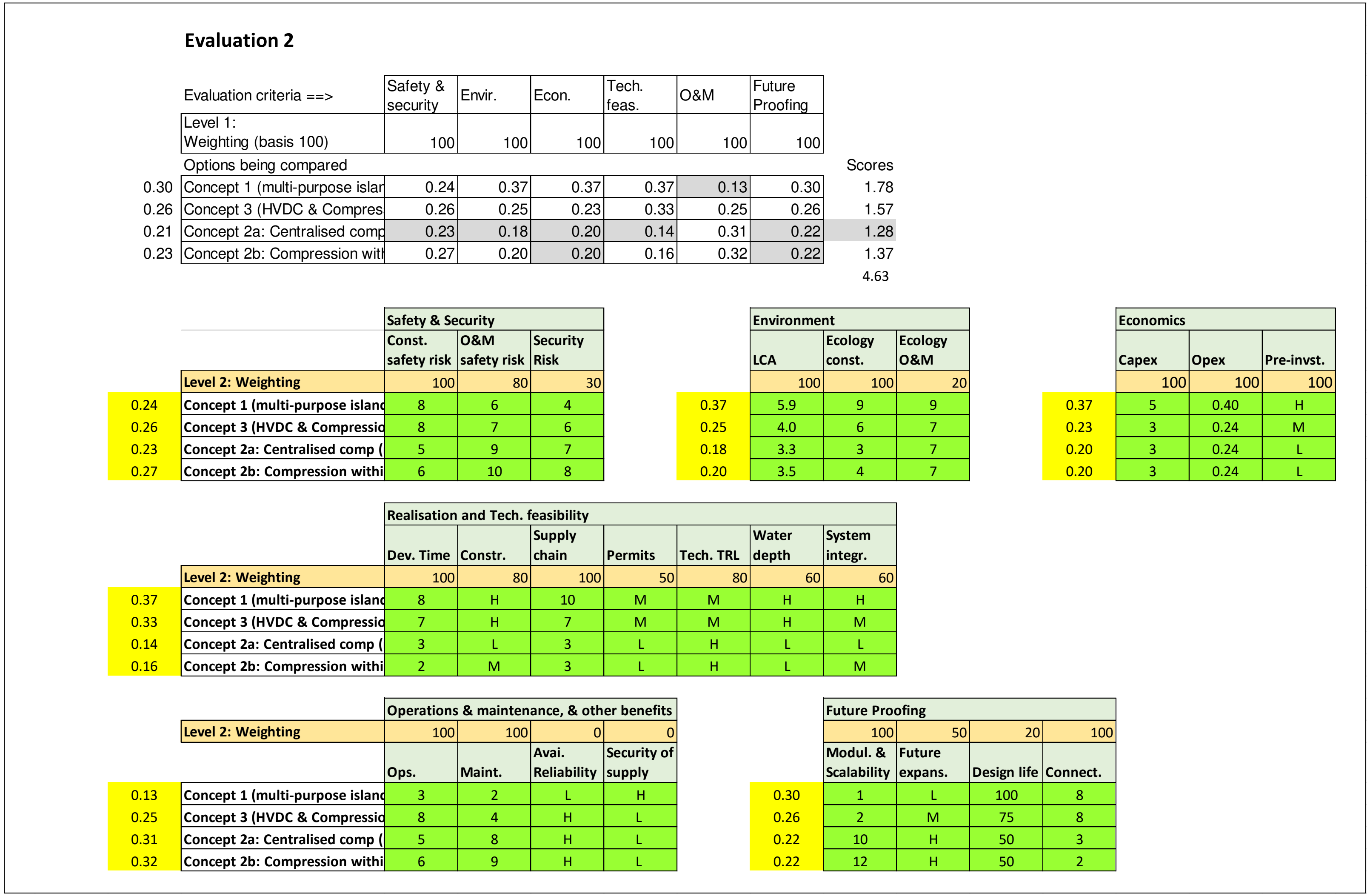
	Economics		
	Capex	**Opex**	**Pre-invst.**
	100	100	50
0.33	70.5	337.8	H
0.33	73	422	M
0.34	75.5	506.3	L

		Realisation and Tech. feasibility						
		Dev. Time	**Constr.**	**Supply chain**	**Permits**	**Tech. TRL**	**Water depth**	**System integr.**
	Level 2: Weighting	100	80	100	50	80	60	60
0.50	**Criteria**	8	H	10	M	M	H	H
0.33	**Level 1: Weighting (basis 100)**	3	M	7	M	M	M	M
0.17	**Options being compared**	2	L	3	L	H	L	L

		Operations & maintenance, & other benefits			
	Level 2: Weighting	100	100	100	50
		Ops.	**Maint.**	**Avai. Reliability**	**Security of supply**
0.20	**Criteria**	8	H	10	M
0.38	**Level 1: Weighting (basis 100)**	3	M	7	M
0.43	**Options being compared**	2	L	3	L

	Future Proofing			
	100	50	20	100
	Modul. & Scalability	**Future expans.**	**Design life**	**Connect.**
0.42	70.5	337.8	H	0
0.27	73	422	M	0
0.31	75.5	506.3	L	0

Figure A.4: Evaluation 2 - Summary of ranking score results.



Evaluation 2

	Evaluation criteria ==>	Safety & security	Envir.	Econ.	Tech. feas.	O&M	Future Proofing	
	Level 1: Weighting (basis 100)	100	100	100	100	100	100	
	Options being compared							Scores
0.30	Concept 1 (multi-purpose islar	0.24	0.37	0.37	0.37	0.13	0.30	1.78
0.26	Concept 3 (HVDC & Compres	0.26	0.25	0.23	0.33	0.25	0.26	1.57
0.21	Concept 2a: Centralised comp	0.23	0.18	0.20	0.14	0.31	0.22	1.28
0.23	Concept 2b: Compression witl	0.27	0.20	0.20	0.16	0.32	0.22	1.37
								4.63

		Safety & Security		
		Const. safety risk	**O&M safety risk**	**Security Risk**
	Level 2: Weighting	100	80	30
0.24	**Concept 1 (multi-purpose island**	8	6	4
0.26	**Concept 3 (HVDC & Compressio**	8	7	6
0.23	**Concept 2a: Centralised comp (**	5	9	7
0.27	**Concept 2b: Compression withi**	6	10	8

	Environment		
	LCA	**Ecology const.**	**Ecology O&M**
	100	100	20
0.37	5.9	9	9
0.25	4.0	6	7
0.18	3.3	3	7
0.20	3.5	4	7

	Economics		
	Capex	**Opex**	**Pre-invst.**
	100	100	100
0.37	5	0.40	H
0.23	3	0.24	M
0.20	3	0.24	L
0.20	3	0.24	L

		Realisation and Tech. feasibility						
		Dev. Time	**Constr.**	**Supply chain**	**Permits**	**Tech. TRL**	**Water depth**	**System integr.**
	Level 2: Weighting	100	80	100	50	80	60	60
0.37	**Concept 1 (multi-purpose island**	8	H	10	M	M	H	H
0.33	**Concept 3 (HVDC & Compressio**	7	H	7	M	M	H	M
0.14	**Concept 2a: Centralised comp (**	3	L	3	L	H	L	L
0.16	**Concept 2b: Compression withi**	2	M	3	L	H	L	M

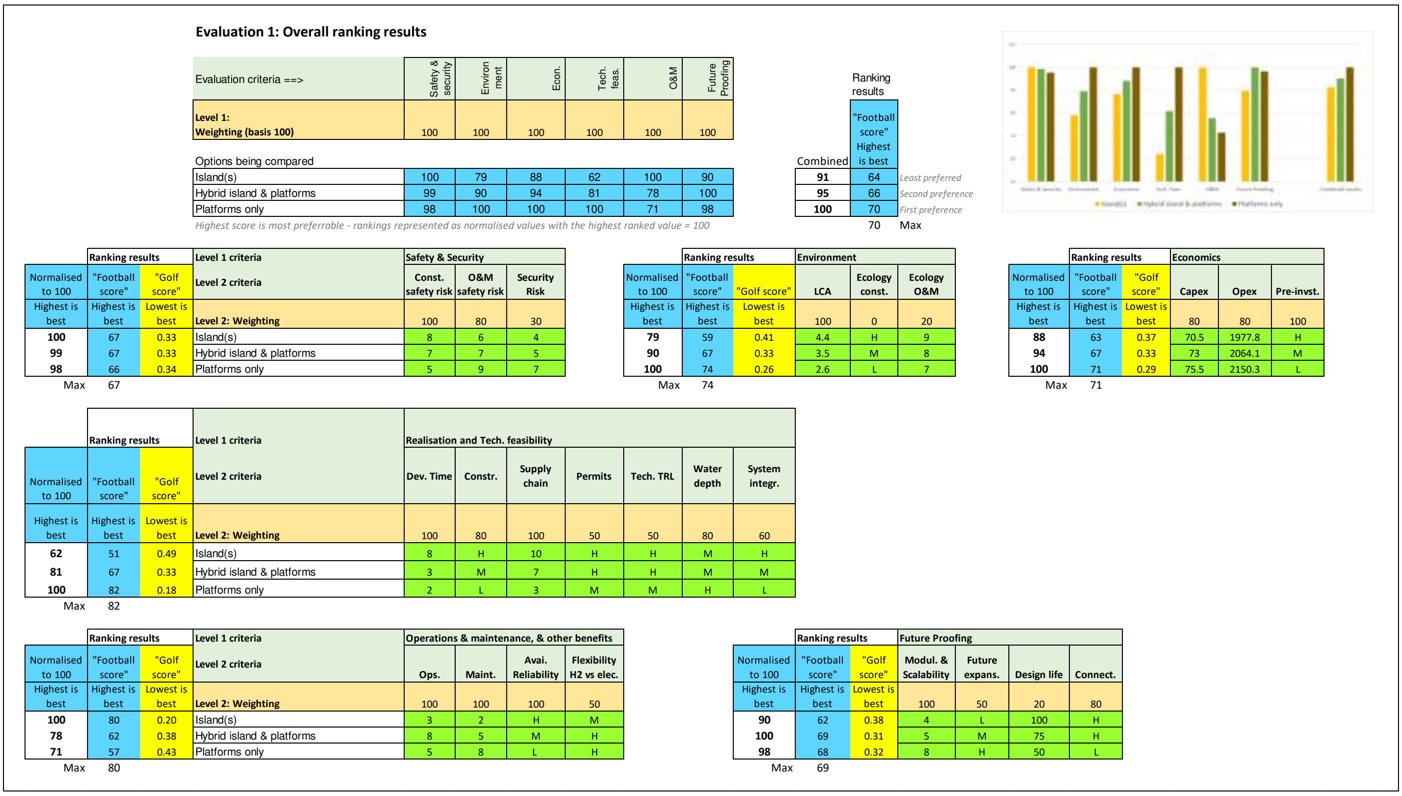
		Operations & maintenance, & other benefits			
	Level 2: Weighting	100	100	0	0
		Ops.	**Maint.**	**Avai. Reliability**	**Security of supply**
0.13	**Concept 1 (multi-purpose island**	3	2	L	H
0.25	**Concept 3 (HVDC & Compressio**	8	4	H	L
0.31	**Concept 2a: Centralised comp (**	5	8	H	L
0.32	**Concept 2b: Compression withi**	6	9	H	L

	Future Proofing			
	100	50	20	100
	Modul. & Scalability	**Future expans.**	**Design life**	**Connect.**
0.30	1	L	100	8
0.26	2	M	75	8
0.22	10	H	50	3
0.22	12	H	50	2

B. Summary of the Scoring Order

Figure B.1: Score cascading from level 2 criteria up to level 1.

Figure B.2: Evaluation 1 – Summary of ranking score results.



Evaluation 1: Overall ranking results

Evaluation criteria ==>	Safety & security	Environ ment	Econ.	Tech. feas.	O&M	Future Proofing
Level 1: Weighting (basis 100)	100	100	100	100	100	100
Options being compared						
Island(s)	100	79	88	62	100	90
Hybrid island & platforms	99	90	94	81	78	100
Platforms only	98	100	100	100	71	98

Highest score is most preferrable - rankings represented as normalised values with the highest ranked value = 100

Combined	Ranking results "Football score" Highest is best	
91	64	*Least preferred*
95	66	*Second preference*
100	70	*First preference*
	70	Max

	Ranking results		**Level 1 criteria**	**Safety & Security**		
Normalised to 100	"Football score"	"Golf score"	**Level 2 criteria**	**Const. safety risk**	**O&M safety risk**	**Security Risk**
Highest is best	Highest is best	Lowest is best	**Level 2: Weighting**	100	80	30
100	67	0.33	Island(s)	8	6	4
99	67	0.33	Hybrid island & platforms	7	7	5
98	66	0.34	Platforms only	5	9	7
Max	67					

	Ranking results		**Environment**		
Normalised to 100	"Football score"	"Golf score"	**LCA**	**Ecology const.**	**Ecology O&M**
Highest is best	Highest is best	Lowest is best	100	0	20
79	59	0.41	4.4	H	9
90	67	0.33	3.5	M	8
100	74	0.26	2.6	L	7
Max	74				

	Ranking results		**Economics**		
Normalised to 100	"Football score"	"Golf score"	**Capex**	**Opex**	**Pre-invst.**
Highest is best	Highest is best	Lowest is best	80	80	100
88	63	0.37	70.5	1977.8	H
94	67	0.33	73	2064.1	M
100	71	0.29	75.5	2150.3	L
Max	71				

	Ranking results		**Level 1 criteria**	**Realisation and Tech. feasibility**						
Normalised to 100	"Football score"	"Golf score"	**Level 2 criteria**	**Dev. Time**	**Constr.**	**Supply chain**	**Permits**	**Tech. TRL**	**Water depth**	**System integr.**
Highest is best	Highest is best	Lowest is best	**Level 2: Weighting**	100	80	100	50	50	80	60
62	51	0.49	Island(s)	8	H	10	H	H	M	H
81	67	0.33	Hybrid island & platforms	3	M	7	H	H	M	M
100	82	0.18	Platforms only	2	L	3	M	M	H	L
Max	82									

	Ranking results		**Level 1 criteria**	**Operations & maintenance, & other benefits**			
Normalised to 100	"Football score"	"Golf score"	**Level 2 criteria**	**Ops.**	**Maint.**	**Avai. Reliability**	**Flexibility H2 vs elec.**
Highest is best	Highest is best	Lowest is best	**Level 2: Weighting**	100	100	100	50
100	80	0.20	Island(s)	3	2	H	M
78	62	0.38	Hybrid island & platforms	8	5	M	H
71	57	0.43	Platforms only	5	8	L	H
Max	80						

	Ranking results		**Future Proofing**			
Normalised to 100	"Football score"	"Golf score"	**Modul. & Scalability**	**Future expans.**	**Design life**	**Connect.**
Highest is best	Highest is best	Lowest is best	100	50	20	80
90	62	0.38	4	L	100	H
100	69	0.31	5	M	75	H
98	68	0.32	8	H	50	L
Max	69					

C. Stakeholder Feedback

After the first revision the stakeholders have commented on the initial scoring. During a workshop on 13th October 2023 the comments were discussed and the scoring was adjusted if needed. A summary of the commentary can be found below:

6.1.4.1.:Safety during operation & maintenance

Gasunie commented that the main safety concerns relate to electrolysis – the risk of hydrogen or oxygen transfer across the membrane resulting in explosion – and that combining compression and electrolysis in one location on the large island increases the risk to operators due to the requirement for regular maintenance of the compressors and. They also commented that being next to HVDC facilities could potentially lead to a larger amount of collateral damage and even casualties. This risk was considered in our original scoring and discussed in the report. During the new scoring workshop the team still considered that due to the separation between electrolysis, compression, HVDC and living quarters on the island and the option of mitigating measures such as blast and fire walls that operators being on the island and carrying out maintenance on compressors would not be excessively exposed to risk from the electrolysers. This does need to be carefully considered in the design of any islands as the project progresses. On balance the risks associated with accessing multiple unmanned platforms for operations and maintenance were considered to exceed those for a permanently manned island with more space in incorporate safe design choices.

Gasunie stated that the risks associated with alkaline electrolysis I the island are judged manageable and asked the basis for this. During the NSWPH programme we developed the design of a caisson island based hydrogen production facility that included alkaline electrolysis. During this study we carefully considered the risks associated with alkaline electrolysers and recommended the approach to be taken to understand and mitigate them as the project progresses.

6.1.4.3.:Security

Gasunie asked why use a low and medium scoring for security when the risk to platforms is still considered low and recommended a numerical scoring instead. During the new scoring workshop the team agreed with this comment and updated the scoring as shown in table 6.4.

TenneT stated that they did not agree with the scoring and asked if the island as a large point of failure was taken into account which would make the platforms preferable. This consideration would apply to sabotage which is outside of the scope of workstream 3. The security criteria relates to the risk of unauthorised personnel accessing the energy hub infrastructure. The team did not consider it credible to have a significant failure due to unauthorised personnel and considered preventing access easier on a manned island than dispersed unmanned platforms.

6.1.4.4 Safety & Security Weighting

Tennet stated that safety should always be the highest rating as it is a core value. The original weighting of 80 for safety during operations was selected relative to the weighting of 100 for safety during construction as the risks during construction were considered greater. However, during the new scoring workshop the team considered that safety should always be a top priority and increased the safety during operations weighting to 100 as shown in table 6.5.

6.1.6.2 Economics

Gasunie asked whether the platforms associated with the large islands necessary to bring the array cables onto the island are included in the cost estimate. The cable entry platforms (including cable bridge) as shown in figure 6.7 above are small in scale and intended only to allow transfer of the array cables to the island. They are required irrespective of the array cable voltage selected and are included in the cost estimate for the island construction within the Power Infrastructure component of the CAPEX build-up (at circa €3.5 million each, supplied and installed).*6.1.6.4 Economics Weighting*

Gasunie commented that due to the uncertainty of the tolerance accuracy (as much as up to 50%) of the CAPEX and OPEX estimates that a greater relative weighting should be given to the need for pre-investment. Information from the Danish island also indicates that the very high requirement for pre-investment was one of the reasons it was not selected. Gasunie also advised that their economic evaluation of island based and platform based hubs found the opoosite to us inthat the CAPEX for islands was higher than platforms although again within the accuracy range of the estimate. Their economic evaliation used the same base information from the NSWPH programme but developed the cost estimates independently with known differences including the amount of HVDC equipment installed on the islands. All these factors suggest there is no clear difference in costs between the concepts which would be a driving factor in concept selection and therefore the team agreed to adjust the weighting of CAPEX, OPEX and the need for pre-investment as indicated in Table 6.20.

