HyNet
North West

HyNet Low Carbon Hydrogen Plant

BEIS HYDROGEN SUPPLY COMPETITION

November 2021

Phase 2 Report for BEIS

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1 | EXECUTIVE SUMMARY

Executive Summary

This report outlines the Front-End Engineering Design (FEED) development of HyNet's first hydrogen production plant, "Plant 1", with some preliminary evaluations of future production plants. This FEED was undertaken by a consortium of Johnson Matthey plc, Essar Oil (UK) Ltd, Kent[1] and Progressive Energy Ltd.

HyNet North West

Low carbon hydrogen is set to play a major role in achieving 'Net Zero emissions' across the UK by 2050. HyNet, an announced Track-1 cluster[2], is centred in the north west of England and north Wales and delivers full scale, deliverable and cost-effective multi-sector decarbonisation by combining fuel switching to low carbon hydrogen and the deployment of Carbon Capture and Storage. Low carbon hydrogen will be supplied to industrial, flexible power, transport and domestic and commercial gas customers to provide an alternative to fossil fuels.

HyNet infrastructure will include:

Hydrogen Production: At the heart of the HyNet cluster, 3 TWh per year of low carbon hydrogen production by 2025, rising to 30 TWh by 2030 at a 'hub' located at the Stanlow Manufacturing Complex consisting of four state-of-the-art hydrogen production plants, which will capture ~97% of by-product CO_2 from processing natural gas and Refinery Off Gas (ROG) feedstocks.

CO_2 Transport and Storage: This hydrogen production will be linked to a Carbon Capture and Storage transport and storage system, designed specifically to sequester CO_2 produced by hydrogen production and other industrial sources into long-term geological storage in the depleted Liverpool Bay gas fields.

Hydrogen Network: Hydrogen will be delivered to multiple end customers via the UK's first hydrogen multi-consumer network, with circa 85 km of 'spine' pipeline in place by 2027 and up to a further 270 km of hydrogen network in place by 2030. The network is routed to supply large industrial and flexible power generators in the area and to enable injection into the existing natural gas Local Transmission System, allowing all customers to readily switch from natural gas to a carbon free fuel. Plant 1 will supply the Stanlow Manufacturing Complex and other nearby industrial sites via a dedicated hydrogen pipeline before the hydrogen network is complete.

Hydrogen Storage: A complex of hydrogen storage salt caverns will be created in the Cheshire salt basin and connected to the hydrogen distribution network. The complex will be able to store around 1.3 TWh of hydrogen, to enable fluctuations in demand to be managed cost effectively, without sizing the production hub to meet peak regional demand.

The FEED for HyNet CO_2 Transport and Storage, as well as the Hydrogen Network and Storage, is currently being developed under UK Research and Innovation's Industrial Decarbonisation Challenge funding.

[1] For the majority of the period of the work, SNC Lavalin UK Ltd. The SNC Lavalin Oil and Gas Business recently merged with Kentech, and now operates under the Kent brand.

[2] GOV.UK (2021) Net Zero Strategy: Build Back Greener, https://www.gov.uk/government/publications/net-zero-strategy

HyNet Hydrogen Production

30 TWh per year of low carbon hydrogen production capacity will be delivered by the HyNet production 'hub' by 2030, executed in four stages – Plants 1 to 4. This report focusses on the FEED undertaken on Plant 1 but also recognises some of the benefits which facilitate the rapid and cost-efficient deployment of Plant 2.

The key messages from this report are:

HyNet Hydrogen Production Plant 1 can deliver 350 MW_{th}[3] of Low Carbon Hydrogen by 2025

- Plant 1 has been developed to a FEED level of technical definition[4], under funding from Phase 2 of the BEIS Hydrogen Supply Competition.
- All required external connections and utilities can be made available to the site at the Stanlow Manufacturing Complex, to support deployment of Plants 1 and 2.
- Consenting has been progressed, with Hazardous Substances Consent application, Environmental Permit variation and Planning Application all submitted.
- A commercial programme of work is under way, to progress the necessary contractual negotiations to take place between now and Final Investment Decision (FID).

This project sits at the heart of a vibrant industrial region driving for energy transition

- HyNet North West (HyNet) is the UK's leading industrial cluster, anchored on the development of hydrogen production, distribution, storage and fuel switching, integrated with carbon capture and storage infrastructure.
- HyNet is demand led. There are more than thirty energy intensive industrials and flexible power generators across the region intending to fuel switch from a carbon-based fuel to low carbon hydrogen. More than 20 of these have already signed Memoranda of Understanding with HyNet for connection to the hydrogen network and supply of low carbon hydrogen when available. For many of these household names, having invested heavily in improving process efficiency, conversion to hydrogen is the most cost effective and fastest solution to meet their carbon reduction targets. Thus HyNet will underpin these businesses and safeguard jobs.
- A resilient and distributed supply of low carbon hydrogen not only supports existing industries, but will attract inward investment to the industrial, power generation, and transport sectors whilst also decarbonising domestic heat.

HyNet hydrogen production's core technology - Johnson Matthey's Low Carbon Hydrogen (LCH™)[5] – delivers world leading performance

- This represents the "best in class" technology for high purity low carbon hydrogen production from natural gas, delivering over 85% thermal efficiency and ~97% carbon capture.
- This performance represents a substantial improvement on the BEIS counterfactual plant (steam methane reforming and Carbon Capture and Storage (CCS). When compared with this counterfactual, Plant 1 will consume approximately 20% less feedstock gas and emit 70% less CO_2 for the same hydrogen output.
- Confidence in the technical performance of the **LCH** has been increased through delivery of a basic engineering package by Johnson Matthey, using knowledge from existing operational plants using similar technology.

Plant 2 can be deployed rapidly and cost effectively to increase HyNet hydrogen production capacity to over 1 GW_{th} by 2026

- This will provide the supply into HyNet's wider hydrogen distribution and storage facilities, to support decarbonisation in the wider north west region.
- Through economies of scale and beneficial use of shared infrastructure established for Plant 1, an accelerated execution timeline and a significant reduction in the levelised cost of hydrogen production from Plant 2 is anticipated.

Co-location with the refinery within Stanlow Manufacturing Complex underpins deliverability, unlocks opportunities and manages risk

- It provides an established operational site, refined and proven frameworks and experienced staff to deliver well managed safe operations.
- Utilisation of a disused brownfield site eliminates the need for additional greenbelt land take and makes for more predictable consenting. It also benefits from established supply chains for project execution.
- Offers synergies which reduce cost, whilst also underpinning energy security for national infrastructure.
- The Stanlow Refinery sits at the heart of regional and national fuel supplies and so is well placed to unlock the transition towards low carbon energy distribution. It also allows rapid decarbonisation of conventional oil refining which will minimise emissions as the UK transitions to low carbon fuel alternatives.

There is appetite for private investment in Hydrogen Production Plant 1 and 2

- A Special Purpose Company (SPC) is being formed as a joint venture by Essar Oil (UK) Ltd and Progressive Energy Ltd to co-own the plant.
- There is appetite from financial markets to support the owners' equity investment with debt financing, providing that the risks associated with the early projects are appropriately mitigated through a well-structured, government supported, business model.

A contracted support regime for Plant 1 is required in 2022, prior to FID, to enable delivery at pace

- Work has been undertaken with BEIS during Phase 2 to establish realistic support regimes: timely execution of these regimes is now critical to meet the targets set out in the UK Government's Ten Point Plan.

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[3] All references to hydrogen energy content, within this report, are Higher Heating Value (HHV).

[4] FEED definition is sufficient to support planning, permitting and cost estimating to the appropriate level of accuracy for financial sanction. Detailed engineering will be undertaken during the Execution phase (post Final Investment Decision).

[5] **LCH** is a trademark of the Johnson Matthey Group of Companies.

2 | PROJECT BACKGROUND

Project Background

Objectives

This report summarises the output of the work carried out by a Consortium under the BEIS Phase 2 Hydrogen Supply Competition. The work carried out in this phase had two key objectives:

1. To demonstrate a method of low carbon hydrogen production which can significantly improve upon performance metrics of a counterfactual plant, delivering cost competitive production of low carbon hydrogen.

2. To develop a specific plant design to a level of technical and commercial definition that will support advancement of the project to FID, in a timeframe that supports the UK's climate targets.

Project History

HyNet was conceived by Progressive Energy in 2016 with support from Cadent Gas under Network Innovation Allowance. The first phase of this work, published in August 2017, considered two core locations; the north west and Humberside, as being potential locations for deployment of the UK's first hydrogen and CCS infrastructure[6]. The north west was chosen as the preferred location due to its close proximity to well characterised depleted oil and gas fields for offshore storage of the CO_2 streams, and the low cost of reusing these assets and existing pipelines, along with close proximity to the Cheshire Salt Basin for underground bulk storage of hydrogen. This initial study was built upon in a subsequently funded report published in June 2018[7].

Following this, the hydrogen production elements of HyNet proceeded through a pre-FEED phase of engineering appraisal in 2019, funded by Phase 1 of the BEIS Hydrogen Supply Competition, and the output of this formed[8] the project definition for this next phase of project development, which is presented in this report.

Plant 1's concept has been built through a long and ongoing relationship between the partners introduced in Section 6; this longstanding commitment to the project demonstrates a shared ambition to deliver HyNet.

[6] Cadent & Progressive Energy (2017) The Liverpool-Manchester Hydrogen Cluster: A Low Cost, Deliverable Project, August 2017 https://hynet.co.uk/wp-content/uploads/2018/05/Liverpool-Manchester-Hydrogen-Cluster-Technical-Report-Cadent.pdf

[7] Cadent & Progressive Energy (2018) HyNet: From Vision to Reality, June 2018 https://hynet.co.uk/wp-content/uploads/2021/06/14368_CADENT_PROJECT_REPORT_AMENDED_v22105.pdf

[8] Johnson Matthey, SNCL, Progressive Energy (2019) HyNet Low Carbon Hydrogen Plant Phase 1 Report for BEIS https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/866401/HS384_-_Progressive_Energy_-_HyNet_hydrogen.pdf

3 | BEIS HYDROGEN SUPPLY COMPETITION

BEIS Hydrogen Supply Competition

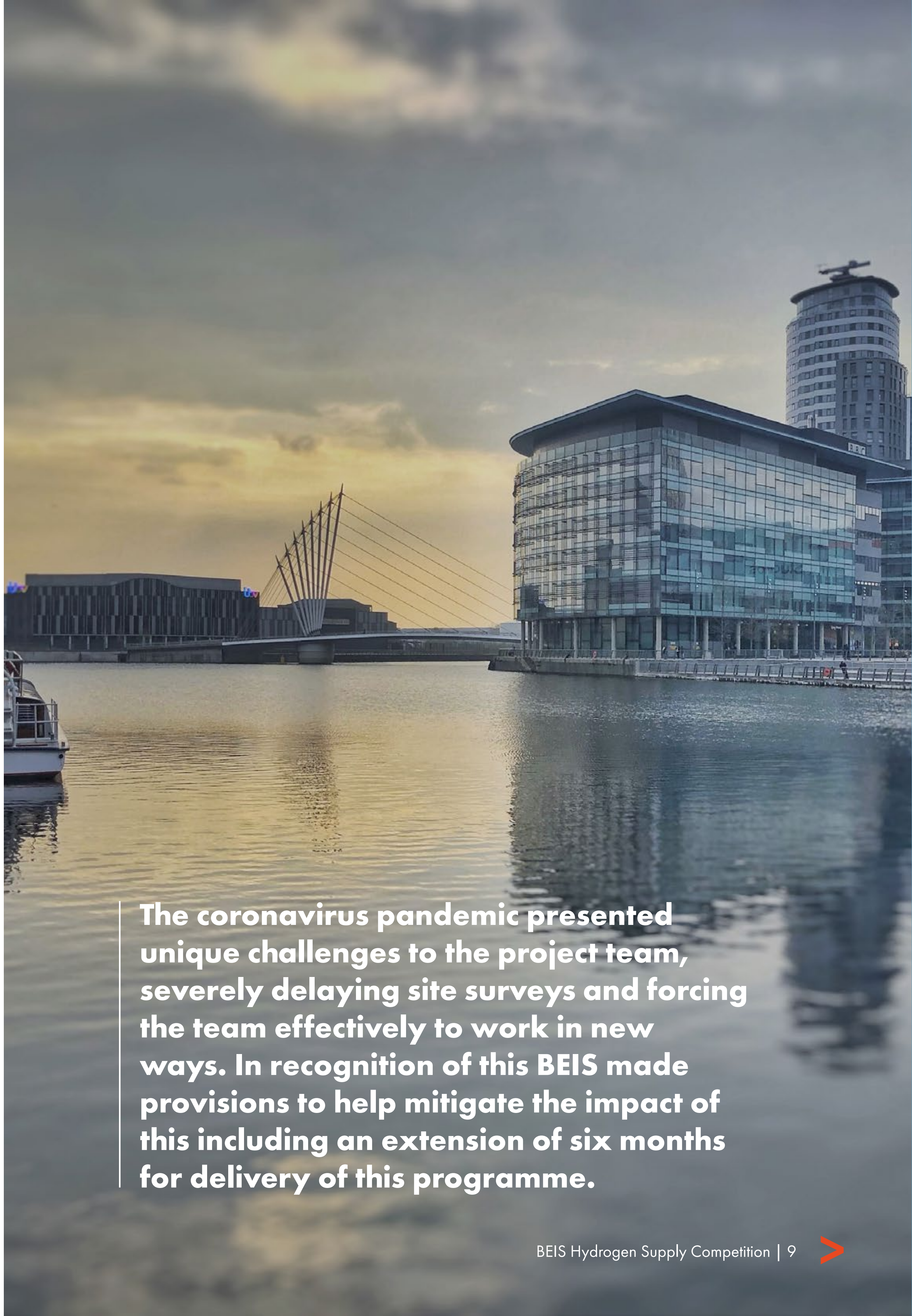
The objective of the Hydrogen Supply Competition is to demonstrate the capability to deliver low carbon hydrogen, at scale and a competitive price. Specifically, to prove that innovative solutions to hydrogen production could improve on conventional technologies (steam methane reforming with CCS), cost and carbon capture rates, and demonstrate that low carbon hydrogen has an essential role to play in the country's low-emission future.