6.1.7.1 Development time to operation

Gasunie recommended that development time to operations become a level one criteria. The team considered this in the follow-up scoring workshop but decided that it should remain part of realisation and technical feasibility. It is considered a key criteria but there is doubt as to the timeline for roll-out of both offshore wind generation and offshore hydrogen production that means there is no specific date after which a concept is eliminated. Therefore, it is considered one of the criteria that contribute to whether the project can be realised.

6.1.7.4 Permitting

TenneT questioned why the risks associated with permitting were not high as they believed this was a concern for the Danish Energy Island. During the new scoring workshop the team agreed there would be challenges to get permit approval for both islands and platforms and adjusted the scoring as shown in Table 6.25.

6.1.7.6 Water Depth

TenneT asked why the hybrid configuration is scored as medium risk and the islands concept is scored high risk when both contain a large island supporting electrolysis. In the new scoring workshop the team took the view that constructing one island is easier than two but also that as the platform infrastructure is required before the island for the hybrid concept this longer timeline reduces the risks of island construction and therefore the scoring was not changed.

6.1.9.1 Modularity & Scalability

There was significant discussion within the comment close out sessions on the achievable modularity and scalability of islands. The consensus was that whilst they are significantly less modular and scalable than a platform-based concept the original scores did not give enough credit to the ability to change the infrastructure installed on the islands within the selected island size and also over emphasised the limitation of a fixed island location relative to the rest of the energy hub. The relative scores for isands and platforms are updated as shown in Table 6.35.

Due to the key importance of modularity and scalability as a criteria the relative weighting of of the impact and importance of connectivity was reduced from 100 to 80 within the future proofing portfolio of level 2 criteria rankings.

6.4.1.1 Safety during construction

Gasunie commented that SIMOPs is significantly reduced for the TSO/HNO island which is part of Concept 3 – platform based hub but with compression and 6GW of HVDC on an island – than it is for a large island with electrolysis which is part of Concept 1. During the new scoring workshop the team agreed with this and decided that greater weight should be placed on the risks of construction next ot live plant inherent in the roll-out of hydrogen production equipment on the large island with electrolysis. The HNO/TSO island would include all compression equipment 6GW of HVDC equipment but the assumption is that this would all be installed initially. The scoring in table 6.41 has been updated to reflect this.

6.4.1.3 Safety during Operation & Maintenance

Gasunie asked why safety is better for centralised compression (Concept 2a) compared to decentralised compression (Concept 2b) as for centralised compresson an explosion in one compressor could impact others. Safety during operation and maintenance was considered in terms of the impact on operators rather than equipment. Having all compressors in a single location was considered to reduce the risk and compelxity of operations and maintenance compared to having to visit multiple locations.

Gasunie also commented that there is no safety risk associated with combining electrolysis and compression on the HNO/TSO island supporting compression and 6GW of HVDC in Concept 3. This is correct but the team considered the risks associated with combining electrolysis and compression on a large island to be manageable.

TenneT commented that it will be different personnel accessing the HVDC, hydrogen production and hydrogen compression platforms allowing them to become familiar with the platform design. During the new scoring workshop the team acknowledged this still considered that there would be a large numbert of each type of platform each with differing designs and that operations and maintenance crews would change frequently in an offshore setting meaning that unfamiliarity with each platform would still be a concern.

6.4.3 Economics

Gasunie commented that due to the up to 50% tolerance accuracy of the CAPEX and OPEX estimates thatr greater weighting should be given to the need for pre-investment. Information from the Danish island also indicates that the very high requirement for pre-investment was one of the reasons it was not selected. Gasunie also advised that their economic evaluation of island based and platform based hubs found the opoosite to us inthat the CAPEX for islands was higher than platforms although again within the accuracy range of the estimate. Their economic evaliation used the same base information from the NSWPH programme but developed the cost estimates independently with known differences including the amount of HVDC equipment installed on the islands. All these factors suggest there is no clear difference in costs between the concepts which would be a driving factor in concept selection and therefore the team agreed to adjust the weighting of CAPEX, OPEX and the need for pre-investment to 80:80:100.

6.4.5.1 Operation complexity

Gasunie commented that they would consider operations and maintenance to be significantly better for Concept 2a – platform based hub with centralised compression compared to Concept 2b – platform based hub with decentralised compression. During the new scoring workshop the team agreed with this comment considering that the combined location of bridge linked central platforms for compression does make operations and maintenance easier than in multiple locations in concept 2b and the score has been updated in table 6.64.

6.4.5.2 Maintenance complexity

Gasunie commented that they would consider operations and maintenance to be significantly better for Concept 2a – platform based hub with centralised compression compared to Concept 2b – platform based hub with decentralised compression. During the new scoring workshop the team agreed with this comment considering that the combined location of bridge linked central platforms for compression does make operations and maintenance easier than in multiple locations in concept 2b and the score has been updated in table 6.65.

6.4.5.3 Availability & Reliability

Gasunie stated that due to easier operations and maintenance at the centralised compression platforms included in Concept 2a reliability/availability would be higher for Concept 2a than Concept 2b. The team considered this and agreed that this would improve reliability/availability but needed to be balanced against other factors including:

- Decentralised platforms would each need to spare equipment potentially increasing overall sparing.
- Impact of any failure would potentially be less on smaller decentralised platforms than at one central location.
- Smaller plaftorms with fewer compressors may be less susceptible to vibrations improving reliability.

On balance the team considered that the current scores for availability/reliability which slightly favour Concept 2b over Concept 2a were correct.

6.4.6 Future proofing

Gasunie asked why future proofing scores were similar between Concept 2a – platform based hub with centralised compression and Concept 2b – platform based hub with decentralised compression when concept 2b seems to apply the same modular approach as concept 2a but with smaller compressor platforms. The overall future proofing score is slightly higher for Concept 2b but the advantages compared to Concept 2a are considered limited as both are platform based hubs with multiple HVDC, hydrogen production and compression platforms.

6.4.6.1 Modularity & Scalability

There was significant discussion within the comment close out sessions on the achievable modularity and scalability of islands. The consensus was that whilst they are significantly less modular and scalable than a platform-based concept the original scores did not give enough credit to the ability to change the infrastructure installed on the islands within the selected island size and also over emphasised the limitation of a fixed island location relative to the rest of the energy hub. The relative scores for isands and platforms are updated as shown in Table 6.68.

Due to the key importance of modularity and scalability as a criteria the weighting of connectivity was reduced from 100 to 80 within future proofing.

D. Adapted Schedules from the NSWPH Programme

North Sea Wind Power Hub Programme

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1 Introduction

Rev

The NSWPH project consists of a planned hydrogen production development – considering combined offshore and onshore and combined caisson island and onshore options – connected wind, of in total up to 10 GW, on and off the coast of the Netherlands. Hydrogen produced by the facility will be exported by pipeline.

1.1 Document Purpose

Identification of the assumptions included within Level 1 combined caisson island and onshore facility

1.2 Document Objectives

The objectives of this document are:

Identify the assumptions included within Level 1 combined caisson island and onshore facility Schedule

1.3 Document Scope

The scope of the document is for the hydrogen production site.

2 Assumptions

2.1 When developing the combined caisson island and onshore facility schedule RevB the following assumptions have been included.

2.2 Assumptions

The caisson island will be constructed in its entirety before commencing any HVDC or PtG installation.

A 15 Month duration has been assumed to undertake the required environmental and planning approvals in order to make the quarry available for rock delivery. Due to the time required it is assumed that these activities will run concurrently with the FEED duration rather than waiting for the Contractor building the Caisson Island to be place.

The 4GW PtG for the Onshore facility will be delivered first in 2GW Block sequenced to be brought online with the construction of the HVDC onshore and on the caisson island.

2GW - 2034
4GW - 2037

The Level 1 schedule currently only includes the onshore and caisson island PtG facilities. The schedule assumes any windfarm expansion is in line with the forecast equipment installation and therefore not on the critical path.

The caisson island section of the schedule has been developed into two main areas, the caisson island and onshore gas receiving facility.

All equipment is deemed to be available and on site as required, therefore it is assumed that the supply chain can deliver to meet forecast dates

Supply chain duration would need validation to ensure delivery dates can be achieved

Each phase is completed with Governance and Assurance before commencing the next.

Concept Development phases for all areas of the project are assumed complete prior to commencing Concept Refinement phases for the PtG processing facility.

Concept Refinement phases for all areas of the project are complete prior to commencing FEED phases for the PtG processing facility.

FEED phases for all areas of the project are complete prior to commencing the first Final Investment Decision and commencing detailed design and implementation phase for the caisson island and PtG processing facility.

No significant investment will be made pre- Final Investment Decision (FID).

Final Investment Decisions are phased for 2GW PtG buildouts and scheduled to meet forecast dates.

The pipeline between the onshore facility and offshore facility is in place prior to the commissioning of the first 2GW block

Power via HVDC cable is available prior to commissioning the onshore PtG

Site power and utilities are in place prior to commencing any on site construction tasks

Onshore Gas Receiving Facility

The FEED design time for the Onshore Gas Receiving Facility is less than the caisson island but there are interdependences between the two, therefore they are scheduled to be completed at the same time.

The Onshore Gas Receiving Facility and hydrogen pipeline can be built independently from the caisson island, but is required to commission prior to the first 2GW of power to gas on the caisson island becoming online. This will not be on the critical path."

The Grid connection will be in place and available for commissioning.

Caisson Island

The Concept refinement phase for the caisson island design (including electrical and PtG infrastructure) is planned to start in Q1 2023

The Concept design for both the onshore facility and caisson island are scheduled to be completed at the same time to enable the project to progress to the next stage

The FEED design for both the onshore facility and caisson island are scheduled to be completed at the same time to enable the project to progress to the next stage

The FEED is required prior to the construction of the caisson island, with the EPC circa four years later a FEED refresh activity of three months has been included prior each of the FID's to catch any technological developments.

The construction for the caisson island is 38 months. This is due to the seasonal constraints for the installation of the temporary reef, the rock bund and the installation of the caissons. The working season is April to September.

The installation of the rock bund is scheduled to take four seasons, this is due to the work being required to be undertaken within the working season of April to September

An assumption has been made that one caisson per week will be placed during the working season of April to September resulting in four seasons of installation.

An assumption has been made that 30,000 tons of sand can be installed daily, however bad weather may cause a reduction in productivity over winter periods. The installation of the sand is completed just after the completion of the installation of the caissons.

An assumption has been made that productivity on the caisson island will be around 80% during the Winter season, as it is anticipated some bad weather will be encountered during this period.

All civil work for the PtG plants, e.g. piling for compressor foundations, is foreseen to be completed before installation and commissioning of the HVDC.

The critical path lies through the construction of the caisson island and the installation of the HVDC equipment on the caisson island

An assumption has been made the Installation of the HVDC and PtG equipment on the caisson island will take up to 20% longer than onshore due to encountering bad weather conditions.

An assumption has been made that Installation of the PtG train 5GW/6GW on the caisson island will take up to 20% longer than previous trains. This is due to the reduced storage/laydown area on the caisson island and therefore equipment will need to be install directly off boats.

The south side of the caisson island consists of an approximately 350m long row of caissons with sufficient water depth for these to form a quay. Outside this is a breakwater to provide protection from waves. This breakwater can be extended to give shelter to the whole width of the island. Moving 500t modules onto the island can be achieved at the rate of 1 per day per berth. But it is unlikely that this can be sustained. One of the berths would be required for smaller deliveries, personnel changes. The delivery rate of 1.5 to 1.9 modules per day is manageable. Additional deliveries of bulk and containerised materials would be across the third berth.' None of these berths will be required for the installation of the flotel

Construction next to a plant in commissioning is not considered desirable from safety / simultaneous operation perspective. For this reason, a 6 month gap prior to construction of the next train is foreseen, to commission the Power-to-Gas trains. The 1GW Power-to-Gas trains are built in 2GW steps, to reduce the number of phases of construction next to live plant

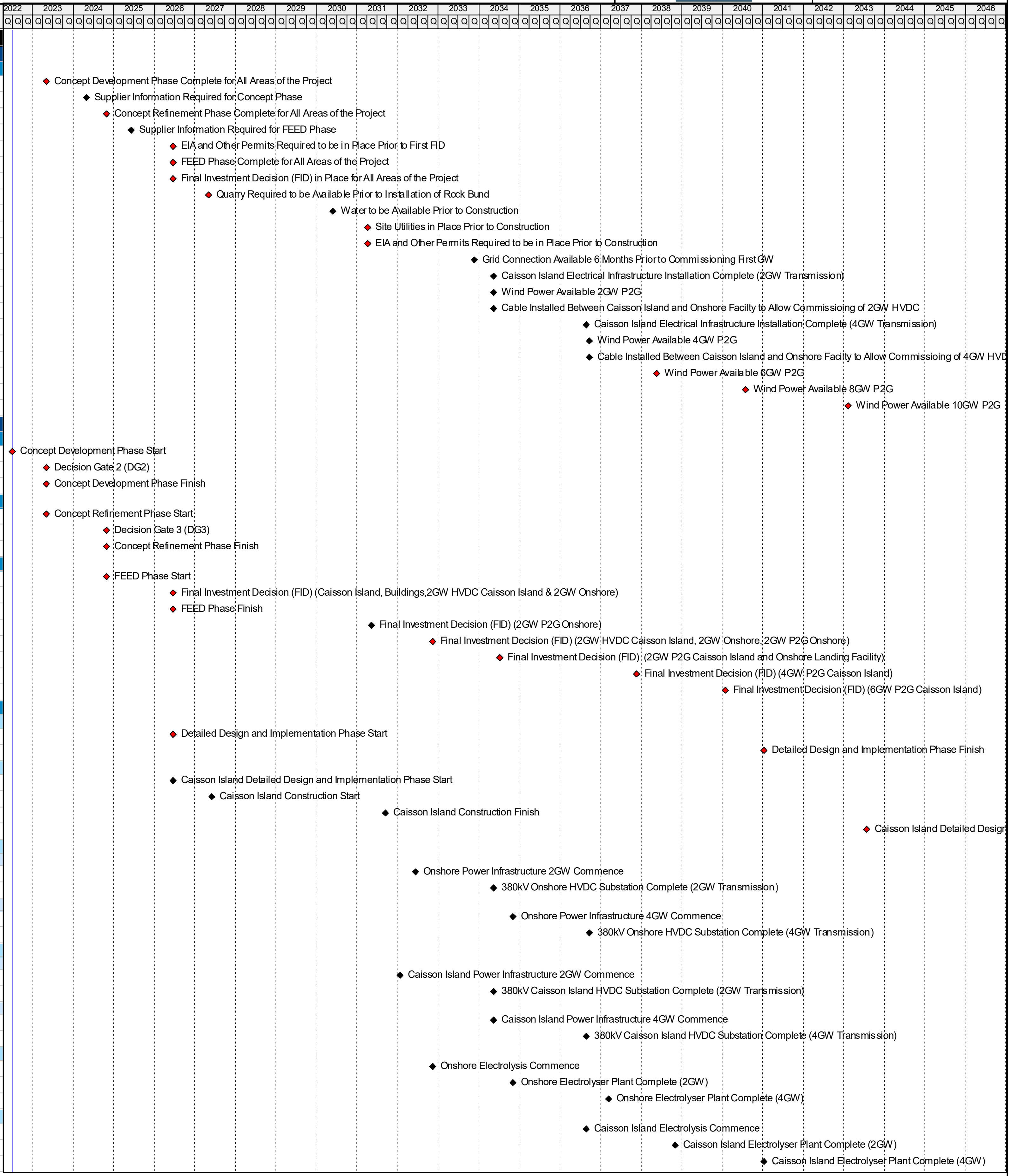
Schedule assumption is that 2 HVDC stations will be built, followed by 3x 2GW PtG plants. It is feasible to prioritise (some of) the PtG trains over the 2nd HVDC station.

Sequential construction of HVDC stations and Power-to-Gas plant are foreseen due to, dock logistic, and personnel and equipment limitations.