In November 2019, BEIS awarded the HyNet hydrogen production project £7.5M to advance the development of a low carbon hydrogen plant at the Stanlow Manufacturing Complex, to deliver low carbon energy to the north west of England and north Wales as part of the wider HyNet cluster project.

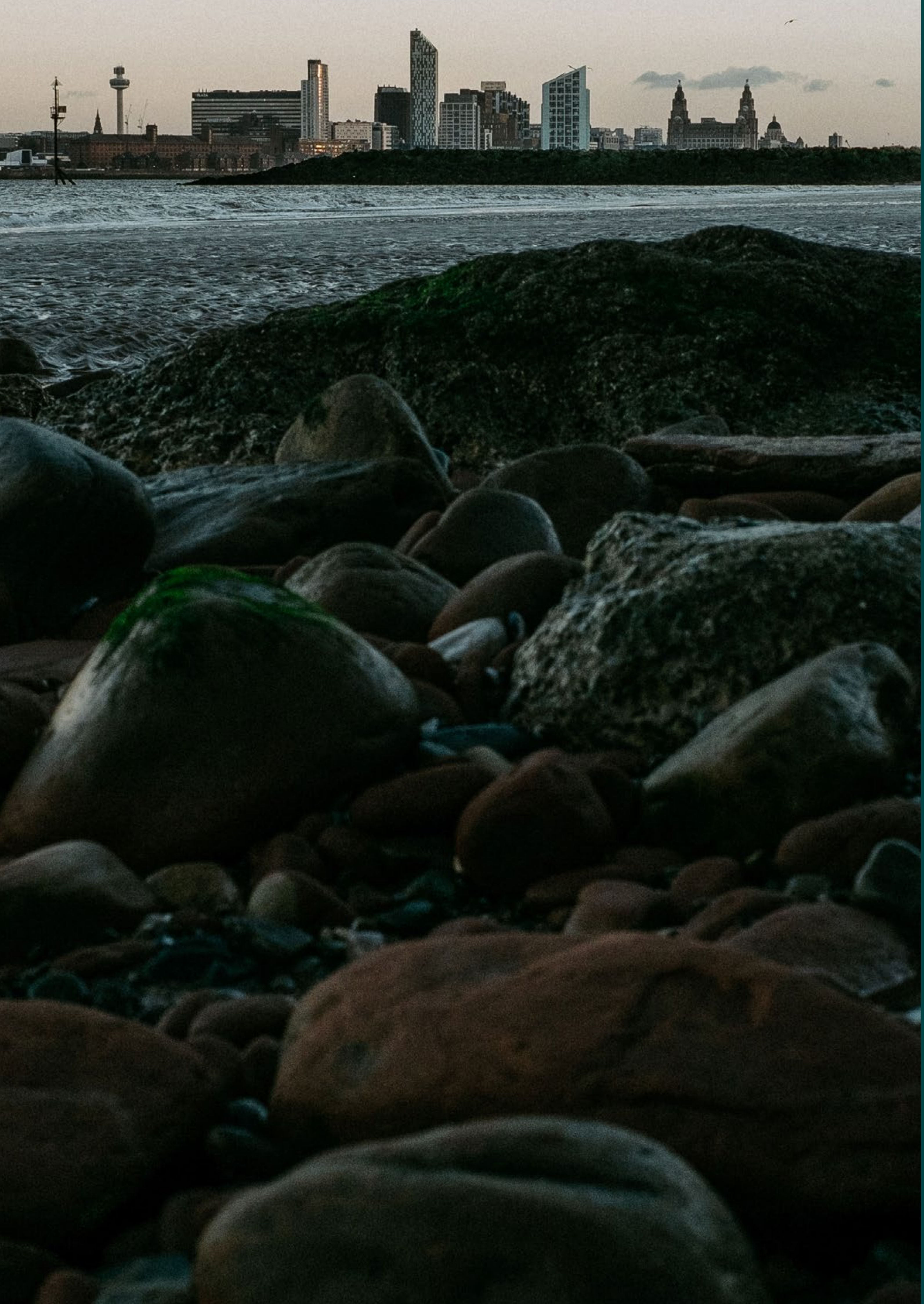
Under this programme, the consortium has developed a FEED package for this plant, which includes a full suite of: technical documents, commercial framework, consenting and financial modelling to turn the conceptual pre-FEED design into a reality. The original deadline to deliver this work was March 2021.

At the stage of submitting this report, Plant 1 is ready for delivery to provide the first low carbon hydrogen to the north west region as early as 2025. Following final optimisation work, full integration to the Stanlow Manufacturing Complex and subject to the required government support frameworks, the plant will be ready for FID before the end of 2022.

To maximise value to the UK Government, this FEED package has been developed with limited elements that are unique to its setting at Stanlow; this will allow the package to be refined for and deployed at other locations, to support the nationwide pursuit of Net Zero emissions. The residual technical work to optimise the integration of the project into the Stanlow Manufacturing Complex will be undertaken prior to FID.



The coronavirus pandemic presented unique challenges to the project team, severely delaying site surveys and forcing the team effectively to work in new ways. In recognition of this BEIS made provisions to help mitigate the impact of this including an extension of six months for delivery of this programme.



4 | UNLOCKING THE HYDROGEN ECONOMY

Unlocking the Hydrogen Economy

In June 2019, consistent with guidance from the Committee on Climate Change (CCC), the Government set an ambitious target to achieve Net Zero carbon dioxide equivalent emissions from 2050[9].

Hydrogen Market

The CCC sees hydrogen as essential to meeting our decarbonisation obligations and, in its Net Zero report, identifies a UK demand for hydrogen of 270 TWh per year by 2050[10]. Hydrogen, alongside electricity, will become the key energy carrier for the country in a Net Zero emission future. This was reinforced in the CCC's Sixth Carbon Budget, stating that the UK requires 90 TWh per year of low carbon hydrogen by 2035 to avoid exceeding this emission budget[11].

In the near term, the Government's "ten-point plan for a green industrial revolution" (The Ten Point Plan), issued in November 2020, has made a pledge: "Working with industry the UK is aiming for 5 GW of low carbon hydrogen production capacity by 2030[12]". This is equivalent to approximately 40 TWh per year of hydrogen, or 15% of the total 2050 CCC Net Zero Report target. More pressing still is that, of this 5 GW, by 2025 the Government "hopes to see 1 GW of hydrogen production capacity".

The recently released UK Hydrogen Strategy[13], reinforces these targets, further indicating a requirement of 7-20 GW of installed capacity by 2035, and an annual expected hydrogen demand of 250-460 TWh per year by 2050.

90 TWh per year of low carbon hydrogen - around 30 times the capacity of HyNet Hydrogen Production Plant 1 - is required by 2035 to meet the UK's 6th Carbon Budget.

Unlocking the Market

As acknowledged by the UK Hydrogen Strategy, in order to deliver a fully-functional low carbon hydrogen economy, all of the key elements will be required simultaneously: Supply, Demand, Infrastructure, Storage, People and Skills, Policy Frameworks and Financial Solutions.

A full chain approach to development is critical; the only credible solution for the initial establishment of the hydrogen economy is a project that can deliver all of these elements together.

Export of Technology and Expertise

In May 2021, the International Energy Agency published their Net Zero 2050 report, which estimates a global need for approximately 7,800 TWh per year of low-emission hydrogen from methane with CCS[14]; equivalent to over 2,600 times the capacity provided by Plant 1.This target requires the international buildout of over 1 GW of hydrogen capacity every week until 2050.

Pushing an ambitious timeline for deployment of industrial hydrogen and CCS clusters will give the UK significant first-mover advantage. Countries globally will be required to deploy similar clusters, in order to achieve their respective emissions targets under the Paris Agreement[15]. Demonstrating this technology at a sufficient scale to mitigate the impact of climate change globally will position UK industry as global low carbon energy experts, unlocking opportunities to export this experience and technology.

[9] GOV.UK (2019) UK becomes first major economy to pass net zero emissions law https://www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law

[10] Committee on Climate Change (2019) "Reducing UK emissions" 2019 Progress Report to Parliament https://www.theccc.org.uk/publication/reducing-uk-emissions-2019-progress-report-to-parliament/

[11] Committee on Climate Change (2020) Sixth Carbon Budget https://www.theccc.org.uk/publication/sixth-carbon-budget/

[12] GOV.UK (2020) Energy white paper: Powering our net zero future https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future

[13] GOV.UK (2021) UK hydrogen strategy https://www.gov.uk/government/publications/uk-hydrogen-strategy

[14] International Energy Agency (2021) Table 2.7, IEA Net Zero by 2050 – A Roadmap for the Global Energy Sector (converted from 200 million t/y) https://iea.blob.core.windows.net/assets/ad0d4830-bd7e-47b6-838c-40d115733c13/NetZeroby2050-ARoadmapfortheGlobalEnergySector.pdf

[15] 'Paris Agreement on Climate Change', 12 December 2015, entered into force 4 November 2016.

5 | HYNET NORTH WEST

Figure 5.1 - HyNet Cluster

HyNet North West

HyNet North West Overview

HyNet will decarbonise industry, domestic heat, flexible power generation and transport in north west England and north Wales. The project will produce hydrogen from natural gas and ROG feedstock using a world class **LCH** technology. It will capture, transport and store the resultant carbon dioxide (CO_2) stream offshore, and transport the hydrogen to industrial and flexible power generation consumers using a newbuild dedicated pipeline network, with additional blending of hydrogen into the existing natural gas distribution network for domestic consumers.

In October 2021, the UK's Net Zero Strategy announced that HyNet is amongst those "confirmed as track 1 clusters for the mid-2020s and will be taken forward into track 1 negotiations."[16]

An overview of the HyNet scheme is shown in Figure 5.1.

[16] GOV.UK (2021) Net Zero Strategy: Build Back Greener, https://www.gov.uk/government/publications/net-zero-strategy

HyNet North West – A Unique Opportunity

HyNet is located in a region of concentrated energy intensive industry, existing technical skill base, and suitable geological features for permanent CO_2 sequestration in the rocks under Liverpool Bay and development of hydrogen storage in salt caverns.

HyNet is essential to delivering the Government's "Ten Point Plan for a Green Industrial Revolution"[17] as:

- The north west is one of the Government's named industrial 'SuperPlaces'; early adoption of a regional scale flagship low carbon fuel will allow the north west's industry to thrive, despite mounting pressure to reduce emissions.
- HyNet is uniquely a cross-border cluster project offering substantial decarbonisation benefits and levelling up to a region from Wrexham and Flintshire, through Cheshire, Liverpool City Region and Greater Manchester and into Lancashire.
- HyNet will deliver 35% of the UK's 1 GW hydrogen target by 2025, 75% of the entire UK target of 5 GW of hydrogen by 2030 and CO_2 CCS capacity for 10 million tonnes per year by 2030, equal to the entire UK 2030 target.
- HyNet is able to support a 'Hydrogen Village' by 2025 and a 'Hydrogen Town'[18] by 2030.

HyNet is the most demand led, deliverable and cost-effective project ready to decarbonise the North West Industrial Cluster, which is economically vital to the UK. Key project benefits are:

Low cost, high confidence CO_2 transport and storage system

- HyNet's CO_2 geological storage is well characterised and deliverable at low cost and on an accelerated timeline due to the opportunity to repurpose existing gas assets.
- The storage site is currently an Eni UK operated gas field; it is a well understood gas-tight geological formation, which dramatically increases confidence that the asset will be suitable for permanent CO_2 storage.

The UK's most advanced large-scale low carbon hydrogen project

- HyNet is the only UK low carbon hydrogen production project to be undertaking FEED today. It is expected to reach FID before the end of 2022 and be operational by end of 2025, subject to government support regimes.
- Plant 1 utilises a "best in class" technology from UK company Johnson Matthey (JM); demonstrating this technology at scale will confirm JM as a world leader in Low Carbon Hydrogen technology, adding a long-term business line to an already highly successful FTSE 100 organisation.

The UK's first integrated low carbon hydrogen infrastructure

- Over 30 industrials and flexible power generators have engaged with HyNet to decarbonise their operations via hydrogen fuel switching, safeguarding jobs and delivering growth.
- HyNet will allow a significant and rapid reduction in domestic CO_2 emissions by blending into the natural gas network, based on learnings from the HyDeploy project trials[19].

Safeguarding jobs and economic growth[20]

- Low carbon energy will protect many high-skilled manufacturing jobs in industry from the adverse commercial effects of rising CO_2 costs, and create an estimated 6,000 new permanent jobs in the north west region.
- Utilising JM's core technology will support UK chemical engineering, catalyst manufacturing and high value proprietary equipment manufacture.
- Direct spend and inward investment will result in £31 billion Gross Value Added for the UK as a whole and around £17 billion for the north west to 2050.

HyNet Hydrogen Production is critical to meet the targets in Government's Ten Point Plan, delivering 35% of the promised 1 GW low carbon hydrogen UK target by 2025.

[17] HM Government (2020) The Ten Point Plan for a Green Industrial Revolution https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/936567/10_POINT_PLAN_BOOKLET.pdf

[18] "Hydrogen Village" and "Hydrogen Town" as defined in UK Government's Hydrogen Strategy; GOV.UK (2021) UK hydrogen strategy https://www.gov.uk/government/publications/uk-hydrogen-strategy

[19] For more information, please visit https://hydeploy.co.uk/

[20] HyNet North West (2020) Unlocking Net Zero for the UK https://hynet.co.uk/wp-content/uploads/2020/10/HyNet_NW-Vision-Document-2020_FINAL.pdf

HyNet Timeline

The nascent hydrogen market will be required to build-up supply and demand in parallel. HyNet is designed to deploy incremental stages, as outlined in Table 5.1.