The installation of the PtG plant, involves installation of the pre-assembled modules as well as stick-build construction to build all required interconnections

NSWPH Level 1 Caisson Island Schedule Revison B

#	Activity ID	Activity Name	Original Duration	Start	Finish
1	**NSWPH Level 1 Caisson Island Schedule Revison B**		5402	04-Jul-22	27-Jul-43
2	**Key Project Milestones**		5072	05-May-23	06-Feb-43
3	**Interfaces Milestones with Other Areas of the Project**		5072	05-May-23	06-Feb-43
4	NSWPH-2530	Concept Development Phase Complete for All Areas of the Project	0		05-May-23
5	NSWPH-2740	Supplier Information Required for Concept Phase	0	03-May-24	
6	NSWPH-2540	Concept Refinement Phase Complete for All Areas of the Project	0		29-Oct-24
7	NSWPH-2750	Supplier Information Required for FEED Phase	0	10-Jun-25	
8	NSWPH-2760	EIA and Other Permits Required to be in Place Prior to First FID	0		16-Jun-26
9	NSWPH-2550	FEED Phase Complete for All Areas of the Project	0		17-Jun-26
10	NSWPH-2560	Final Investment Decision (FID) in Place for All Areas of the Project	0		17-Jun-26
11	NSWPH-5330	Quarry Required to be Available Prior to Installation of Rock Bund	0		06-May-27
12	NSWPH-2380	Water to be Available Prior to Construction	0		28-May-30
13	NSWPH-2730	Site Utilities in Place Prior to Construction	0		09-Apr-31
14	NSWPH-2360	EIA and Other Permits Required to be in Place Prior to Construction	0		09-Apr-31
15	NSWPH-2770	Grid Connection Available 6 Months Prior to Commissioning First GW	0		18-Nov-33
16	NSWPH-2780	Caisson Island Electrical Infrastructure Installation Complete (2GW Transmission)	0		15-May-34
17	NSWPH-4210	Wind Power Available 2GW P2G	0		15-May-34
18	NSWPH-2860	Cable Installed Between Caisson Island and Onshore Facilty to Allow Commissioing of 2GW HVDC	0		15-May-34
19	NSWPH-2790	Caisson Island Electrical Infrastructure Installation Complete (4GW Transmission)	0		26-Aug-36
20	NSWPH-4220	Wind Power Available 4GW P2G	0		25-Sep-36
21	NSWPH-5310	Cable Installed Between Caisson Island and Onshore Facilty to Allow Commissioing of 4GW HVDC	0		25-Sep-36
22	NSWPH-4230	Wind Power Available 6GW P2G	0		18-May-38
23	NSWPH-4240	Wind Power Available 8GW P2G	0		26-Jul-40
24	NSWPH-5320	Wind Power Available 10GW P2G	0		06-Feb-43
25	**Caisson Island Milestones**		5402	04-Jul-22	27-Jul-43
26	**Concept Development Phase**		210	04-Jul-22	05-May-23
27	NSWPH-3460	Concept Development Phase Start	0	04-Jul-22	
28	NSWPH-1090	Decision Gate 2 (DG2)	0		05-May-23
29	NSWPH-1100	Concept Development Phase Finish	0		05-May-23
30	**Concept Refinement Phase**		374	08-May-23	29-Oct-24
31	NSWPH-1110	Concept Refinement Phase Start	0	08-May-23	
32	NSWPH-2840	Decision Gate 3 (DG3)	0		29-Oct-24
33	NSWPH-2850	Concept Refinement Phase Finish	0		29-Oct-24
34	**FEED Phase**		3908	30-Oct-24	27-Jan-40
35	NSWPH-3690	FEED Phase Start	0	30-Oct-24	
36	NSWPH-3680	Final Investment Decision (FID) (Caisson Island, Buildings,2GW HVDC Caisson Island & 2GW Onshore)	0		17-Jun-26
37	NSWPH-3700	FEED Phase Finish	0		17-Jun-26
38	NSWPH-4060	Final Investment Decision (FID) (2GW P2G Onshore)	0		09-May-31
39	NSWPH-3720	Final Investment Decision (FID) (2GW HVDC Caisson Island, 2GW Onshore, 2GW P2G Onshore)	0		11-Nov-32
40	NSWPH-3710	Final Investment Decision (FID) (2GW P2G Caisson Island and Onshore Landing Facility)	0		10-Jul-34
41	NSWPH-4070	Final Investment Decision (FID) (4GW P2G Caisson Island)	0		19-Nov-37
42	NSWPH-5170	Final Investment Decision (FID) (6GW P2G Caisson Island)	0		27-Jan-40
43	**Detailed Design and Implementation Phase**		4408	18-Jun-26	27-Jul-43
44	**General**		3748	18-Jun-26	12-Jan-41
45	NSWPH-2680	Detailed Design and Implementation Phase Start	0	18-Jun-26	
46	NSWPH-2690	Detailed Design and Implementation Phase Finish	0		12-Jan-41
47	**Caisson Island**		4408	18-Jun-26	26-Jul-43
48	NSWPH-5180	Caisson Island Detailed Design and Implementation Phase Start	0	18-Jun-26	
49	NSWPH-5200	Caisson Island Construction Start	0	04-Jun-27	
50	NSWPH-5210	Caisson Island Construction Finish	0		10-Sep-31
51	NSWPH-5190	Caisson Island Detailed Design and Implementation Phase Finish	0		26-Jul-43
52	**Power Infrastructure Onshore**		1102	11-Jun-32	25-Sep-36
53	**2GW Transmission**		490	11-Jun-32	15-May-34
54	NSWPH-524	Onshore Power Infrastructure 2GW Commence	0	11-Jun-32	
55	NSWPH-522	380kV Onshore HVDC Substation Complete (2GW Transmission)	0		15-May-34
56	**4GW Transmission**		490	02-Nov-34	25-Sep-36
57	NSWPH-525	Onshore Power Infrastructure 4GW Commence	0	02-Nov-34	
58	NSWPH-523	380kV Onshore HVDC Substation Complete (4GW Transmission)	0		25-Sep-36
59	**Power Infrastructure Caisson Island**		1180	23-Jan-32	26-Aug-36
60	**2GW Transmission**		590	23-Jan-32	15-May-34
61	NSWPH-360	Caisson Island Power Infrastructure 2GW Commence	0	23-Jan-32	
62	NSWPH-359	380kV Caisson Island HVDC Substation Complete (2GW Transmission)	0		15-May-34
63	**4GW Transmission**		590	16-May-34	26-Aug-36
64	NSWPH-332	Caisson Island Power Infrastructure 4GW Commence	0	16-May-34	
65	NSWPH-331	380kV Caisson Island HVDC Substation Complete (4GW Transmission)	0		26-Aug-36
66	**Electrolysis Onshore**		27-Jul-43	12-Nov-32	16-Mar-37
67	NSWPH-2500	Onshore Electrolysis Commence	0	12-Nov-32	
68	NSWPH-2480	Onshore Electrolyser Plant Complete (2GW)	0		01-Nov-34
69	NSWPH-2440	Onshore Electrolyser Plant Complete (4GW)	0		16-Mar-37
70	**Electrolysis Caisson Island**		1803	27-Aug-36	27-Jul-43
71	NSWPH-5280	Caisson Island Electrolysis Commence	0	27-Aug-36	
72	NSWPH-5270	Caisson Island Electrolyser Plant Complete (2GW)	0		04-Nov-38
73	NSWPH-5260	Caisson Island Electrolyser Plant Complete (4GW)	0		14-Jan-41



🟦 Actual Work
🟥 Critical Remaining Work
◆ Critical Milestone
🟩 Remaining Work
◆ Milestone

Date	Revision	Checked	Approved
04-Aug-22	NSWPH - Caisson Island Schedule Rev B for Submission	PT	

NSWPH Level 1 Caisson Island Schedule Revison B

North Sea Wind Power Hub Programme

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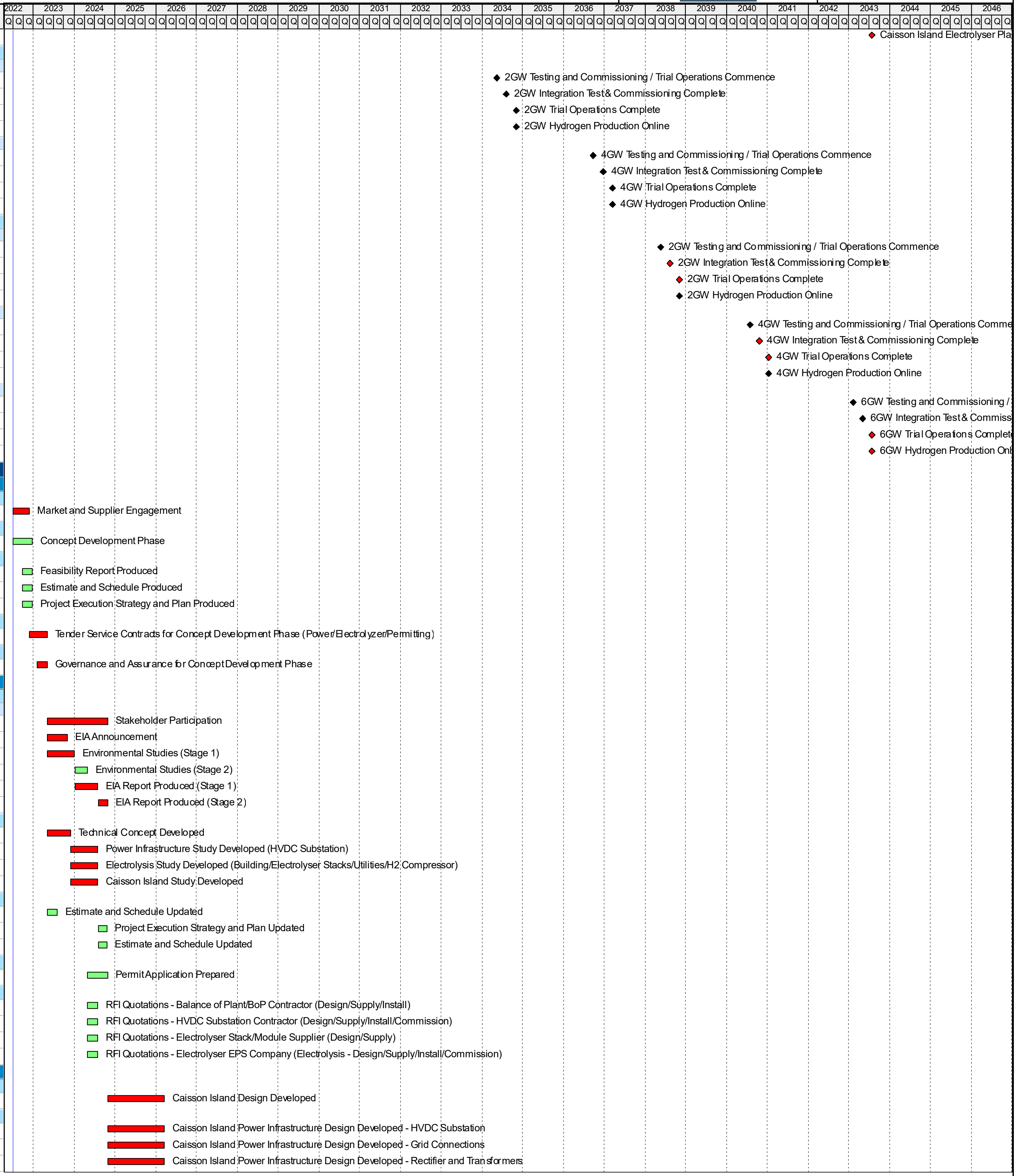
#	Activity ID	Activity Name	Original Duration	Start	Finish
74	NSWPH-5290	Caisson Island Electrolyser Plant Complete (6GW)	0		27-Jul-43
75		**Integrated T&C/Trial Operations/Hydrogen Production Online P2G Onshore**	733	16-May-34	15-Mar-37
76		**2GW Power**	122	16-May-34	02-Nov-34
77	NSWPH-393	2GW Testing and Commissioning / Trial Operations Commence	0	16-May-34	
78	NSWPH-381	2GW Integration Test & Commissioning Complete	0		08-Aug-34
79	NSWPH-510	2GW Trial Operations Complete	0		01-Nov-34
80	NSWPH-385	2GW Hydrogen Production Online	0	02-Nov-34	
81		**4GW Power**	121	26-Sep-36	15-Mar-37
82	NSWPH-395	4GW Testing and Commissioning / Trial Operations Commence	0	26-Sep-36	
83	NSWPH-383	4GW Integration Test & Commissioning Complete	0		19-Dec-36
84	NSWPH-512	4GW Trial Operations Complete	0		14-Mar-37
85	NSWPH-387	4GW Hydrogen Production Online	0	15-Mar-37	
86		**Integrated T&C/Trial Operations/Hydrogen Production Online P2G Caisson Island**	1353	19-May-38	27-Jul-43
87		**2GW Power**	122	19-May-38	05-Nov-38
88	NSWPH-283	2GW Testing and Commissioning / Trial Operations Commence	0	19-May-38	
89	NSWPH-280	2GW Integration Test & Commissioning Complete	0		11-Aug-38
90	NSWPH-282	2GW Trial Operations Complete	0		04-Nov-38
91	NSWPH-281	2GW Hydrogen Production Online	0	05-Nov-38	
92		**4GW Power**	121	27-Jul-40	13-Jan-41
93	NSWPH-308	4GW Testing and Commissioning / Trial Operations Commence	0	27-Jul-40	
94	NSWPH-305	4GW Integration Test & Commissioning Complete	0		19-Oct-40
95	NSWPH-307	4GW Trial Operations Complete	0		12-Jan-41
96	NSWPH-306	4GW Hydrogen Production Online	0	13-Jan-41	
97		**6GW Power**	120	09-Feb-43	27-Jul-43
98	NSWPH-508	6GW Testing and Commissioning / Trial Operations Commence	0	09-Feb-43	
99	NSWPH-506	6GW Integration Test & Commissioning Complete	0		02-May-43
100	NSWPH-530	6GW Trial Operations Complete	0		26-Jul-43
101	NSWPH-507	6GW Hydrogen Production Online	0	27-Jul-43	
102		**Caisson Island**	5402	04-Jul-22	27-Jul-43
103		**Concept Development Phase**	210	04-Jul-22	05-May-23
104		**Market & Supplier Engagement**	102	04-Jul-22	23-Nov-22
105	NSWPH-3410	Market and Supplier Engagement	102	04-Jul-22	23-Nov-22
106		**MMD Work**	124	04-Jul-22	23-Dec-22
107	NSWPH-3550	Concept Development Phase	124	04-Jul-22	23-Dec-22
108		**Project Management**	64	27-Sep-22	23-Dec-22
109	NSWPH-2700	Feasibility Report Produced	64	27-Sep-22	23-Dec-22
110	NSWPH-2710	Estimate and Schedule Produced	64	27-Sep-22	23-Dec-22
111	NSWPH-2720	Project Execution Strategy and Plan Produced	64	27-Sep-22	23-Dec-22
112		**Contracting & Procurement for Concept Development Phase**	108	24-Nov-22	05-May-23
113	NSWPH-3300	Tender Service Contracts for Concept Development Phase (Power/Electrolyzer/Permitting)	108	24-Nov-22	05-May-23
114		**Governance & Assurance for Concept Development Phase**	64	02-Feb-23	05-May-23
115	NSWPH-3420	Governance and Assurance for Concept Development Phase	64	02-Feb-23	05-May-23
116		**Concept Refinement Phase**	374	08-May-23	29-Oct-24
117		**Regulatory & Permitting for Concept Refinement Phase**	374	08-May-23	29-Oct-24
118		**Environmental Impact Assessment (EIA)**	374	08-May-23	29-Oct-24
119	NSWPH-112	Stakeholder Participation	373	08-May-23	28-Oct-24
120	NSWPH-115	EIA Announcement	124	08-May-23	30-Oct-23
121	NSWPH-376	Environmental Studies (Stage 1)	167	08-May-23	05-Jan-24
122	NSWPH-377	Environmental Studies (Stage 2)	82	08-Jan-24	02-May-24
123	NSWPH-378	EIA Report Produced (Stage 1)	146	08-Jan-24	02-Aug-24
124	NSWPH-379	EIA Report Produced (Stage 2)	61	05-Aug-24	29-Oct-24
125		**BDP**	313	08-May-23	02-Aug-24
126	NSWPH-3090	Technical Concept Developed	145	08-May-23	28-Nov-23
127	NSWPH-3100	Power Infrastructure Study Developed (HVDC Substation)	168	29-Nov-23	02-Aug-24
128	NSWPH-3110	Electrolysis Study Developed (Building/Electrolyser Stacks/Utilities/H2 Compressor)	168	29-Nov-23	02-Aug-24
129	NSWPH-3880	Caisson Island Study Developed	168	29-Nov-23	02-Aug-24
130		**Project Management**	368	08-May-23	21-Oct-24
131	NSWPH-2950	Estimate and Schedule Updated	62	08-May-23	02-Aug-23
132	NSWPH-2930	Project Execution Strategy and Plan Updated	55	05-Aug-24	21-Oct-24
133	NSWPH-2940	Estimate and Schedule Updated	55	05-Aug-24	21-Oct-24
134		**Regulatory & Permitting for Concept Refinement Phase**	125	03-May-24	29-Oct-24
135	NSWPH-3580	Permit Application Prepared	125	03-May-24	29-Oct-24
136		**Contracting & Procurement**	64	03-May-24	02-Aug-24
137	NSWPH-2640	RFI Quotations - Balance of Plant/BoP Contractor (Design/Supply/Install)	64	03-May-24	02-Aug-24
138	NSWPH-2650	RFI Quotations - HVDC Substation Contractor (Design/Supply/Install/Commission)	64	03-May-24	02-Aug-24
139	NSWPH-2660	RFI Quotations - Electrolyser Stack/Module Supplier (Design/Supply)	64	03-May-24	02-Aug-24
140	NSWPH-2670	RFI Quotations - Electrolyser EPS Company (Electrolysis - Design/Supply/Install/Commission)	64	03-May-24	02-Aug-24
141		**FEED Phase**	3908	30-Oct-24	27-Jan-40
142		**Caisson Island**	344	30-Oct-24	17-Mar-26
143	NSWPH-4290	Caisson Island Design Developed	344	30-Oct-24	17-Mar-26
144		**Power Infrastructure**	344	30-Oct-24	17-Mar-26
145	NSWPH-3430	Caisson Island Power Infrastructure Design Developed - HVDC Substation	344	30-Oct-24	17-Mar-26
146	NSWPH-3440	Caisson Island Power Infrastructure Design Developed - Grid Connections	344	30-Oct-24	17-Mar-26
147	NSWPH-3450	Caisson Island Power Infrastructure Design Developed - Rectifier and Transformers	344	30-Oct-24	17-Mar-26