	Hydrogen Production	Hydrogen Network	Hydrogen Storage	Hydrogen Consumers
Initial Investment	Plant 1 (350 MW) in operation by 2025 at Stanlow	Phase 1 pipelines from plant to Essar and 2 or 3 other local consumers	None	Stanlow Manufacturing Complex, 2 other industrial consumers, Hydrogen Village and local blending
All System Components	Plant 2 (700 MW) in operation by 2026 at Stanlow	Phase 2 network from Stanlow to storage, St Helens Warrington and Trafford commissioned by 2026/7	First salt caverns at Keuper in operation by 2026/7	Connections to 10-15 large industrial and flexible power generation consumers close to Phase 2 network in operation by 2026/7. Also connection into Cadent Local Transmission System for blending at scale
Expansion	Plants 3 and 4 in operation by 2028 and 2030 respectively bringing total capacity to 3.8 GW	Phase 3 network commissioned by 2030	1.3 TWh of working storage capacity in operation	30 TWh/y of demand connected across the whole system to include Transport users as well as further blending into Cadent and Wales and West Utilities networks. Over 30 industrials and flexible power generators receiving hydrogen from HyNet

Table 5.1 – HyNet Build Out Stages

Build Out of Hydrogen Production

The hydrogen production hub sits at the heart of the HyNet cluster. The hydrogen economy in the UK is in its infancy. Therefore, hydrogen demand and supply need to grow together over the next decade to support the investments required across the value-chain.

The HyNet project has modelled the north west region and estimated a total demand for low carbon hydrogen of 30 TWh per year by 2030, to put the region on the trajectory to achieve Net Zero by 2050. The ambition of HyNet is to switch approximately 45% of the region's natural gas consumption to low carbon hydrogen by 2030.

To meet the forecasted growth in demand for hydrogen in the region, HyNet hydrogen production is to be developed and constructed in phases, referred to as "Plants". The design throughput of each plant is shown in Table 52. Note that the four plants combined will produce a total of 33 TWh per year by 2030; some 3 TWh per year of this production will be used to underpin HyNet operations.

Plant	Hydrogen (kNm³/h)	Hydrogen (MW_{th} - HHV)	Hydrogen (TWh/y)	Cumulative (TWh/y)
1	100	350	3	3
2	200	700	6	9
3	400	1400	12	21
4	400	1400	12	33

Table 5.2 – Hydrogen Design Rate (Plants 1 - 4)

By 2030, HyNet can deliver 30 TWh per year of low carbon hydrogen to multiple consumers, cost-effectively replacing 45% of the region's current natural gas consumption and reducing CO_2 emissions by around 6 million tonnes per year.

This report focusses primarily on the FEED for Plant 1. However, in order to move rapidly into delivery of subsequent facilities, it is recognised that the site must also accommodate Plant 2 so key factors such as: layout, offsite connections and utility tank sizing are considered to manage interfaces, equipment and infrastructure scaling. Plants 3 and 4, which are also expected to be located at the Stanlow Manufacturing Complex, are considered for major offsite pipeline connections only.

6 | HYDROGEN SUPPLY COMPETITION
- PHASE 2

Hydrogen Supply Competition

Phase 2

At Phase 1 of the Hydrogen Supply Competition, HyNet developed a pre-FEED feasibility assessment for the deployment of a low carbon hydrogen plant at Stanlow Manufacturing Complex. The overall objective of Phase 2 of the competition was to drive the delivery of this project, by demonstrating a real-world project that can deliver low carbon hydrogen at competitive cost, and to support decarbonisation of a UK region.

In order to be a deliverable project, it needs to be technically coherent, appropriate for consenting and commercially viable; the Phase 2 work – delivered by the Consortium of Partners in Table 6.1 – has concluded that Plant 1 is expected to be deliverable from each of these perspectives.

The primary requirements for this phase of the project were:

- Deliver FEED within the requirements of the BEIS Contract (scope, quality, schedule, cost).
- To provide the basis for investment and delivery subject to the commercial frameworks being established by government.
- Developing a safe and deliverable technical solution which maximises carbon savings and minimises environmental and planning footprint.
- Optimise economics of plant operation (efficiency, availability, CO_2 recovery) to minimise the cost of CO_2 abatement and thus the requirement for government support.
- Optimise delivery and schedule to meet government policy objectives and satisfying the urgent needs of hydrogen customers.
- Scalable and deployable (in planned location, on other sites within Stanlow Manufacturing Complex, and throughout the UK).
- Develop and apply for all pre-FID consents required to build and operate the plant.
- Establish a basis for all external connections and utilities.
- Develop a financial assessment of the plant.
- Share learnings through a suite of Knowledge Transfer activities such as: a final report, information sharing with BEIS, stakeholder engagement and industry events.

The Phase 2 work has included the production of over 1,000 drawings and documents, produced by a collaborative team of 200 and engaging with well over 100 third-party organisations.

Consortium Partners

The Phase 2 scope was delivered by the Partners shown in Table 6.1.

Partner	Role in HyNet Hydrogen Production	Role in Phase 2 Development
Johnson Matthey plc (JM)	• Technology licensor and operational support of core **LCH** plant technology. • Developer and supplier of proprietary catalysts.	• Basic Engineering Package for core **LCH** plant technology. • Review of interfacing facilities to ensure safe and coherent total plant design.
Kent – formerly SNC-Lavalin	• Engineering design for Plant 1 – FEED and pre-FID engineering. • Engaged with plant owners to explore delivery strategies for Plant 1 to satisfy owner and Government requirements of Value for Money and certainty of project outturn.	• Overall responsibility for the plant technical FEED work, including the balance of plant engineering, delivery planning, programme and constructability. • Basic Engineering Package for carbon capture technology, working alongside technology licensor. • Capital Expense (CAPEX) and Operational Expense (OPEX) estimates. • Supporting documentation for planning application, consenting and permitting.
Essar Oil (UK) Ltd (Essar)	• Provide land and shared infrastructure for the plant. • Operations and Maintenance (O&M) service provider. • Co-owner of the plant together with Progressive Energy. • Provider of part of the feedstock supply as ROG. • Largest single consumer of Plant 1 output.	• Review of FEED definition (Owner's Engineer role). • Provide site data and information to support FEED design. • Development of O&M strategy. • Operator role in safety reviews. • Submission of planning application, hazardous substances consent and Stanlow permit variation.
Progressive Energy Limited (Progressive)	• FEED project management. • Lead project development of Plants 1 to 4 and the wider HyNet cluster. • Lead development of large cohort of hydrogen consumers across the industrial and flexible power generation sectors. • Co-owner of the plant with Essar.	• Overall co-ordination of Phase 2, including provision of Project Director. • Interface with BEIS and regulatory bodies. • Technical lead on wider HyNet project, including interfaces with hydrogen distribution and CCS. • Lead on policy and commercial arrangements, hydrogen policy framework, financial modelling and financing requirements. • Lead on utility connections.