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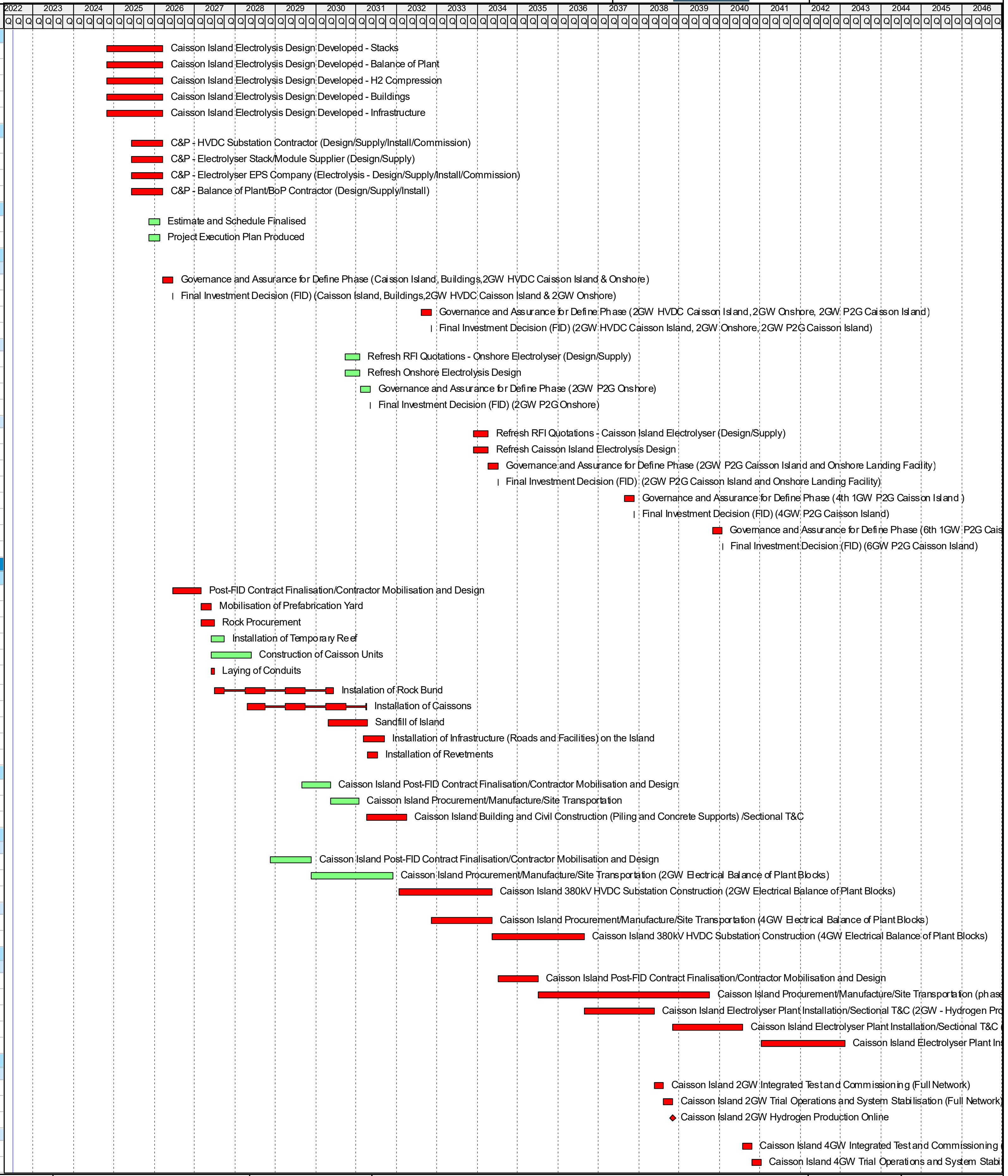
04-Aug-22	NSWPH - Caisson Island Schedule Rev B for Submission	PT	

NSWPH Level 1 Caisson Island Schedule Revison B

#	Activity ID	Activity Name	Original Duration	Start	Finish
148	**Electrolysis**		344	30-Oct-24	17-Mar-26
149	NSWPH-3160	Caisson Island Electrolysis Design Developed - Stacks	344	30-Oct-24	17-Mar-26
150	NSWPH-3170	Caisson Island Electrolysis Design Developed - Balance of Plant	344	30-Oct-24	17-Mar-26
151	NSWPH-3180	Caisson Island Electrolysis Design Developed - H2 Compression	344	30-Oct-24	17-Mar-26
152	NSWPH-3190	Caisson Island Electrolysis Design Developed - Buildings	344	30-Oct-24	17-Mar-26
153	NSWPH-3200	Caisson Island Electrolysis Design Developed - Infrastructure	344	30-Oct-24	17-Mar-26
154	**Contracting & Procurement**		194	10-Jun-25	17-Mar-26
155	NSWPH-1370	C&P - HVDC Substation Contractor (Design/Supply/Install/Commission)	194	10-Jun-25	17-Mar-26
156	NSWPH-1380	C&P - Electrolyser Stack/Module Supplier (Design/Supply)	194	10-Jun-25	17-Mar-26
157	NSWPH-1390	C&P - Electrolyser EPS Company (Electrolysis - Design/Supply/Install/Commission)	194	10-Jun-25	17-Mar-26
158	NSWPH-2630	C&P - Balance of Plant/BoP Contractor (Design/Supply/Install)	194	10-Jun-25	17-Mar-26
159	**Project Management**		60	18-Nov-25	18-Feb-26
160	NSWPH-3340	Estimate and Schedule Finalised	60	18-Nov-25	18-Feb-26
161	NSWPH-3350	Project Execution Plan Produced	60	18-Nov-25	18-Feb-26
162	**Governance & Assurance for FEED Phase**		3564	18-Mar-26	27-Jan-40
163	**Caisson Island and Electrical Infrastructure**		1701	18-Mar-26	11-Nov-32
164	NSWPH-147	Governance and Assurance for Define Phase (Caisson Island, Buildings,2GW HVDC Caisson Island & Onshore)	65	18-Mar-26	16-Jun-26
165	NSWPH-148	Final Investment Decision (FID) (Caisson Island, Buildings,2GW HVDC Caisson Island & 2GW Onshore)	1	17-Jun-26	17-Jun-26
166	NSWPH-402	Governance and Assurance for Define Phase (2GW HVDC Caisson Island, 2GW Onshore, 2GW P2G Caisson Island)	65	12-Aug-32	10-Nov-32
167	NSWPH-403	Final Investment Decision (FID) (2GW HVDC Caisson Island, 2GW Onshore, 2GW P2G Caisson Island)	1	11-Nov-32	11-Nov-32
168	**P2G Onshore**		156	26-Sep-30	09-May-31
169	NSWPH-514	Refresh RFI Quotations - Onshore Electrolyser (Design/Supply)	90	26-Sep-30	06-Feb-31
170	NSWPH-326	Refresh Onshore Electrolysis Design	90	26-Sep-30	06-Feb-31
171	NSWPH-338	Governance and Assurance for Define Phase (2GW P2G Onshore)	65	07-Feb-31	08-May-31
172	NSWPH-339	Final Investment Decision (FID) (2GW P2G Onshore)	1	09-May-31	09-May-31
173	**P2G Caisson Island**		1599	25-Nov-33	27-Jan-40
174	NSWPH-515	Refresh RFI Quotations - Caisson Island Electrolyser (Design/Supply)	90	25-Nov-33	07-Apr-34
175	NSWPH-516	Refresh Caisson Island Electrolysis Design	90	25-Nov-33	07-Apr-34
176	NSWPH-336	Governance and Assurance for Define Phase (2GW P2G Caisson Island and Onshore Landing Facility)	65	10-Apr-34	07-Jul-34
177	NSWPH-337	Final Investment Decision (FID) (2GW P2G Caisson Island and Onshore Landing Facility)	1	10-Jul-34	10-Jul-34
178	NSWPH-489	Governance and Assurance for Define Phase (4th 1GW P2G Caisson Island)	65	20-Aug-37	18-Nov-37
179	NSWPH-490	Final Investment Decision (FID) (4GW P2G Caisson Island)	1	19-Nov-37	19-Nov-37
180	NSWPH-501	Governance and Assurance for Define Phase (6th 1GW P2G Caisson Island)	65	28-Oct-39	26-Jan-40
181	NSWPH-502	Final Investment Decision (FID) (6GW P2G Caisson Island)	1	27-Jan-40	27-Jan-40
182	**Detailed Design and Implementation Phase**		4408	18-Jun-26	27-Jul-43
183	**Caisson Island**		1335	18-Jun-26	10-Sep-31
184	NSWPH-4250	Post-FID Contract Finalisation/Contractor Mobilisation and Design	180	18-Jun-26	04-Mar-27
185	NSWPH-4280	Mobilisation of Prefabrication Yard	65	05-Mar-27	03-Jun-27
186	NSWPH-4300	Rock Procurement	85	05-Mar-27	01-Jul-27
187	NSWPH-4310	Installation of Temporary Reef	85	04-Jun-27	30-Sep-27
188	NSWPH-4320	Construction of Caisson Units	250	04-Jun-27	26-May-28
189	NSWPH-4330	Laying of Conduits	20	04-Jun-27	01-Jul-27
190	NSWPH-4340	Instalation of Rock Bund	380	02-Jul-27	14-Jun-30
191	NSWPH-4360	Installation of Caissons	380	24-Apr-28	04-Apr-31
192	NSWPH-4370	Sandfill of Island	250	22-Apr-30	14-Apr-31
193	NSWPH-4390	Installation of Infrastructure (Roads and Facilities) on the Island	130	13-Mar-31	10-Sep-31
194	NSWPH-4380	Installation of Revetments	65	15-Apr-31	14-Jul-31
195	**Buildings**		659	29-Aug-29	01-Apr-32
196	NSWPH-1540	Caisson Island Post-FID Contract Finalisation/Contractor Mobilisation and Design	180	29-Aug-29	15-May-30
197	NSWPH-2970	Caisson Island Procurement/Manufacture/Site Transportation	180	16-May-30	30-Jan-31*
198	NSWPH-2960	Caisson Island Building and Civil Construction (Piling and Concrete Supports) /Sectional T&C	250	10-Apr-31	01-Apr-32
199	**Caisson Island HVDC Substation**		1985	20-Nov-28	26-Aug-36
200	**2GW Transmission**		1395	20-Nov-28	15-May-34
201	NSWPH-152	Caisson Island Post-FID Contract Finalisation/Contractor Mobilisation and Design	258	20-Nov-28	22-Nov-29
202	NSWPH-171	Caisson Island Procurement/Manufacture/Site Transportation (2GW Electrical Balance of Plant Blocks)	513	23-Nov-29	27-Nov-31*
203	NSWPH-176	Caisson Island 380kV HVDC Substation Construction (2GW Electrical Balance of Plant Blocks)	590	23-Jan-32	15-May-34
204	**4GW Transmission**		970	12-Nov-32	26-Aug-36
205	NSWPH-353	Caisson Island Procurement/Manufacture/Site Transportation (4GW Electrical Balance of Plant Blocks)	380	12-Nov-32	15-May-34
206	NSWPH-351	Caisson Island 380kV HVDC Substation Construction (4GW Electrical Balance of Plant Blocks)	590	16-May-34	26-Aug-36
207	**Caisson Island Power to Gas**		2233	11-Jul-34	06-Feb-43
208	**Electrolyser Plant**		2233	11-Jul-34	06-Feb-43
209	NSWPH-324	Caisson Island Post-FID Contract Finalisation/Contractor Mobilisation and Design	250	11-Jul-34	03-Jul-35
210	NSWPH-325	Caisson Island Procurement/Manufacture/Site Transportation (phased for 1-6GW)	1109	04-Jul-35	03-Oct-39
211	NSWPH-327	Caisson Island Electrolyser Plant Installation/Sectional T&C (2GW - Hydrogen Production Offline)	450	27-Aug-36	18-May-38
212	NSWPH-329	Caisson Island Electrolyser Plant Installation/Sectional T&C (4GW - Hydrogen Production Offline)	450	05-Nov-38	26-Jul-40
213	NSWPH-492	Caisson Island Electrolyser Plant Installation/Sectional T&C (6GW - Hydrogen Production Offline)	540	14-Jan-41	06-Feb-43
214	**Integrated T&C/Trial Operations P2G Caisson Island**		1895	19-May-38	27-Jul-43
215	**2GW Production**		170	19-May-38	05-Nov-38
216	NSWPH-298	Caisson Island 2GW Integrated Test and Commissioning (Full Network)	85	19-May-38	11-Aug-38
217	NSWPH-299	Caisson Island 2GW Trial Operations and System Stabilisation (Full Network)	85	12-Aug-38	04-Nov-38
218	NSWPH-300	Caisson Island 2GW Hydrogen Production Online	0	05-Nov-38	
219	**4GW Production**		170	27-Jul-40	13-Jan-41
220	NSWPH-321	Caisson Island 4GW Integrated Test and Commissioning (Full Network)	85	27-Jul-40	19-Oct-40
221	NSWPH-322	Caisson Island 4GW Trial Operations and System Stabilisation (Full Network)	85	20-Oct-40	12-Jan-41

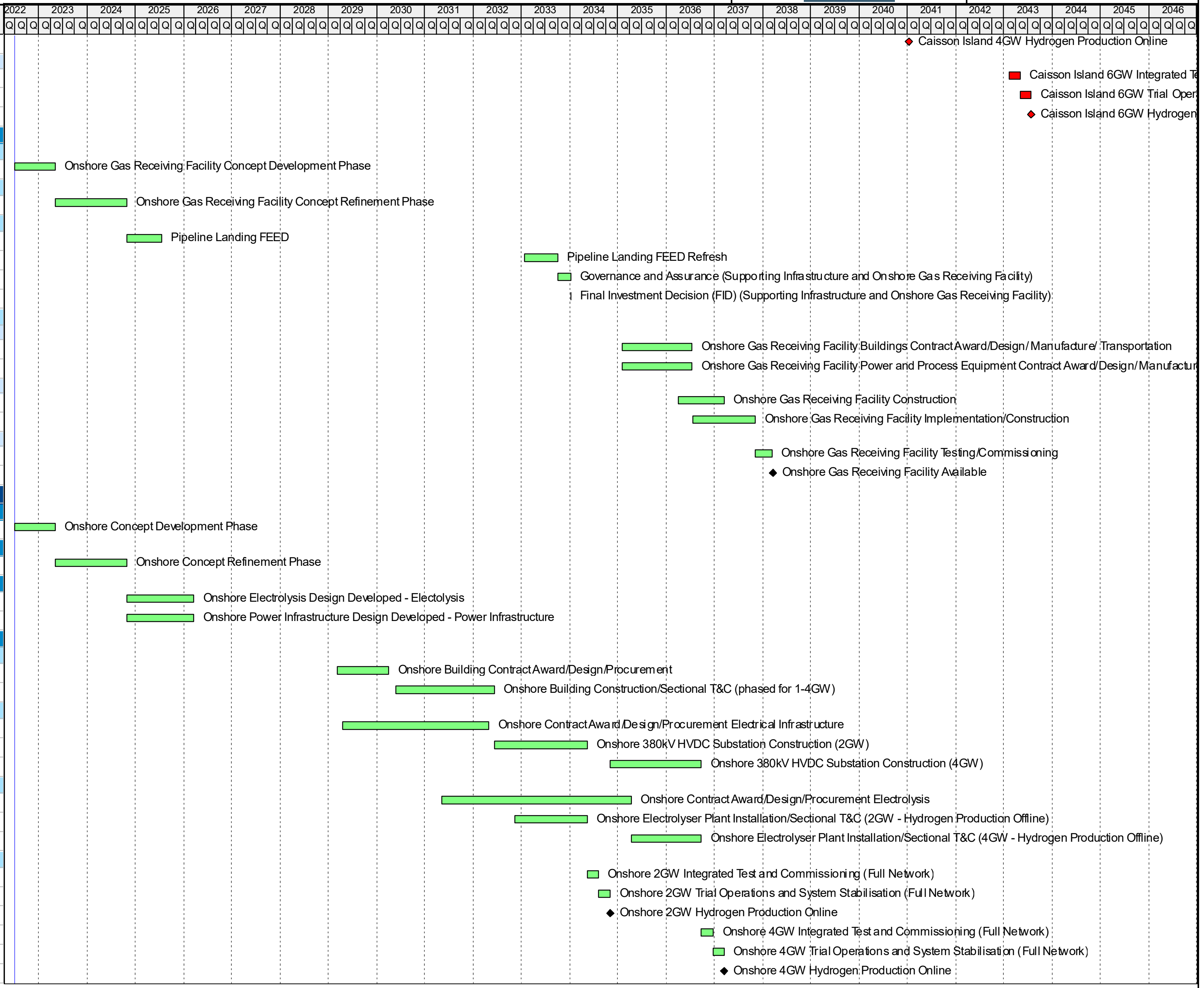


🟦 Actual Work
🟩 Remaining Work
🟥 Critical Remaining Work
◆ Milestone
◆ Critical Milestone

Date	Revision	Checked	Approved
04-Aug-22	NSWPH - Caisson Island Schedule Rev B for Submission	PT	