Table 6.1: HyNet Hydrogen Production Plant Consortium Partners

7 | PROJECT BASIS OF DESIGN

Project Basis of Design

A basis of design (BOD) document was developed and maintained for Phase 2; a summary of this is shown in Table 7.1.

Inevitably during the design process, changes arose as the project developed. Any change to this BOD required a formal change request and approval by all consortium partners.

Parameter	Basis of Design
Hydrogen Production	100 kNm^3/hr (equivalent to 350 MW_{th})
Plant Turndown	The whole plant shall be capable of turning down to 40% of maximum hydrogen output
Feedstocks	Natural Gas (up to 100% of feedstock energy, at 100% output) ROG (up to 40% of feedstock energy, at 100% output)
Feedstock Specifications	Detailed composition and operating conditions specification given for: Natural Gas, ROG, Water and Oxygen
Product Specifications	Detailed composition and operating conditions specification given for: Hydrogen and CO_2
Availability	The plant should be designed with a target availability of 95% averaged over its lifetime (based on a preliminary assumption of a 20-day turnaround duration every 4 years). Note that preliminary assessments in FEED have demonstrated an estimated 94% availability, based on a 30-day turnaround; discussed further in Section 11
Thermal Efficiency	The plant shall be designed to maximise the thermal efficiency (i.e. energy out as hydrogen, divided by, energy in as feedstocks)
Carbon Capture Rate	The plant shall capture as CO_2 a minimum of 95% of the total carbon entering the plant with a target of 97%
Design Life	The plant should be designed to have an operational life of 25 years with some exceptions (for example, Fired Heater and Boiler tubes should be designed for 100,000 hours per API 530[21])
Build Out	A second plant is planned; Plant 2 will be twice the capacity of Plant 1. Decisions have been made in FEED to invest in the infrastructure for Plant 1 to be commensurate with the rapid and cost optimised implementation of Plant 2 in the following areas: • Plant layout • Pipeline connections, AGIs, and headers • Electrical supply • Raw Water • Storage Tanks • Sparing of machinery (pumps and compressors)

Table 7.1: Plant 1 Basis of Design Summary

[21] API RP 530 2nd Edition, May 1978, 'Recommended Practice for Calculation of Heater-Tube Thickness in Petroleum Refineries'

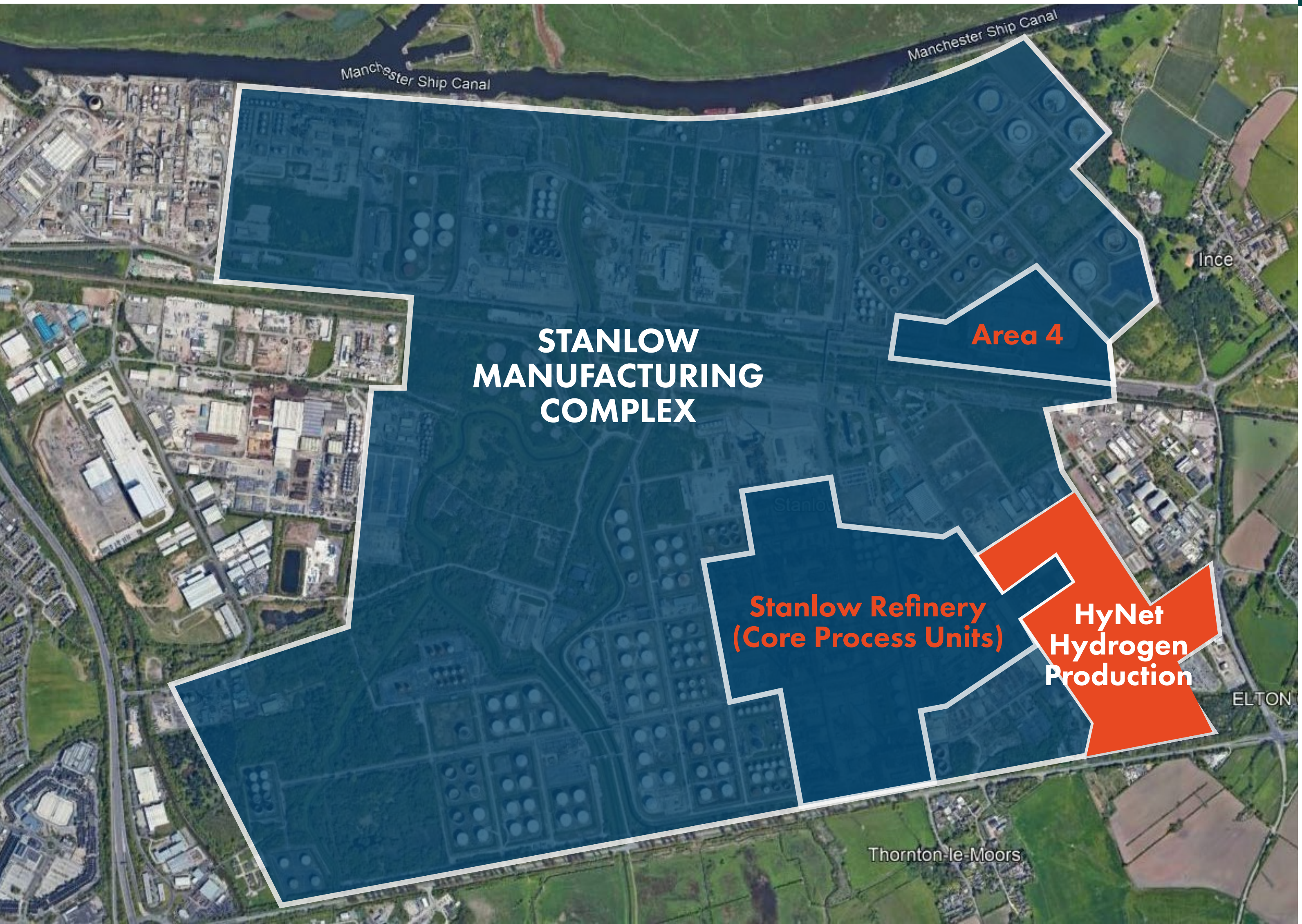
8 | PLANT LOCATION AND LAYOUT

Plant Location and Layout

Plant Location

At the heart of the HyNet cluster, the plant is located on the former Alcohols production site in the south east corner of the Stanlow Manufacturing Complex, as shown in Figure 8.1. Following Pre-FEED, the Phase 1 basis for plant location was Area 4 – shown for reference. However, work during FEED concluded that the former Alcohols site would be the more appropriate location for the reasons set out below.

Figure 8.1 – Plant Location within Stanlow Manufacturing Complex



Process Interfaces

As discussed in more detail in Section 9, the plant has a number of key interfaces to external facilities. The below were considered when opting to change the selected location.