NSWPH Level 1 Caisson Island Schedule Revison B

#	Activity ID	Activity Name	Original Duration	Start	Finish
222	NSWPH-323	Caisson Island 4GW Hydrogen Production Online	0	13-Jan-41	
223	**6GW Production**		170	07-Feb-43	27-Jul-43
224	NSWPH-496	Caisson Island 6GW Integrated Test and Commissioning (Full Network)	85	07-Feb-43	02-May-43
225	NSWPH-497	Caisson Island 6GW Trial Operations and System Stabilisation (Full Network)	85	03-May-43	26-Jul-43
226	NSWPH-498	Caisson Island 6GW Hydrogen Production Online	0	27-Jul-43	
227	**Onshore Gas Receiving Facility**		4003	04-Jul-22	16-Mar-38
228	**Concept Development Phase**		210	04-Jul-22	05-May-23
229	NSWPH-1260	Onshore Gas Receiving Facility Concept Development Phase	210	04-Jul-22	05-May-23
230	**Concept Refinement Phase**		374	08-May-23	29-Oct-24
231	NSWPH-1270	Onshore Gas Receiving Facility Concept Refinement Phase	374	08-May-23	29-Oct-24
232	**FEED Phase**		2335	30-Oct-24	09-Jan-34
233	NSWPH-1280	Pipeline Landing FEED	181	30-Oct-24	22-Jul-25
234	NSWPH-1340	Pipeline Landing FEED Refresh	180	24-Jan-33	30-Sep-33
235	NSWPH-1360	Governance and Assurance (Supporting Infrastructure and Onshore Gas Receiving Facility)	65	03-Oct-33	09-Jan-34
236	NSWPH-1310	Final Investment Decision (FID) (Supporting Infrastructure and Onshore Gas Receiving Facility)	1	09-Jan-34*	09-Jan-34
237	**Detailed Design and Implementation Phase**		811	05-Feb-35	16-Mar-38
238	**Detailed Design and Procurement**		380	05-Feb-35	18-Jul-36
239	NSWPH-129	Onshore Gas Receiving Facility Buildings Contract Award/Design/Manufacture/ Transportation	380	05-Feb-35*	18-Jul-36
240	NSWPH-133	Onshore Gas Receiving Facility Power and Process Equipment Contract Award/Design/Manufacture/ Transportation	380	05-Feb-35*	18-Jul-36
241	**Implementation/Construction**		419	31-Mar-36	05-Nov-37
242	NSWPH-132	Onshore Gas Receiving Facility Construction	250	31-Mar-36	13-Mar-37
243	NSWPH-135	Onshore Gas Receiving Facility Implementation/Construction	339	21-Jul-36	05-Nov-37
244	**Testing and Commissioning**		130	06-Nov-37	16-Mar-38
245	NSWPH-179	Onshore Gas Receiving Facility Testing/Commissioning	130	06-Nov-37	15-Mar-38
246	NSWPH-180	Onshore Gas Receiving Facility Available	0	16-Mar-38	
247	**Onshore Facility**		3742	04-Jul-22	15-Mar-37
248	**Concept Development Phase**		210	04-Jul-22	05-May-23
249	NSWPH-1000	Onshore Concept Development Phase	210	04-Jul-22	05-May-23
250	**Concept Refinement Phase**		374	08-May-23	29-Oct-24
251	NSWPH-1010	Onshore Concept Refinement Phase	374	08-May-23*	29-Oct-24
252	**FEED Phase**		344	30-Oct-24	17-Mar-26
253	NSWPH-4710	Onshore Electrolysis Design Developed - Electolysis	344	30-Oct-24	17-Mar-26
254	NSWPH-4720	Onshore Power Infrastructure Design Developed - Power Infrastructure	344	30-Oct-24	17-Mar-26
255	**Detailed Design and Implementation Phase**		2054	12-Mar-29	15-Mar-37
256	**Buildings**		831	12-Mar-29	10-Jun-32
257	NSWPH-1610	Onshore Building Contract Award/Design/Procurement	271	12-Mar-29	02-Apr-30
258	NSWPH-1620	Onshore Building Construction/Sectional T&C (phased for 1-4GW)	520	29-May-30	10-Jun-32
259	**Power Infrastructure**		1903	23-Apr-29	25-Sep-36
260	NSWPH-4850	Onshore Contract Award/Design/Procurement Electrical Infrastructure	771	23-Apr-29	29-Apr-32*
261	NSWPH-4730	Onshore 380kV HVDC Substation Construction (2GW)	490	11-Jun-32	15-May-34
262	NSWPH-1980	Onshore 380kV HVDC Substation Construction (4GW)	490	02-Nov-34	25-Sep-36
263	**Electrolysis**		1380	12-May-31	25-Sep-36
264	NSWPH-4860	Onshore Contract Award/Design/Procurement Electrolysis	1000	12-May-31	12-Apr-35
265	NSWPH-1820	Onshore Electrolyser Plant Installation/Sectional T&C (2GW - Hydrogen Production Offline)	380	12-Nov-32	15-May-34
266	NSWPH-2030	Onshore Electrolyser Plant Installation/Sectional T&C (4GW - Hydrogen Production Offline)	380	13-Apr-35	25-Sep-36
267	**Integrated T&C/Trial Operations/Hydrogen Production Online**		1034	16-May-34	15-Mar-37
268	NSWPH-2180	Onshore 2GW Integrated Test and Commissioning (Full Network)	85	16-May-34	08-Aug-34
269	NSWPH-2230	Onshore 2GW Trial Operations and System Stabilisation (Full Network)	85	09-Aug-34	01-Nov-34
270	NSWPH-2260	Onshore 2GW Hydrogen Production Online	0	02-Nov-34	
271	NSWPH-2390	Onshore 4GW Integrated Test and Commissioning (Full Network)	85	26-Sep-36	19-Dec-36
272	NSWPH-2420	Onshore 4GW Trial Operations and System Stabilisation (Full Network)	85	20-Dec-36	14-Mar-37
273	NSWPH-4760	Onshore 4GW Hydrogen Production Online	0	15-Mar-37	



🟦 Actual Work
🟥 Critical Remaining Work
◆ Critical Milestone
🟩 Remaining Work
◆ Milestone

Date	Revision	Checked	Approved
04-Aug-22	NSWPH - Caisson Island Schedule Rev B for Submission	PT	

North Sea
Wind Power Hub
Programme

MOTT MACDONALD

Client: NSWPH

Project: NSWPH

Project Number: 424532

Document Name: Combined Schedule

Document Number: 424532-N-RP-0005

Revision: B

Pages: 1 of 8

B	21-Jan-22	-	Issued for Review	Paul Towse	Jamie Paul	Ian Day
A	25-Nov-21	-	Issued for Review	Paul Towse	Jamie Paul	Ian Day
Rev	**Date**	**Status**	**Description**	**By**	**Check**	**Approved**

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1 Introduction

Rev

The NSWPH project plans to develop an electrolysis-based hydrogen production facility in the coastal province of the North Sea. The electrolysis plant will be supplied by 4GW of offshore wind power. Hydrogen produced by the facility will be exported by pipeline.

1.1 Document Purpose

Identification of the Assumptions included within Level 1 Combined Onshore and Offshore Schedule RevB, to provide context on how the schedule has been developed.

1.2 Document Objectives

The objectives of this document are:

Identify the assumptions included within Level 1 Combined Onshore and Offshore Schedule RevB

1.3 Document Scope

The scope of the document is for the hydrogen production site.

2 Assumptions

2.1 When developing the Combined NSWPH Level 1 Schedule RevB the following assumptions have been included.

2.2 Assumptions

The Onshore facility will be delivered first with each 1GW Block sequenced to be brought online individually in one year staggers as below

1GW - 2030
2GW - 2031
3GW - 2032
4GW - 2033

The first offshore P2G facility 1GW block (2 platforms) is schedule to be completed 1 year after 4GW of the Onshore facility is complete. This is in line with the phasing presentation.

The Combined Level 1 schedule currently only includes the onshore and offshore P2G facilities. The schedule assumes any windfarm expansion is in line with the forecast platform installation and therefore not on the critical path.

The Offshore section of the Schedule has been developed into two main areas, Onshore Gas Receiving Facility and Offshore facility. The offshore facility section of the schedule is broken down in to two further areas to aid in the planning and monitoring of the project. These areas are Power and Process equipment and the Platform structures.

All equipment is deemed to be available and on site as required, therefore it is assumed that the supply chain can deliver to meet forecast dates

Supply chain duration would need validation to ensure delivery dates can be achieved

Each phase is completed with Governance and Assurance before commencing the next.

Milestones (NSWPH-1170 and NSWPH-2650) have been included to identify when information would be required from the supply chain to meet forecast dates for concept design and FEED respectively.

Milestones (NSWPH-2750 and NSWPH-2760) have been included to identify when 2GW and 4GW Onshore Electrical Infrastructure will be complete.

Concept Development phases for all areas of the project are assumed complete prior to commencing Concept Refinement phases for the P2G processing facility.

Concept Refinement phases for all areas of the project are complete prior to commencing FEED phases for the P2G processing facility.

FEED phases for all areas of the project are complete prior to commencing the first Final Investment Decision and commencing Detailed Design and Implementation phase for the P2G processing facility.

No significant investment will be made pre- Final Investment Decision (FID).

Final Investment Decisions are staged for two platforms (1GW) at a time and scheduled to meet forecast dates.

The pipeline between the onshore facility and offshore facility is in place prior to the commissioning of the first 1GW block

Site power and utilities are in place prior to commencing any on site construction tasks

Onshore Gas Receiving Facility

The FEED design time for the Onshore Gas Receiving Facility is less than the offshore facility but there are interdependences between the two, therefore they are scheduled to be completed at the same time.

The Onshore Gas Receiving Facility can be built independently from the offshore platforms but is required to commission the first 1GW platforms.

The Grid connection will be in place and available for commissioning.

Offshore Facility

The Concept design for both the Power and Process and Platform Structures are scheduled to be completed at the same time to enable the project to progress to the next stage

The FEED design for both the Power and Process and Platform Structures are scheduled to be completed at the same time to enable the project to progress to the next stage

The Process and Power equipment is scheduled to be available in time for the required installation date. This is assumed to be staged in line with the forecast dates for the construction of each level of the module. (ie the equipment for Level one will be delivered prior to that required for level 2). These forecast dates are identified within the schedule.

Due to the gap between the FEED design of the Offshore facility and the next steps, a FEED refresh activity has been included prior to the first FID.

The construction duration for the first topside modules are 36 months. It is assumed that this period can be slightly reduced for the later units

It is assumed that there is no constraint on the availability of locations to build the topside modules

The critical path lies through the construction and installation of the topside modules. In the current schedule the substructures are not critical.

The Jacket substructures are included in the current schedule, however it is felt that as the critical path is through the construction of the first topside modules, any of the substructure solutions proposed would not impact on the forecast completion dates of the Platforms.

The Jacket substructures are sequenced to be install 1 year before the topside module.

It is assumed that the critical activity for the float-over installation of the topside’s modules needs to be undertaken during the summer months (May to August)

To deliver 1GW, 2 modules are required and the schedule assumes that both would be installed within the same summer installation window.

The first GW is scheduled to be complete one year after the completion of the 4GW Onshore facility in 2035

The remaining 3GW are sequenced to be brought online individually in one year staggers as below

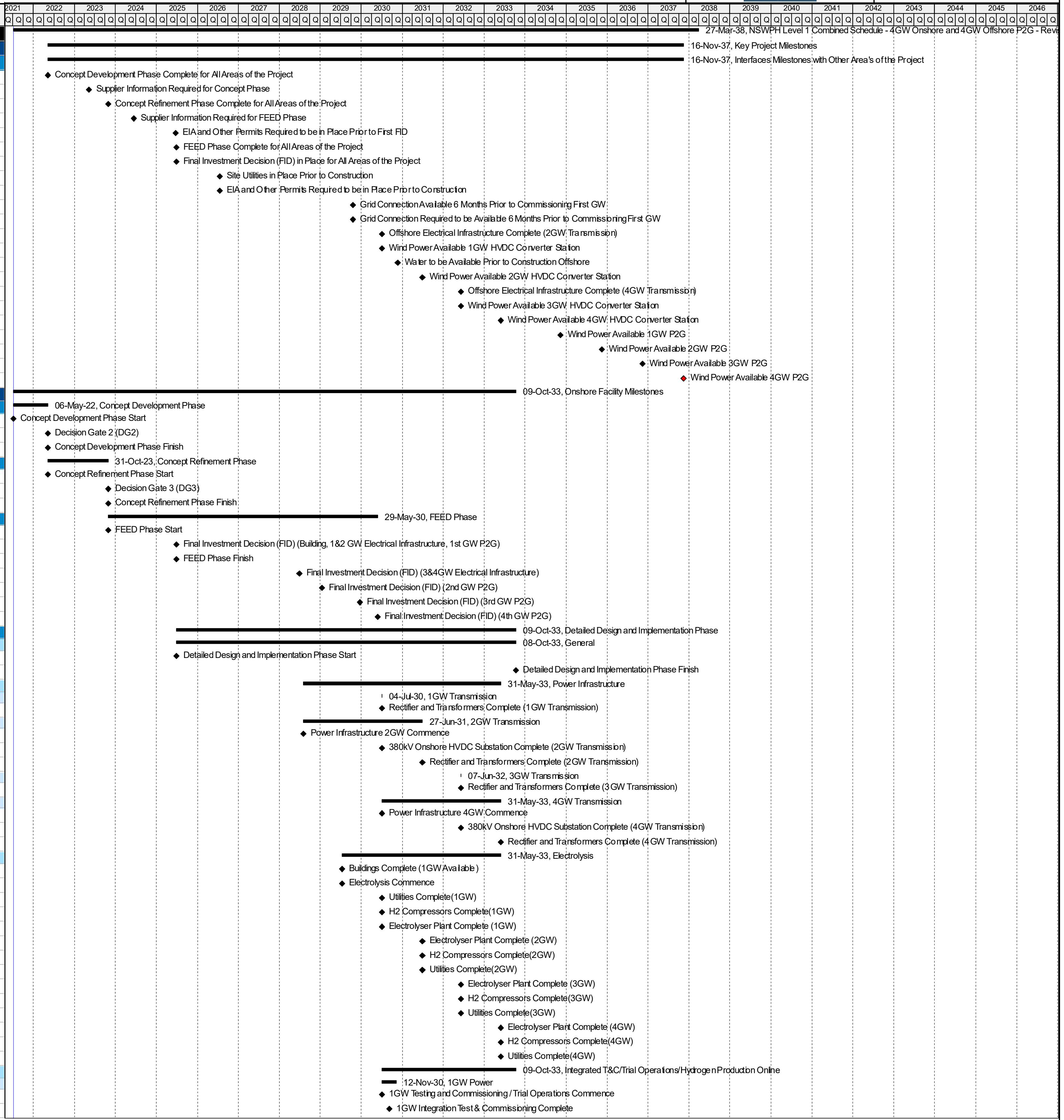
2GW - 2036
3GW - 2037
4GW - 2038

NSWPH Level 1 Combined Schedule - 4GW Onshore and 4GW Offshore P2G - Revison B

North Sea Wind Power Hub Programme

MOTT MACDONALD

#	Activity ID	Activity Name	Original Duration	Remaining Duration	Start	Finish
1	**NSWPH Level 1 Combined Schedule - 4GW Onshore and 4GW Offshore P2G - Revison B**		4261	4261	05-Jul-21	27-Mar-38
2	**Key Project Milestones**		3957	3957	06-May-22	16-Nov-37
3	**Interfaces Milestones with Other Area's of the Project**		3957	3957	06-May-22	16-Nov-37
4	NSWPH-2530	Concept Development Phase Complete for All Areas of the Project	0	0		06-May-22
5	NSWPH-2740	Supplier Information Required for Concept Phase	0	0	08-May-23	
6	NSWPH-2540	Concept Refinement Phase Complete for All Areas of the Project	0	0		31-Oct-23
7	NSWPH-2750	Supplier Information Required for FEED Phase	0	0	12-Jun-24	
8	NSWPH-2760	EIA and Other Permits Required to be in Place Prior to First FID	0	0		23-Jun-25
9	NSWPH-2550	FEED Phase Complete for All Areas of the Project	0	0		24-Jun-25
10	NSWPH-2560	Final Investment Decision (FID) in Place for All Areas of the Project	0	0		24-Jun-25
11	NSWPH-2730	Site Utilities in Place Prior to Construction	0	0		17-Jul-26
12	NSWPH-2360	EIA and Other Permits Required to be in Place Prior to Construction	0	0		17-Jul-26
13	NSWPH-2770	Grid Connection Available 6 Months Prior to Commissioning First GW	0	0		17-Oct-29
14	NSWPH-2370	Grid Connection Required to be Available 6 Months Prior to Commissioning First GW	0	0		17-Oct-29
15	NSWPH-2780	Offshore Electrical Infrastructure Complete (2GW Transmission)	0	0		04-Jul-30
16	NSWPH-4170	Wind Power Available 1GW HVDC Converter Station	0	0		04-Jul-30
17	NSWPH-2380	Water to be Available Prior to Construction Offshore	0	0		20-Nov-30
18	NSWPH-4180	Wind Power Available 2GW HVDC Converter Station	0	0		27-Jun-31
19	NSWPH-2790	Offshore Electrical Infrastructure Complete (4GW Transmission)	0	0		07-Jun-32
20	NSWPH-4190	Wind Power Available 3GW HVDC Converter Station	0	0		07-Jun-32
21	NSWPH-4200	Wind Power Available 4GW HVDC Converter Station	0	0		31-May-33
22	NSWPH-4210	Wind Power Available 1GW P2G	0	0		14-Nov-34
23	NSWPH-4220	Wind Power Available 2GW P2G	0	0		14-Nov-35
24	NSWPH-4230	Wind Power Available 3GW P2G	0	0		12-Nov-36
25	NSWPH-4240	Wind Power Available 4GW P2G	0	0		16-Nov-37
26	**Onshore Facility Milestones**		3108	3108	05-Jul-21	09-Oct-33
27	**Concept Development Phase**		210	210	05-Jul-21	06-May-22
28	NSWPH-3460	Concept Development Phase Start	0	0	05-Jul-21	
29	NSWPH-1090	Decision Gate 2 (DG2)	0	0		06-May-22
30	NSWPH-1100	Concept Development Phase Finish	0	0		06-May-22
31	**Concept Refinement Phase**		374	374	09-May-22	31-Oct-23
32	NSWPH-1110	Concept Refinement Phase Start	0	0	09-May-22	
33	NSWPH-2840	Decision Gate 3 (DG3)	0	0		31-Oct-23
34	NSWPH-2850	Concept Refinement Phase Finish	0	0		31-Oct-23
35	**FEED Phase**		1665	1665	01-Nov-23	29-May-30
36	NSWPH-3690	FEED Phase Start	0	0	01-Nov-23	
37	NSWPH-3680	Final Investment Decision (FID) (Building, 1&2 GW Electrical Infrastructure, 1st GW P2G)	0	0		24-Jun-25
38	NSWPH-3700	FEED Phase Finish	0	0		24-Jun-25
39	NSWPH-3720	Final Investment Decision (FID) (3&4GW Electrical Infrastructure)	0	0		29-Jun-28
40	NSWPH-4060	Final Investment Decision (FID) (2nd GW P2G)	0	0		16-Jan-29
41	NSWPH-4070	Final Investment Decision (FID) (3rd GW P2G)	0	0		18-Dec-29
42	NSWPH-3710	Final Investment Decision (FID) (4th GW P2G)	0	0		29-May-30
43	**Detailed Design and Implementation Phase**		2114	2114	25-Jun-25	09-Oct-33
44	**General**		2114	2114	25-Jun-25	08-Oct-33
45	NSWPH-2680	Detailed Design and Implementation Phase Start	0	0	25-Jun-25	
46	NSWPH-2690	Detailed Design and Implementation Phase Finish	0	0		08-Oct-33
47	**Power Infrastructure**		1230	1230	02-Aug-28	31-May-33
48	**1GW Transmission**		0	0	04-Jul-30	04-Jul-30
49	NSWPH-3400	Rectifier and Transformers Complete (1GW Transmission)	0	0		04-Jul-30
50	**2GW Transmission**		740	740	02-Aug-28	27-Jun-31
51	NSWPH-3600	Power Infrastructure 2GW Commence	0	0	02-Aug-28	
52	NSWPH-3590	380kV Onshore HVDC Substation Complete (2GW Transmission)	0	0		04-Jul-30
53	NSWPH-3610	Rectifier and Transformers Complete (2GW Transmission)	0	0		27-Jun-31
54	**3GW Transmission**		0	0	07-Jun-32	07-Jun-32
55	NSWPH-3500	Rectifier and Transformers Complete (3GW Transmission)	0	0		07-Jun-32
56	**4GW Transmission**		740	740	05-Jul-30	31-May-33
57	NSWPH-3320	Power Infrastructure 4GW Commence	0	0	05-Jul-30	
58	NSWPH-3310	380kV Onshore HVDC Substation Complete (4GW Transmission)	0	0		07-Jun-32
59	NSWPH-3330	Rectifier and Transformers Complete (4GW Transmission)	0	0		31-May-33
60	**Electrolysis**		990	990	12-Jul-29	31-May-33
61	NSWPH-2430	Buildings Complete (1GW Available)	0	0		12-Jul-29
62	NSWPH-2500	Electrolysis Commence	0	0	12-Jul-29	
63	NSWPH-2450	Utilities Complete(1GW)	0	0		04-Jul-30
64	NSWPH-2460	H2 Compressors Complete(1GW)	0	0		04-Jul-30
65	NSWPH-2490	Electrolyser Plant Complete (1GW)	0	0		04-Jul-30
66	NSWPH-2480	Electrolyser Plant Complete (2GW)	0	0		27-Jun-31
67	NSWPH-2570	H2 Compressors Complete(2GW)	0	0		27-Jun-31
68	NSWPH-2600	Utilities Complete(2GW)	0	0		27-Jun-31
69	NSWPH-2470	Electrolyser Plant Complete (3GW)	0	0		07-Jun-32
70	NSWPH-2580	H2 Compressors Complete(3GW)	0	0		07-Jun-32
71	NSWPH-2610	Utilities Complete(3GW)	0	0		07-Jun-32
72	NSWPH-2440	Electrolyser Plant Complete (4GW)	0	0		31-May-33
73	NSWPH-2590	H2 Compressors Complete(4GW)	0	0		31-May-33
74	NSWPH-2620	Utilities Complete(4GW)	0	0		31-May-33
75	**Integrated T&C/Trial Operations/Hydrogen Production Online**		833	833	05-Jul-30	09-Oct-33
76	**1GW Power**		92	92	05-Jul-30	12-Nov-30
77	NSWPH-3040	1GW Testing and Commissioning / Trial Operations Commence	0	0	05-Jul-30	
78	NSWPH-3010	1GW Integration Test & Commissioning Complete	0	0		07-Sep-30



🟦 Actual Work	🟥 Critical Remaining Work	◆ Milestone
🟩 Remaining Work	▬ Summary	◆ Critical Milestone

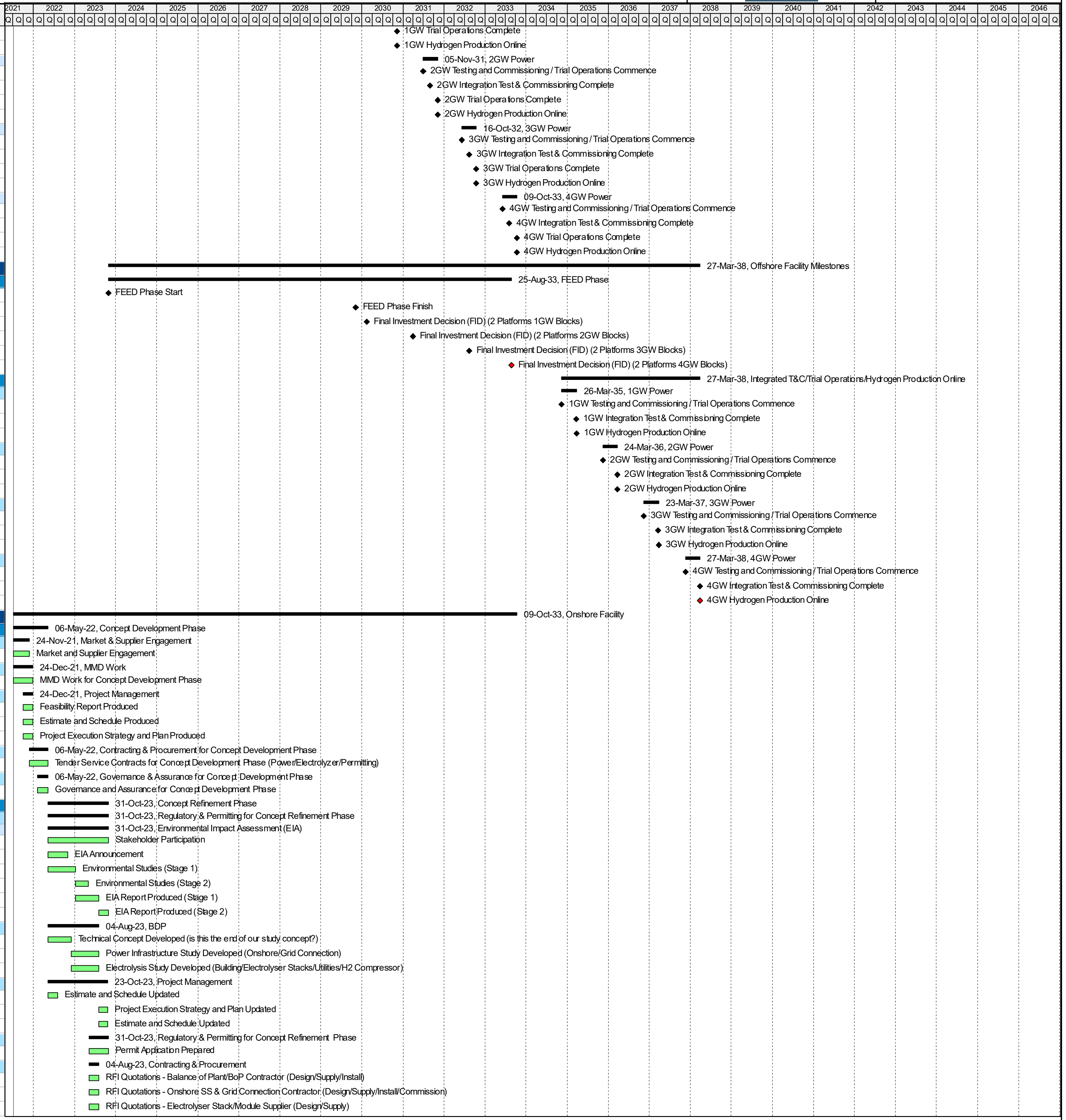
Date	Revision	Checked	Approved
21-Jan-22	NSWPH - Combined Onshore and Offshore Schedule	PT	

NSWPH Level 1 Combined Schedule - 4GW Onshore and 4GW Offshore P2G - Revison B

North Sea Wind Power Hub Programme

MOTT MACDONALD

#	Activity ID	Activity Name	Original Duration	Remaining Duration	Start	Finish
79	NSWPH-3030	1GW Trial Operations Complete	0	0		11-Nov-30
80	NSWPH-3020	1GW Hydrogen Production Online	0	0	12-Nov-30	
81	**2GW Power**		92	92	30-Jun-31	05-Nov-31
82	NSWPH-2830	2GW Testing and Commissioning / Trial Operations Commence	0	0	30-Jun-31	
83	NSWPH-2800	2GW Integration Test & Commissioning Complete	0	0		31-Aug-31
84	NSWPH-2820	2GW Trial Operations Complete	0	0		04-Nov-31
85	NSWPH-2810	2GW Hydrogen Production Online	0	0	05-Nov-31	
86	**3GW Power**		94	94	08-Jun-32	16-Oct-32
87	NSWPH-3150	3GW Testing and Commissioning / Trial Operations Commence	0	0	08-Jun-32	
88	NSWPH-3120	3GW Integration Test & Commissioning Complete	0	0		11-Aug-32
89	NSWPH-3140	3GW Trial Operations Complete	0	0		15-Oct-32
90	NSWPH-3130	3GW Hydrogen Production Online	0	0	16-Oct-32	
91	**4GW Power**		93	93	01-Jun-33	09-Oct-33
92	NSWPH-3080	4GW Testing and Commissioning / Trial Operations Commence	0	0	01-Jun-33	
93	NSWPH-3050	4GW Integration Test & Commissioning Complete	0	0		04-Aug-33
94	NSWPH-3070	4GW Trial Operations Complete	0	0		08-Oct-33
95	NSWPH-3060	4GW Hydrogen Production Online	0	0	09-Oct-33	
96	**Offshore Facility Milestones**		3677	3677	01-Nov-23	27-Mar-38
97	**FEED Phase**		2493	2493	01-Nov-23	25-Aug-33
98	NSWPH-3970	FEED Phase Start	0	0	01-Nov-23	
99	NSWPH-3980	FEED Phase Finish	0	0		05-Nov-29
100	NSWPH-3960	Final Investment Decision (FID) (2 Platforms 1GW Blocks)	0	0		13-Feb-30
101	NSWPH-3990	Final Investment Decision (FID) (2 Platforms 2GW Blocks)	0	0		27-Mar-31
102	NSWPH-4000	Final Investment Decision (FID) (2 Platforms 3GW Blocks)	0	0		16-Aug-32
103	NSWPH-4010	Final Investment Decision (FID) (2 Platforms 4GW Blocks)	0	0		25-Aug-33
104	**Integrated T&C/Trial Operations/Hydrogen Production Online**		872	872	15-Nov-34	27-Mar-38
105	**1GW Power**		87	87	15-Nov-34	26-Mar-35
106	NSWPH-3920	1GW Testing and Commissioning / Trial Operations Commence	0	0	15-Nov-34	
107	NSWPH-3800	1GW Integration Test & Commissioning Complete	0	0		24-Mar-35
108	NSWPH-3840	1GW Hydrogen Production Online	0	0	26-Mar-35	
109	**2GW Power**		92	92	15-Nov-35	24-Mar-36
110	NSWPH-3930	2GW Testing and Commissioning / Trial Operations Commence	0	0	15-Nov-35	
111	NSWPH-3810	2GW Integration Test & Commissioning Complete	0	0		23-Mar-36
112	NSWPH-3850	2GW Hydrogen Production Online	0	0	24-Mar-36	
113	**3GW Power**		92	92	13-Nov-36	23-Mar-37
114	NSWPH-3940	3GW Testing and Commissioning / Trial Operations Commence	0	0	13-Nov-36	
115	NSWPH-3820	3GW Integration Test & Commissioning Complete	0	0		22-Mar-37
116	NSWPH-3860	3GW Hydrogen Production Online	0	0	23-Mar-37	
117	**4GW Power**		94	94	17-Nov-37	27-Mar-38
118	NSWPH-3950	4GW Testing and Commissioning / Trial Operations Commence	0	0	17-Nov-37	
119	NSWPH-3830	4GW Integration Test & Commissioning Complete	0	0		26-Mar-38
120	NSWPH-3870	4GW Hydrogen Production Online	0	0	27-Mar-38	
121	**Onshore Facility**		3108	3108	05-Jul-21	09-Oct-33
122	**Concept Development Phase**		210	210	05-Jul-21	06-May-22
123	**Market & Supplier Engagement**		102	102	05-Jul-21	24-Nov-21
124	NSWPH-3410	Market and Supplier Engagement	102	102	05-Jul-21	24-Nov-21
125	**MMD Work**		124	124	05-Jul-21	24-Dec-21
126	NSWPH-3550	MMD Work for Concept Development Phase	124	124	05-Jul-21	24-Dec-21
127	**Project Management**		64	64	28-Sep-21	24-Dec-21
128	NSWPH-2700	Feasibility Report Produced	64	64	28-Sep-21	24-Dec-21
129	NSWPH-2710	Estimate and Schedule Produced	64	64	28-Sep-21	24-Dec-21
130	NSWPH-2720	Project Execution Strategy and Plan Produced	64	64	28-Sep-21	24-Dec-21
131	**Contracting & Procurement for Concept Development Phase**		108	108	25-Nov-21	06-May-22
132	NSWPH-3300	Tender Service Contracts for Concept Development Phase (Power/Electrolyzer/Permitting)	108	108	25-Nov-21	06-May-22
133	**Governance & Assurance for Concept Development Phase**		64	64	03-Feb-22	06-May-22
134	NSWPH-3420	Governance and Assurance for Concept Development Phase	64	64	03-Feb-22	06-May-22
135	**Concept Refinement Phase**		374	374	09-May-22	31-Oct-23
136	**Regulatory & Permitting for Concept Refinement Phase**		374	374	09-May-22	31-Oct-23
137	**Environmental Impact Assessment (EIA)**		374	374	09-May-22	31-Oct-23
138	NSWPH-1120	Stakeholder Participation	373	373	09-May-22	30-Oct-23
139	NSWPH-1150	EIA Announcement	124	124	09-May-22	31-Oct-22
140	NSWPH-3760	Environmental Studies (Stage 1)	167	167	09-May-22	06-Jan-23
141	NSWPH-3770	Environmental Studies (Stage 2)	82	82	09-Jan-23	05-May-23
142	NSWPH-3780	EIA Report Produced (Stage 1)	146	146	09-Jan-23	04-Aug-23
143	NSWPH-3790	EIA Report Produced (Stage 2)	61	61	07-Aug-23	31-Oct-23
144	**BDP**		313	313	09-May-22	04-Aug-23
145	NSWPH-3090	Technical Concept Developed (is this the end of our study concept?)	145	145	09-May-22	29-Nov-22
146	NSWPH-3100	Power Infrastructure Study Developed (Onshore/Grid Connection)	168	168	30-Nov-22	04-Aug-23
147	NSWPH-3110	Electrolysis Study Developed (Building/Electrolyser Stacks/Utilities/H2 Compressor)	168	168	30-Nov-22	04-Aug-23
148	**Project Management**		368	368	09-May-22	23-Oct-23
149	NSWPH-2950	Estimate and Schedule Updated	62	62	09-May-22	03-Aug-22
150	NSWPH-2930	Project Execution Strategy and Plan Updated	55	55	07-Aug-23	23-Oct-23
151	NSWPH-2940	Estimate and Schedule Updated	55	55	07-Aug-23	23-Oct-23
152	**Regulatory & Permitting for Concept Refinement Phase**		125	125	08-May-23	31-Oct-23
153	NSWPH-3580	Permit Application Prepared	125	125	08-May-23	31-Oct-23
154	**Contracting & Procurement**		64	64	08-May-23	04-Aug-23
155	NSWPH-2640	RFI Quotations - Balance of Plant/BoP Contractor (Design/Supply/Install)	64	64	08-May-23	04-Aug-23
156	NSWPH-2650	RFI Quotations - Onshore SS & Grid Connection Contractor (Design/Supply/Install/Commission)	64	64	08-May-23	04-Aug-23
157	NSWPH-2660	RFI Quotations - Electrolyser Stack/Module Supplier (Design/Supply)	64	64	08-May-23	04-Aug-23



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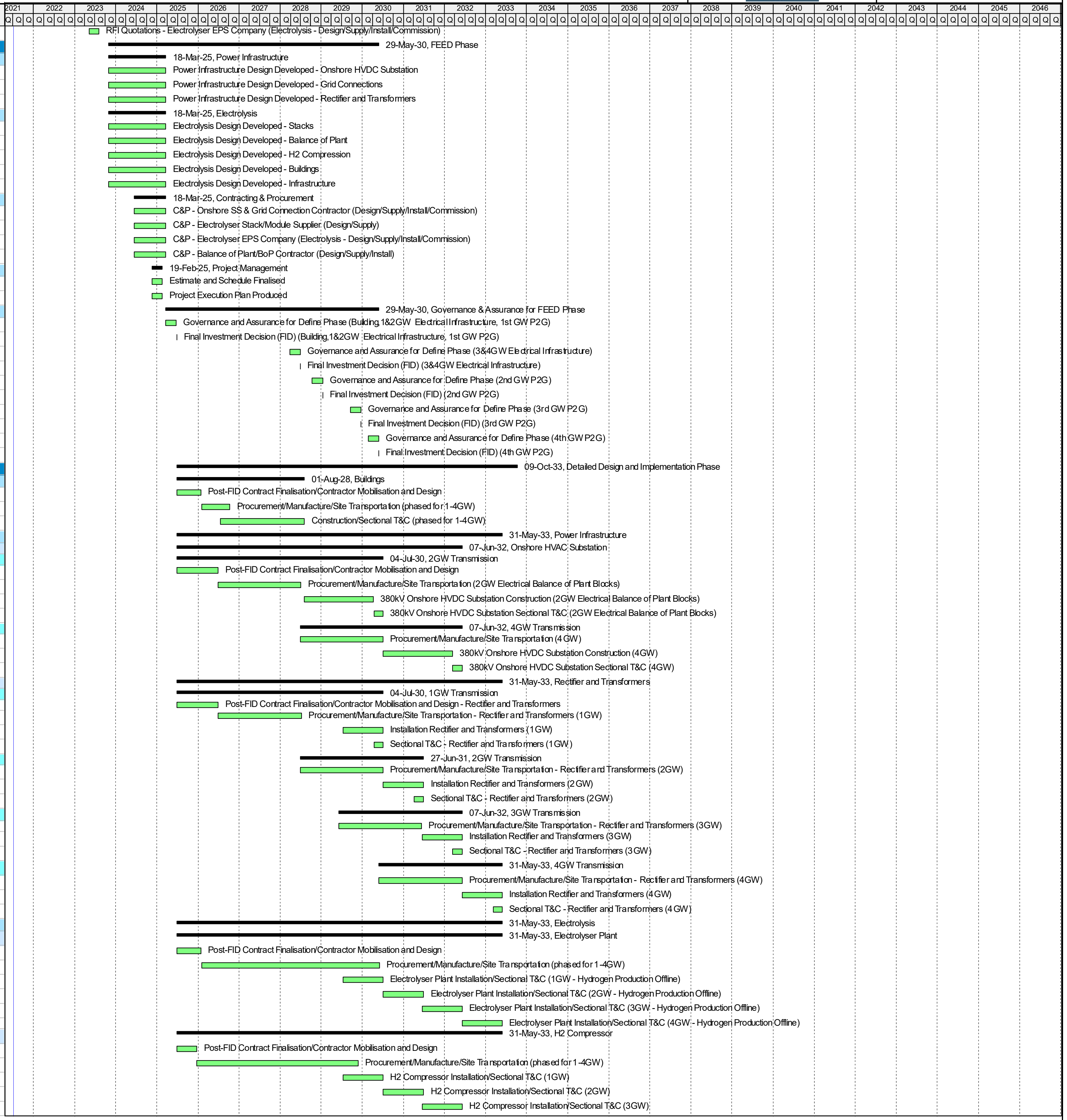
Date	Revision	Checked	Approved
21-Jan-22	NSWPH - Combined Onshore and Offshore Schedule	PT	