- The majority of offsite pipeline routings (Hydrogen Network, CO_2 transport and storage and natural gas feedstock) are all simplified from a design and consenting perspective, as well as reduced capital investment for the wider HyNet cluster. In addition, the Alcohols site allows significantly more space for third-party Above Ground Installations (AGIs), which is important to allow separation between multiple facilities, each of which will be operated by different entities.
- ROG and hydrogen pipelines to Stanlow Refinery are both approximately 1 km shorter than would have been required for Area 4, reducing both CAPEX and ongoing inspection and maintenance of cross-site pipelines.
- The local 132 kV electrical network passes along the southern boundary of the Alcohols site, significantly reducing the length of high voltage power cables to the incoming substation.
- The Alcohols site is located closer to both raw water and effluent treatment connections.

Safety Considerations

The need to develop a plant which can be accepted as being safe has been at the foundation of all design decisions, and has underpinned not just the plant layout, but the fundamental decisions on site location, pipeline routing and the choice of gas pressures. Where available, design standards and codes of practice have been used, and where these have not been available, industry best practice has been employed. Discussions with the Health and Safety Executive (HSE) were initiated at an early stage in the project and an ongoing exchange has been set up.

During Phase 2 technical work, once preliminary equipment sizes, piping sizes and operating conditions were known, DNV GL completed a Quantitative Risk Assessment (QRA) using industry norms to establish the risk contours for the plant. This work concluded that Stanlow Manufacturing Complex is a suitable location for constructing and operating such a plant within. Considering the QRA risk contours during detailed site selection, the Alcohols plot provided a better opportunity than Area 4 to house both Plants 1 and 2 at a suitable distance from site boundaries.

Plant Layout

The site is laid out to provide a sufficient safety distance between the new **LCH** and the public road to the south, and to the Thornton Science Park to the east. A dedicated non-continuous flare is provided for the site and is located in the north west corner of the site, away from public areas. Pipelines will approach the site from the south under the A5117 with AGI located within the southern part of the process area of the site from where there is good access to the pipe racks serving the site. The site-based utilities for the plant are located to the south east of the plot and include water treatment and electrical power distribution.

Plants 1 and 2 will be operated from the existing central control room for the refinery such that there will be no permanently staffed buildings on the site.

The layout has considered plot space for Plant 2 **LCH** unit and associated Air Separation Unit (ASU), based on an assumed percentage increase in footprint; JM and ASU vendors respectively have reviewed these. These Plant 2 units are shown as an outline on the plot plan in Figure 8.2. The FEED 3D model of Plant 1 is shown in Figure 8.3.

Plant layout design undertaken in FEED allows sufficient plot space for the fast-track expansion of the hub to 1 GW hydrogen output.

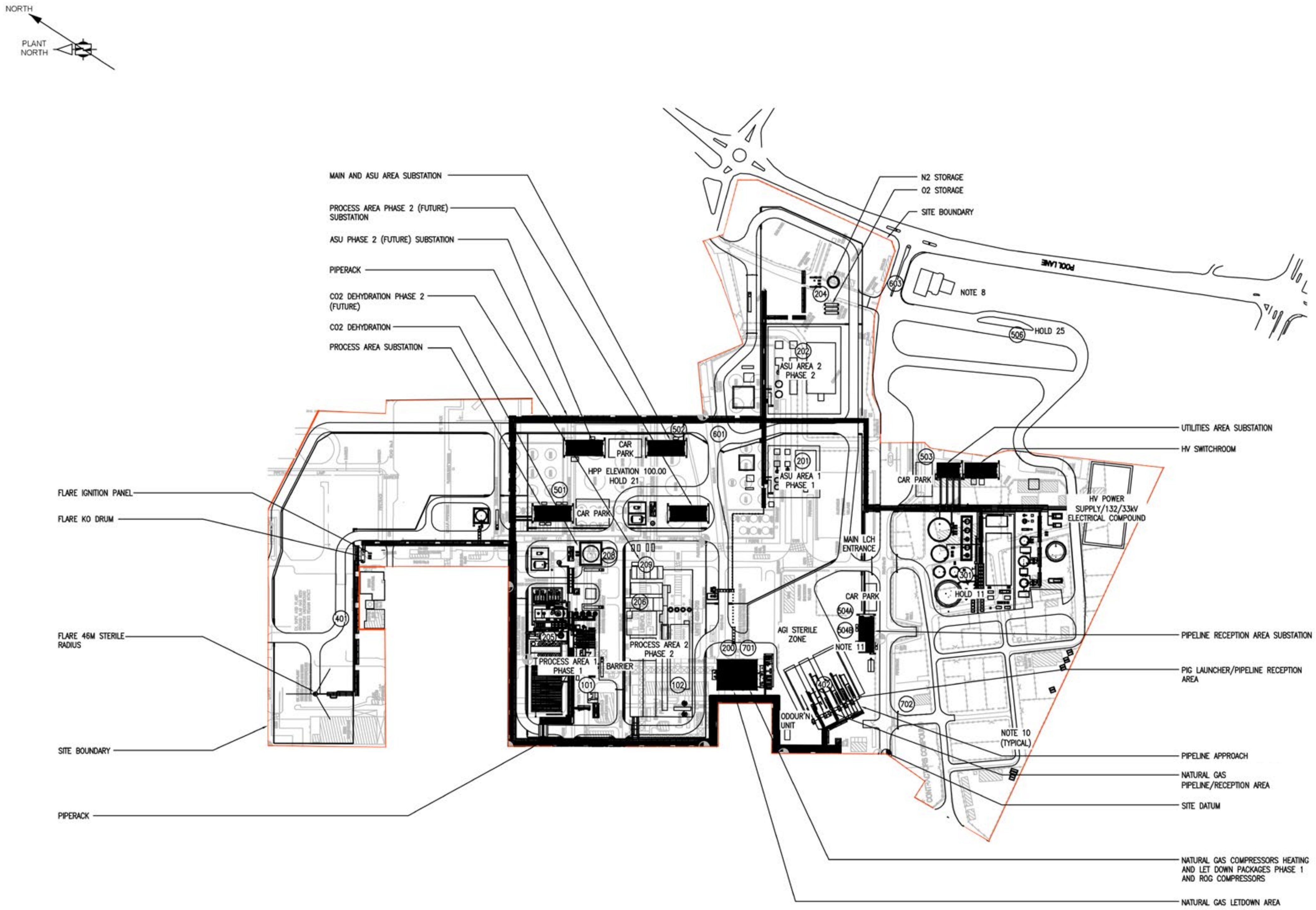


Figure 8.2[22] - HyNet Hydrogen Production Plants 1 and 2 Plot Plan.

[22] Figure 8.2 refers to "Phase" in substitute of "Plant" as described in this report. Plant equipment shown in grey is existing equipment to be removed as required to construct the Hydrogen Production Plant.

Figure 8.3 - HyNet Hydrogen Production Plant 1 3D Model.

9 | TECHNOLOGY AND PROCESS

Technology and Process

Plant 1 has been designed to a FEED level of definition, including all utilities and external connections required to deliver a fully functional facility. The plant has been designed as a number of interconnecting units; the process units that make up Plant 1 are outlined below.