NSWPH Level 1 Combined Schedule - 4GW Onshore and 4GW Offshore P2G - Revison B

#	Activity ID	Activity Name	Original Duration	Remaining Duration	Start	Finish
158	NSWPH-2670	RFI Quotations - Electrolyser EPS Company (Electrolysis - Design/Supply/Install/Commission)	64	64	08-May-23	04-Aug-23
159	**FEED Phase**		1665	1665	01-Nov-23	29-May-30
160	**Power Infrastructure**		344	344	01-Nov-23	18-Mar-25
161	NSWPH-3430	Power Infrastructure Design Developed - Onshore HVDC Substation	344	344	01-Nov-23	18-Mar-25
162	NSWPH-3440	Power Infrastructure Design Developed - Grid Connections	344	344	01-Nov-23	18-Mar-25
163	NSWPH-3450	Power Infrastructure Design Developed - Rectifier and Transformers	344	344	01-Nov-23	18-Mar-25
164	**Electrolysis**		344	344	01-Nov-23	18-Mar-25
165	NSWPH-3160	Electrolysis Design Developed - Stacks	344	344	01-Nov-23	18-Mar-25
166	NSWPH-3170	Electrolysis Design Developed - Balance of Plant	344	344	01-Nov-23	18-Mar-25
167	NSWPH-3180	Electrolysis Design Developed - H2 Compression	344	344	01-Nov-23	18-Mar-25
168	NSWPH-3190	Electrolysis Design Developed - Buildings	344	344	01-Nov-23	18-Mar-25
169	NSWPH-3200	Electrolysis Design Developed - Infrastructure	344	344	01-Nov-23	18-Mar-25
170	**Contracting & Procurement**		194	194	12-Jun-24	18-Mar-25
171	NSWPH-1370	C&P - Onshore SS & Grid Connection Contractor (Design/Supply/Install/Commission)	194	194	12-Jun-24	18-Mar-25
172	NSWPH-1380	C&P - Electrolyser Stack/Module Supplier (Design/Supply)	194	194	12-Jun-24	18-Mar-25
173	NSWPH-1390	C&P - Electrolyser EPS Company (Electrolysis - Design/Supply/Install/Commission)	194	194	12-Jun-24	18-Mar-25
174	NSWPH-2630	C&P - Balance of Plant/BoP Contractor (Design/Supply/Install)	194	194	12-Jun-24	18-Mar-25
175	**Project Management**		60	60	20-Nov-24	19-Feb-25
176	NSWPH-3340	Estimate and Schedule Finalised	60	60	20-Nov-24	19-Feb-25
177	NSWPH-3350	Project Execution Plan Produced	60	60	20-Nov-24	19-Feb-25
178	**Governance & Assurance for FEED Phase**		1321	1321	19-Mar-25	29-May-30
179	NSWPH-1470	Governance and Assurance for Define Phase (Building,1&2GW Electrical Infrastructure, 1st GW P2G)	65	65	19-Mar-25	23-Jun-25
180	NSWPH-1480	Final Investment Decision (FID) (Building,1&2GW Electrical Infrastructure, 1st GW P2G)	1	1	24-Jun-25	24-Jun-25
181	NSWPH-3380	Governance and Assurance for Define Phase (3&4GW Electrical Infrastructure)	65	65	30-Mar-28	28-Jun-28
182	NSWPH-3390	Final Investment Decision (FID) (3&4GW Electrical Infrastructure)	1	1	29-Jun-28	29-Jun-28
183	NSWPH-4020	Governance and Assurance for Define Phase (2nd GW P2G)	65	65	10-Oct-28	16-Jan-29
184	NSWPH-4030	Final Investment Decision (FID) (2nd GW P2G)	1	1	17-Jan-29	17-Jan-29
185	NSWPH-4040	Governance and Assurance for Define Phase (3rd GW P2G)	65	65	19-Sep-29	18-Dec-29
186	NSWPH-4050	Final Investment Decision (FID) (3rd GW P2G)	1	1	19-Dec-29	19-Dec-29
187	NSWPH-3360	Governance and Assurance for Define Phase (4th GW P2G)	65	65	27-Feb-30	28-May-30
188	NSWPH-3370	Final Investment Decision (FID) (4th GW P2G)	1	1	29-May-30	29-May-30
189	**Detailed Design and Implementation Phase**		2114	2114	25-Jun-25	09-Oct-33
190	**Buildings**		791	791	25-Jun-25	01-Aug-28
191	NSWPH-1540	Post-FID Contract Finalisation/Contractor Mobilisation and Design	151	151	25-Jun-25	30-Jan-26
192	NSWPH-2970	Procurement/Manufacture/Site Transportation (phased for 1-4GW)	180	180	02-Feb-26	09-Oct-26
193	NSWPH-2960	Construction/Sectional T&C (phased for 1-4GW)	520	520	20-Jul-26	01-Aug-28
194	**Power Infrastructure**		2021	2021	25-Jun-25	31-May-33
195	**Onshore HVAC Substation**		1771	1771	25-Jun-25	07-Jun-32
196	**2GW Transmission**		1281	1281	25-Jun-25	04-Jul-30
197	NSWPH-1520	Post-FID Contract Finalisation/Contractor Mobilisation and Design	258	258	25-Jun-25	30-Jun-26
198	NSWPH-1710	Procurement/Manufacture/Site Transportation (2GW Electrical Balance of Plant Blocks)	513	513	01-Jul-26	04-Jul-28
199	NSWPH-1760	380kV Onshore HVDC Substation Construction (2GW Electrical Balance of Plant Blocks)	430	430	02-Aug-28	11-Apr-30
200	NSWPH-3540	380kV Onshore HVDC Substation Sectional T&C (2GW Electrical Balance of Plant Blocks)	60	60	12-Apr-30	04-Jul-30
201	**4GW Transmission**		1003	1003	30-Jun-28	07-Jun-32
202	NSWPH-3530	Procurement/Manufacture/Site Transportation (4GW)	513	513	30-Jun-28	04-Jul-30
203	NSWPH-3510	380kV Onshore HVDC Substation Construction (4GW)	430	430	05-Jul-30	15-Mar-32
204	NSWPH-3520	380kV Onshore HVDC Substation Sectional T&C (4GW)	60	60	16-Mar-32	07-Jun-32
205	**Rectifier and Transformers**		2021	2021	25-Jun-25	31-May-33
206	**1GW Transmission**		1281	1281	25-Jun-25	04-Jul-30
207	NSWPH-2860	Post-FID Contract Finalisation/Contractor Mobilisation and Design - Rectifier and Transformers	258	258	25-Jun-25	30-Jun-26
208	NSWPH-2870	Procurement/Manufacture/Site Transportation - Rectifier and Transformers (1GW)	516	516	01-Jul-26	07-Jul-28
209	NSWPH-1770	Installation Rectifier and Transformers (1GW)	250	250	12-Jul-29	04-Jul-30
210	NSWPH-2880	Sectional T&C - Rectifier and Transformers (1GW)	60	60	12-Apr-30	04-Jul-30
211	**2GW Transmission**		766	766	27-Jun-28	27-Jun-31
212	NSWPH-3560	Procurement/Manufacture/Site Transportation - Rectifier and Transformers (2GW)	516	516	27-Jun-28	04-Jul-30
213	NSWPH-1780	Installation Rectifier and Transformers (2GW)	250	250	05-Jul-30	27-Jun-31
214	NSWPH-3570	Sectional T&C - Rectifier and Transformers (2GW)	60	60	07-Apr-31	27-Jun-31
215	**3GW Transmission**		766	766	06-Jun-29	07-Jun-32
216	NSWPH-3630	Procurement/Manufacture/Site Transportation - Rectifier and Transformers (3GW)	516	516	06-Jun-29	13-Jun-31
217	NSWPH-3620	Installation Rectifier and Transformers (3GW)	250	250	16-Jun-31	07-Jun-32
218	NSWPH-3640	Sectional T&C - Rectifier and Transformers (3GW)	60	60	16-Mar-32	07-Jun-32
219	**4GW Transmission**		766	766	30-May-30	31-May-33
220	NSWPH-1750	Procurement/Manufacture/Site Transportation - Rectifier and Transformers (4GW)	516	516	30-May-30	07-Jun-32
221	NSWPH-2890	Installation Rectifier and Transformers (4GW)	250	250	08-Jun-32	31-May-33
222	NSWPH-2900	Sectional T&C - Rectifier and Transformers (4GW)	60	60	09-Mar-33	31-May-33
223	**Electrolysis**		2021	2021	25-Jun-25	31-May-33
224	**Electrolyser Plant**		2021	2021	25-Jun-25	31-May-33
225	NSWPH-3240	Post-FID Contract Finalisation/Contractor Mobilisation and Design	151	151	25-Jun-25	30-Jan-26
226	NSWPH-3250	Procurement/Manufacture/Site Transportation (phased for 1-4GW)	1109	1109	02-Feb-26	05-Jun-30
227	NSWPH-3260	Electrolyser Plant Installation/Sectional T&C (1GW - Hydrogen Production Offline)	250	250	12-Jul-29	04-Jul-30
228	NSWPH-3270	Electrolyser Plant Installation/Sectional T&C (2GW - Hydrogen Production Offline)	250	250	05-Jul-30	27-Jun-31
229	NSWPH-3280	Electrolyser Plant Installation/Sectional T&C (3GW - Hydrogen Production Offline)	250	250	16-Jun-31	07-Jun-32
230	NSWPH-3290	Electrolyser Plant Installation/Sectional T&C (4GW - Hydrogen Production Offline)	250	250	08-Jun-32	31-May-33
231	**H2 Compressor**		2021	2021	25-Jun-25	31-May-33
232	NSWPH-1570	Post-FID Contract Finalisation/Contractor Mobilisation and Design	129	129	25-Jun-25	23-Dec-25
233	NSWPH-1600	Procurement/Manufacture/Site Transportation (phased for 1-4GW)	998	998	24-Dec-25	22-Nov-29
234	NSWPH-1690	H2 Compressor Installation/Sectional T&C (1GW)	250	250	12-Jul-29	04-Jul-30
235	NSWPH-3730	H2 Compressor Installation/Sectional T&C (2GW)	250	250	05-Jul-30	27-Jun-31
236	NSWPH-3740	H2 Compressor Installation/Sectional T&C (3GW)	250	250	16-Jun-31	07-Jun-32



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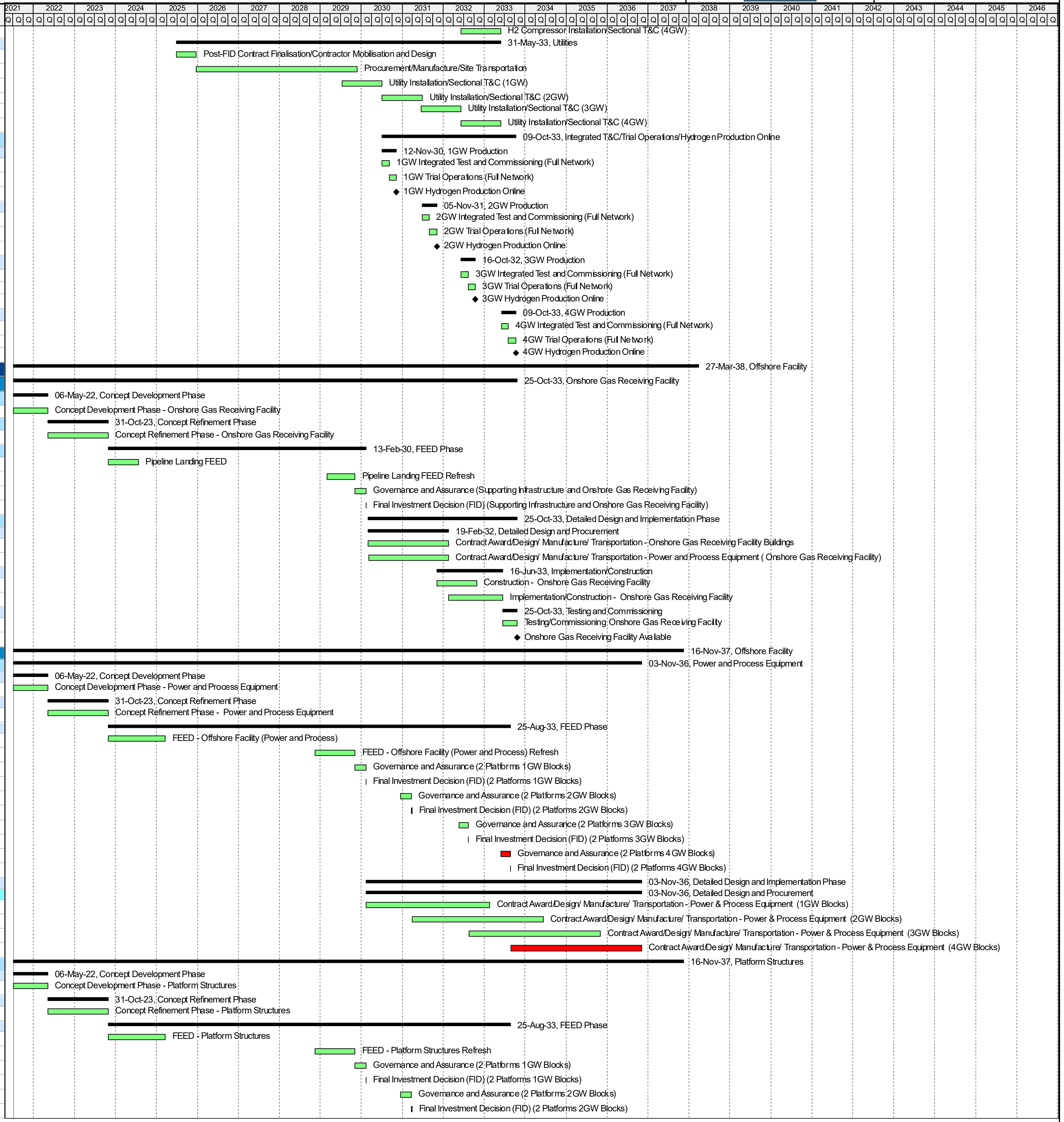
Date	Revision	Checked	Approved
21-Jan-22	NSWPH - Combined Onshore and Offshore Schedule	PT	

NSWPH Level 1 Combined Schedule - 4GW Onshore and 4GW Offshore P2G - Revison B

#	Activity ID	Activity Name	Original Duration	Remaining Duration	Start	Finish
237	NSWPH-3750	H2 Compressor Installation/Sectional T&C (4GW)	250	250	08-Jun-32	31-May-33
238	**Utilities**		2021	2021	25-Jun-25	31-May-33
239	NSWPH-1560	Post-FID Contract Finalisation/Contractor Mobilisation and Design	129	129	25-Jun-25	23-Dec-25
240	NSWPH-1590	Procurement/Manufacture/Site Transportation	999	999	24-Dec-25	23-Nov-29
241	NSWPH-2910	Utility Installation/Sectional T&C (1GW)	250	250	12-Jul-29	04-Jul-30
242	NSWPH-2920	Utility Installation/Sectional T&C (2GW)	250	250	05-Jul-30	27-Jun-31
243	NSWPH-2510	Utility Installation/Sectional T&C (3GW)	250	250	16-Jun-31	07-Jun-32
244	NSWPH-2520	Utility Installation/Sectional T&C (4GW)	250	250	08-Jun-32	31-May-33
245	**Integrated T&C/Trial Operations/Hydrogen Production Online**		1192	1192	05-Jul-30	09-Oct-33
246	**1GW Production**		130	130	05-Jul-30	12-Nov-30
247	NSWPH-3470	1GW Integrated Test and Commissioning (Full Network)	65	65	05-Jul-30	07-Sep-30
248	NSWPH-3480	1GW Trial Operations (Full Network)	65	65	08-Sep-30	11-Nov-30
249	NSWPH-3490	1GW Hydrogen Production Online	0	0	12-Nov-30	
250	**2GW Production**		130	130	28-Jun-31	05-Nov-31
251	NSWPH-2980	2GW Integrated Test and Commissioning (Full Network)	65	65	28-Jun-31	31-Aug-31
252	NSWPH-2990	2GW Trial Operations (Full Network)	65	65	01-Sep-31	04-Nov-31
253	NSWPH-3000	2GW Hydrogen Production Online	0	0	05-Nov-31	
254	**3GW Production**		130	130	08-Jun-32	16-Oct-32
255	NSWPH-3650	3GW Integrated Test and Commissioning (Full Network)	65	65	08-Jun-32	11-Aug-32
256	NSWPH-3660	3GW Trial Operations (Full Network)	65	65	12-Aug-32	15-Oct-32
257	NSWPH-3670	3GW Hydrogen Production Online	0	0	16-Oct-32	
258	**4GW Production**		130	130	01-Jun-33	09-Oct-33
259	NSWPH-3210	4GW Integrated Test and Commissioning (Full Network)	65	65	01-Jun-33	04-Aug-33
260	NSWPH-3220	4GW Trial Operations (Full Network)	65	65	05-Aug-33	08-Oct-33
261	NSWPH-3230	4GW Hydrogen Production Online	0	0	09-Oct-33	
262	**Offshore Facility**		4261	4261	05-Jul-21	27-Mar-38
263	**Onshore Gas Receiving Facility**		3119	3119	05-Jul-21	25-Oct-33
264	**Concept Development Phase**		210	210	05-Jul-21	06-May-22
265	NSWPH-1260	Concept Development Phase - Onshore Gas Receiving Facility	210	210	05-Jul-21	06-May-22
266	**Concept Refinement Phase**		374	374	09-May-22	31-Oct-23
267	NSWPH-1270	Concept Refinement Phase - Onshore Gas Receiving Facility	374	374	09-May-22	31-Oct-23
268	**FEED Phase**		1590	1590	01-Nov-23	13-Feb-30
269	NSWPH-1280	Pipeline Landing FEED	181	181	01-Nov-23	24-Jul-24
270	NSWPH-1340	Pipeline Landing FEED Refresh	180	180	27-Feb-29	05-Nov-29
271	NSWPH-1360	Governance and Assurance (Supporting Infrastructure and Onshore Gas Receiving Facility)	65	65	06-Nov-29	12-Feb-30
272	NSWPH-1310	Final Investment Decision (FID) (Supporting Infrastructure and Onshore Gas Receiving Facility)	1	1	13-Feb-30*	13-Feb-30
273	**Detailed Design and Implementation Phase**		932	932	05-Mar-30	25-Oct-33
274	**Detailed Design and Procurement**		501	501	05-Mar-30	19-Feb-32
275	NSWPH-1290	Contract Award/Design/ Manufacture/ Transportation - Onshore Gas Receiving Facility Buildings	500	500	05-Mar-30	18-Feb-32
276	NSWPH-1330	Contract Award/Design/ Manufacture/ Transportation - Power and Process Equipment (Onshore Gas Receiving I	500	500	06-Mar-30	19-Feb-32
277	**Implementation/Construction**		410	410	05-Nov-31	16-Jun-33
278	NSWPH-1320	Construction - Onshore Gas Receiving Facility	250	250	05-Nov-31	27-Oct-32
279	NSWPH-1350	Implementation/Construction - Onshore Gas Receiving Facility	339	339	20-Feb-32	16-Jun-33
280	**Testing and Commissioning**		130	130	17-Jun-33	25-Oct-33
281	NSWPH-1790	Testing/Commissioning Onshore Gas Receiving Facility	130	130	17-Jun-33	24-Oct-33
282	NSWPH-1800	Onshore Gas Receiving Facility Available	0	0	25-Oct-33	
283	**Offshore Facility**		4167	4167	05-Jul-21	16-Nov-37
284	**Power and Process Equipment**		3897	3897	05-Jul-21	03-Nov-36
285	**Concept Development Phase**		210	210	05-Jul-21	06-May-22
286	NSWPH-1490	Concept Development Phase - Power and Process Equipment	210	210	05-Jul-21	06-May-22
287	**Concept Refinement Phase**		374	374	09-May-22	31-Oct-23
288	NSWPH-1500	Concept Refinement Phase - Power and Process Equipment	374	374	09-May-22	31-Oct-23
289	**FEED Phase**		2493	2493	01-Nov-23	25-Aug-33
290	NSWPH-1510	FEED - Offshore Facility (Power and Process)	344	344	01-Nov-23	18-Mar-25
291	NSWPH-2390	FEED - Offshore Facility (Power and Process) Refresh	250	250	13-Nov-28	05-Nov-29
292	NSWPH-1580	Governance and Assurance (2 Platforms 1GW Blocks)	65	65	06-Nov-29	12-Feb-30
293	NSWPH-1530	Final Investment Decision (FID) (2 Platforms 1GW Blocks)	1	1	13-Feb-30	13-Feb-30
294	NSWPH-1630	Governance and Assurance (2 Platforms 2GW Blocks)	65	65	18-Dec-30	26-Mar-31
295	NSWPH-1620	Final Investment Decision (FID) (2 Platforms 2GW Blocks)	1	1	27-Mar-31	27-Mar-31
296	NSWPH-1980	Governance and Assurance (2 Platforms 3GW Blocks)	65	65	17-May-32	13-Aug-32
297	NSWPH-1990	Final Investment Decision (FID) (2 Platforms 3GW Blocks)	1	1	16-Aug-32	16-Aug-32
298	NSWPH-2000	Governance and Assurance (2 Platforms 4GW Blocks)	65	65	26-May-33	24-Aug-33
299	NSWPH-2010	Final Investment Decision (FID) (2 Platforms 4GW Blocks)	1	1	25-Aug-33	25-Aug-33
300	**Detailed Design and Implementation Phase**		1723	1723	14-Feb-30	03-Nov-36
301	**Detailed Design and Procurement**		1723	1723	14-Feb-30	03-Nov-36
302	NSWPH-1550	Contract Award/Design/ Manufacture/ Transportation - Power & Process Equipment (1GW Blocks)	771	771	14-Feb-30	22-Feb-33
303	NSWPH-1810	Contract Award/Design/ Manufacture/ Transportation - Power & Process Equipment (2GW Blocks)	820	820	28-Mar-31	13-Jun-34
304	NSWPH-1820	Contract Award/Design/ Manufacture/ Transportation - Power & Process Equipment (3GW Blocks)	820	820	17-Aug-32	01-Nov-35
305	NSWPH-1830	Contract Award/Design/ Manufacture/ Transportation - Power & Process Equipment (4GW Blocks)	820	820	26-Aug-33	03-Nov-36
306	**Platform Structures**		4167	4167	05-Jul-21	16-Nov-37
307	**Concept Development Phase**		210	210	05-Jul-21	06-May-22
308	NSWPH-1640	Concept Development Phase - Platform Structures	210	210	05-Jul-21	06-May-22
309	**Concept Refinement Phase**		374	374	09-May-22	31-Oct-23
310	NSWPH-1650	Concept Refinement Phase - Platform Structures	374	374	09-May-22	31-Oct-23
311	**FEED Phase**		2493	2493	01-Nov-23	25-Aug-33
312	NSWPH-1660	FEED - Platform Structures	344	344	01-Nov-23	18-Mar-25
313	NSWPH-2400	FEED - Platform Structures Refresh	250	250	13-Nov-28	05-Nov-29
314	NSWPH-1730	Governance and Assurance (2 Platforms 1GW Blocks)	65	65	06-Nov-29	12-Feb-30
315	NSWPH-1680	Final Investment Decision (FID) (2 Platforms 1GW Blocks)	1	1	13-Feb-30	13-Feb-30
316	NSWPH-2110	Governance and Assurance (2 Platforms 2GW Blocks)	65	65	18-Dec-30	26-Mar-31
317	NSWPH-2060	Final Investment Decision (FID) (2 Platforms 2GW Blocks)	1	1	27-Mar-31	27-Mar-31

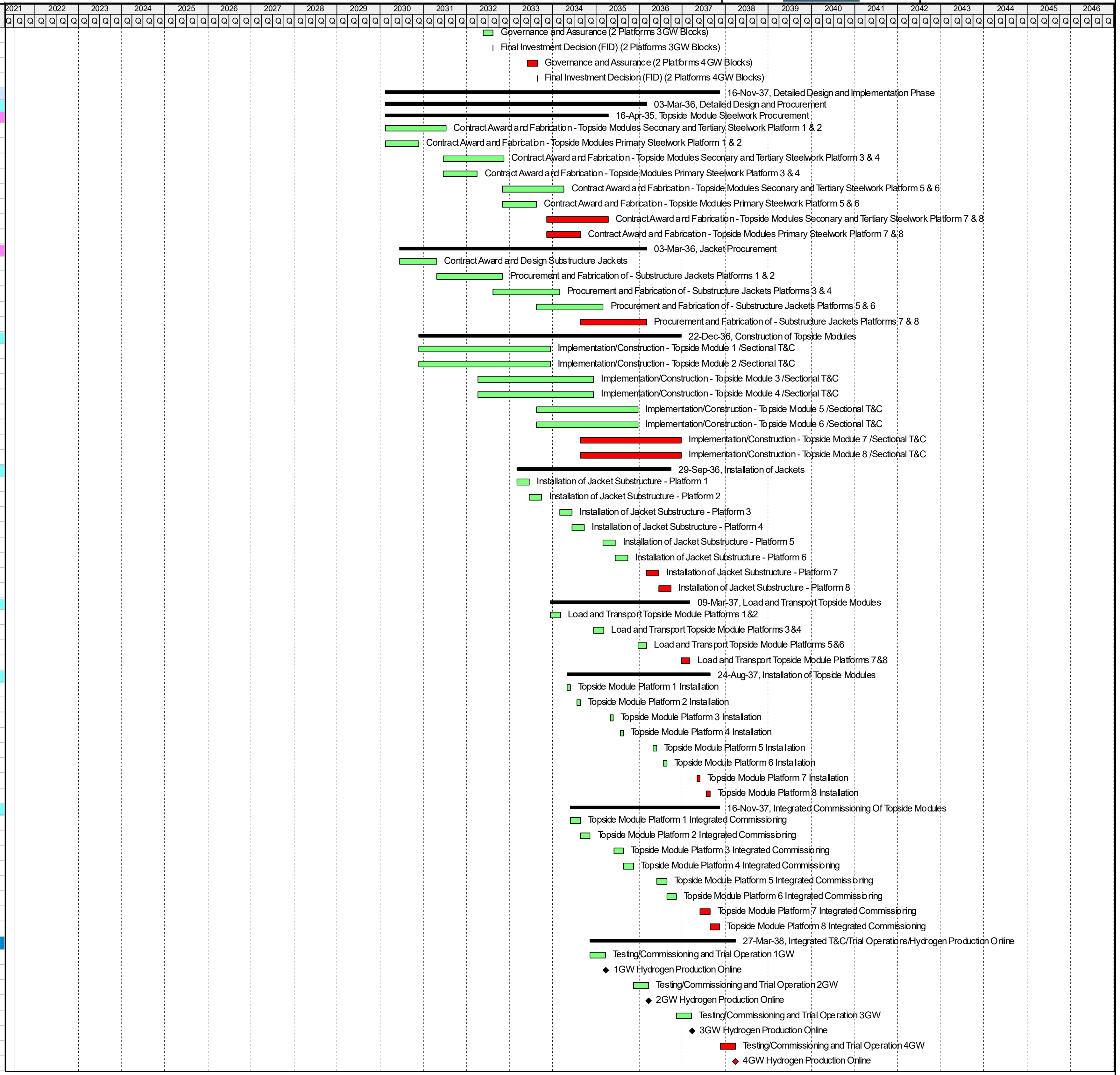


🟦 Actual Work
🟥 Critical Remaining Work
◆ Milestone
🟩 Remaining Work
▬ Summary
♦ Critical Milestone

Date	Revision	Checked	Approved
21-Jan-22	NSWPH - Combined Onshore and Offshore Schedule	PT	

NSWPH Level 1 Combined Schedule - 4GW Onshore and 4GW Offshore P2G - Revison B

#	Activity ID	Activity Name	Original Duration	Remaining Duration	Start	Finish
318	NSWPH-2070	Governance and Assurance (2 Platforms 3GW Blocks)	65	65	17-May-32	13-Aug-32
319	NSWPH-2080	Final Investment Decision (FID) (2 Platforms 3GW Blocks)	1	1	16-Aug-32	16-Aug-32
320	NSWPH-2090	Governance and Assurance (2 Platforms 4GW Blocks)	65	65	26-May-33	24-Aug-33
321	NSWPH-2100	Final Investment Decision (FID) (2 Platforms 4GW Blocks)	1	1	25-Aug-33	25-Aug-33
322	**Detailed Design and Implementation Phase**		1993	1993	14-Feb-30	16-Nov-37
323	**Detailed Design and Procurement**		1548	1548	14-Feb-30	03-Mar-36
324	**Topside Module Steelwork Procurement**		1318	1318	14-Feb-30	16-Apr-35
325	NSWPH-1700	Contract Award and Fabrication - Topside Modules Seconary and Tertiary Steelwork Platform 1 & 2	360	360	14-Feb-30	10-Jul-31
326	NSWPH-2210	Contract Award and Fabrication - Topside Modules Primary Steelwork Platform 1 & 2	200	200	14-Feb-30	20-Nov-30
327	NSWPH-4080	Contract Award and Fabrication - Topside Modules Seconary and Tertiary Steelwork Platform 3 & 4	360	360	20-Jun-31	12-Nov-32
328	NSWPH-4090	Contract Award and Fabrication - Topside Modules Primary Steelwork Platform 3 & 4	200	200	20-Jun-31	02-Apr-32
329	NSWPH-4100	Contract Award and Fabrication - Topside Modules Seconary and Tertiary Steelwork Platform 5 & 6	360	360	01-Nov-32	04-Apr-34
330	NSWPH-4110	Contract Award and Fabrication - Topside Modules Primary Steelwork Platform 5 & 6	200	200	01-Nov-32	15-Aug-33
331	NSWPH-4120	Contract Award and Fabrication - Topside Modules Seconary and Tertiary Steelwork Platform 7 & 8	360	360	11-Nov-33	16-Apr-35
332	NSWPH-4130	Contract Award and Fabrication - Topside Modules Primary Steelwork Platform 7 & 8	200	200	11-Nov-33	25-Aug-34
333	**Jacket Procurement**		1463	1463	13-Jun-30	03-Mar-36
334	NSWPH-2050	Contract Award and Design Substructure Jackets	220	220	13-Jun-30	24-Apr-31
335	NSWPH-1670	Procurement and Fabrication of - Substructure Jackets Platforms 1 & 2	390	390	25-Apr-31	29-Oct-32
336	NSWPH-4140	Procurement and Fabrication of - Substructure Jackets Platforms 3 & 4	390	390	16-Aug-32	28-Feb-34
337	NSWPH-4150	Procurement and Fabrication of - Substructure Jackets Platforms 5 & 6	390	390	16-Aug-33	28-Feb-35
338	NSWPH-4160	Procurement and Fabrication of - Substructure Jackets Platforms 7 & 8	390	390	28-Aug-34	03-Mar-36
339	**Construction of Topside Modules**		1558	1558	21-Nov-30	22-Dec-36
340	NSWPH-1720	Implementation/Construction - Topside Module 1 /Sectional T&C	780	780	21-Nov-30	12-Dec-33
341	NSWPH-1840	Implementation/Construction - Topside Module 2 /Sectional T&C	780	780	21-Nov-30	12-Dec-33
342	NSWPH-1850	Implementation/Construction - Topside Module 3 /Sectional T&C	690	690	05-Apr-32	12-Dec-34
343	NSWPH-1860	Implementation/Construction - Topside Module 4 /Sectional T&C	690	690	05-Apr-32	12-Dec-34
344	NSWPH-1870	Implementation/Construction - Topside Module 5 /Sectional T&C	600	600	16-Aug-33	19-Dec-35
345	NSWPH-1880	Implementation/Construction - Topside Module 6 /Sectional T&C	600	600	16-Aug-33	19-Dec-35
346	NSWPH-1890	Implementation/Construction - Topside Module 7 /Sectional T&C	600	600	28-Aug-34	22-Dec-36
347	NSWPH-1900	Implementation/Construction - Topside Module 8 /Sectional T&C	600	600	28-Aug-34	22-Dec-36
348	**Installation of Jackets**		923	923	01-Mar-33	29-Sep-36
349	NSWPH-2120	Installation of Jacket Substructure - Platform 1	75	75	01-Mar-33	13-Jun-33
350	NSWPH-2130	Installation of Jacket Substructure - Platform 2	75	75	14-Jun-33	26-Sep-33
351	NSWPH-2140	Installation of Jacket Substructure - Platform 3	75	75	01-Mar-34	13-Jun-34
352	NSWPH-2150	Installation of Jacket Substructure - Platform 4	75	75	14-Jun-34	26-Sep-34
353	NSWPH-2160	Installation of Jacket Substructure - Platform 5	75	75	01-Mar-35	13-Jun-35
354	NSWPH-2170	Installation of Jacket Substructure - Platform 6	75	75	14-Jun-35	26-Sep-35
355	NSWPH-2180	Installation of Jacket Substructure - Platform 7	75	75	04-Mar-36	16-Jun-36
356	NSWPH-2190	Installation of Jacket Substructure - Platform 8	75	75	17-Jun-36	29-Sep-36
357	**Load and Transport Topside Modules**		833	833	13-Dec-33	09-Mar-37
358	NSWPH-2240	Load and Transport Topside Module Platforms 1 &2	55	55	13-Dec-33	07-Mar-34
359	NSWPH-2250	Load and Transport Topside Module Platforms 3 &4	55	55	13-Dec-34	07-Mar-35
360	NSWPH-2260	Load and Transport Topside Module Platforms 5 &6	55	55	20-Dec-35	05-Mar-36
361	NSWPH-2270	Load and Transport Topside Module Platforms 7 &8	55	55	23-Dec-36	09-Mar-37
362	**Installation of Topside Modules**		858	858	03-May-34	24-Aug-37
363	NSWPH-1740	Topside Module Platform 1 Installation	20	20	03-May-34*	30-May-34
364	NSWPH-1910	Topside Module Platform 2 Installation	20	20	26-Jul-34	22-Aug-34
365	NSWPH-1920	Topside Module Platform 3 Installation	20	20	03-May-35*	30-May-35
366	NSWPH-1930	Topside Module Platform 4 Installation	20	20	26-Jul-35	22-Aug-35
367	NSWPH-1940	Topside Module Platform 5 Installation	20	20	01-May-36*	28-May-36
368	NSWPH-1950	Topside Module Platform 6 Installation	20	20	24-Jul-36	20-Aug-36
369	NSWPH-1960	Topside Module Platform 7 Installation	20	20	05-May-37*	01-Jun-37
370	NSWPH-1970	Topside Module Platform 8 Installation	20	20	28-Jul-37	24-Aug-37
371	**Integrated Commissioning Of Topside Modules**		898	898	31-May-34	16-Nov-37
372	NSWPH-2280	Topside Module Platform 1 Integrated Commissioning	60	60	31-May-34	22-Aug-34
373	NSWPH-2290	Topside Module Platform 2 Integrated Commissioning	60	60	23-Aug-34	14-Nov-34
374	NSWPH-2300	Topside Module Platform 3 Integrated Commissioning	60	60	31-May-35	22-Aug-35
375	NSWPH-2310	Topside Module Platform 4 Integrated Commissioning	60	60	23-Aug-35	14-Nov-35
376	NSWPH-2320	Topside Module Platform 5 Integrated Commissioning	60	60	29-May-36	20-Aug-36
377	NSWPH-2330	Topside Module Platform 6 Integrated Commissioning	60	60	21-Aug-36	12-Nov-36
378	NSWPH-2340	Topside Module Platform 7 Integrated Commissioning	60	60	02-Jun-37	24-Aug-37
379	NSWPH-2350	Topside Module Platform 8 Integrated Commissioning	60	60	25-Aug-37	16-Nov-37
380	**Integrated T&C/Trial Operations/Hydrogen Production Online**		872	872	15-Nov-34	27-Mar-38
381	NSWPH-1300	Testing/Commissioning and Trial Operation 1GW	130	130	15-Nov-34	24-Mar-35
382	NSWPH-1400	1GW Hydrogen Production Online	0	0	26-Mar-35	
383	NSWPH-1410	Testing/Commissioning and Trial Operation 2GW	130	130	15-Nov-35	23-Mar-36
384	NSWPH-1420	2GW Hydrogen Production Online	0	0	24-Mar-36	
385	NSWPH-1430	Testing/Commissioning and Trial Operation 3GW	130	130	13-Nov-36	22-Mar-37
386	NSWPH-1440	3GW Hydrogen Production Online	0	0	23-Mar-37	
387	NSWPH-1450	Testing/Commissioning and Trial Operation 4GW	130	130	17-Nov-37	26-Mar-38
388	NSWPH-1460	4GW Hydrogen Production Online	0	0	27-Mar-38	



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