Low Carbon Hydrogen Plant

The hydrogen production technology selected is the JM Low Carbon Hydrogen **LCH** flowsheet which offers very high overall efficiency by coupling a Gas Heated Reformer (GHR) with an Autothermal Reformer (ATR). The main differences between the **LCH** and typical Steam Methane Reforming (SMR) flowsheets are that the energy to drive the reaction is provided by introducing oxygen to the ATR as opposed to burning natural gas in air in an SMR, and that CO_2 can be removed from the product gas (syngas) at pressure – allowing for smaller vessels and greater capture rates. GHRs and ATRs are already used in the production of syngas and are part of most modern schemes for production of methanol and liquid fuels from Fischer-Tropsch processes; these existing plants demonstrate that the technology is capable of producing hydrogen at comparable, although smaller, scale to that required for HyNet, and therefore the scale-up risk for the technology is minimised.

At a basic level, a flowsheet showing hydrogen production using **LCH** technology is shown in Figure 9.1.

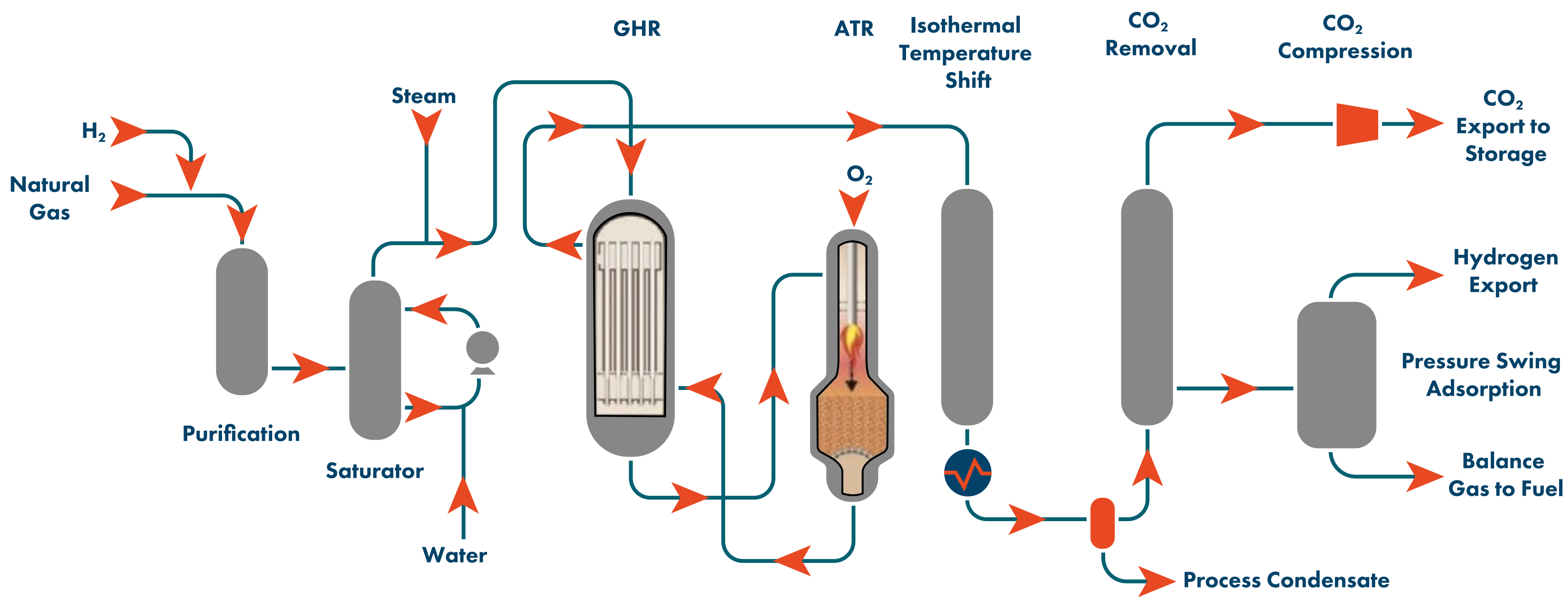


*Figure 9.1: JM **LCH** Flowsheet*

Purified natural gas (or ROG, or a mixture thereof) is pre-heated and reformed in the GHR before entering the ATR. In the GHR, 30% of the total hydrocarbon is reformed by reaction with steam to form syngas. In the second stage, the ATR, oxygen is added and combusts some of the partially-reformed gas to raise the process gas temperature. The resultant gas then passes through a bed of reforming catalyst inside the same vessel for further reforming. Since the reaction is limited by equilibrium, operation at high temperature and steam flows minimises the methane content of the product gas which in turn minimises overall CO_2 emissions. The hot gas exiting the ATR passes back to the GHR providing the heat necessary to drive the reforming reaction in the GHR tubeside.

The syngas, following reforming, is passed through the Isothermal Shift Converter, where the residual carbon monoxide reacts with water to produce additional product hydrogen. This reaction is exothermic, so is used to generate additional steam for the process.

Before FID, JM and SPC will negotiate a licensing agreement for the **LCH** technology, which will include a set of performance metrics guaranteed by JM.

Figure 9.2: CO_2 Capture Unit 3D Model

Integrated Carbon Capture

The CO_2 Capture Unit (shown in Figure 9.2) recovers CO_2 from the syngas, downstream of the **LCH** Isothermal Shift Converter. In order to maximise the overall capture rate of the plant, it is critical that the carbon capture unit is able to isolate a very high proportion of the CO_2 present in the syngas fed to the unit; approximately 99.9% of CO_2 entering the carbon capture unit is isolated by the amine for storage.

Prior to FEED, the project issued an enquiry to market for the provision of the carbon capture technology. The proposals and technologies were technically and commercially evaluated, which concluded that BASF technology was recommended. BASF was evaluated as meeting all technical requirements, whilst offering the lowest risk technology and the highest CO_2 removal efficiency. Following technology selection and licensing, Kent developed a basic engineering package for the plant based on BASF's flowsheet.

Syngas at moderate temperatures (~65°C), is passed to the carbon capture unit absorber tower, where it is contacted with BASF's OASE White® solvent to remove CO_2.

Hydrogen rich syngas leaves the unit, from the top of the absorber, and passes to downstream hydrogen purification. CO_2 rich amine leaves the bottom of the absorber tower, where the pressure is reduced and heat added to remove the CO_2 from the amine in the stripper tower. The removed CO_2 leaves the unit for downstream compression.

Regeneration energy is required to heat and strip CO_2 from the rich amine. Plant 1 design is fully integrated so that the duty required by the CO_2 stripper reboiler is provided by heat carried by the hot syngas in the **LCH**; no supplemental steam or fuel is required.

Pressure Swing Adsorption

The hydrogen rich stream exiting the CO_2 Capture Unit is purified using a Pressure Swing Adsorption (PSA) unit. The PSA produces the final product hydrogen stream by removing residual carbon monoxide, CO_2, methane, methanol and nitrogen in a tail gas stream. The result is >99.9% pure hydrogen. This tail gas is recycled to the Feed Fired Heater and Steam Boiler in the **LCH** unit; the use of this tail gas for steam generation and feedstock heating eliminates the need for any supplemental fuel or steam under normal operation.

CO_2 Dehydration

To minimise risk of corrosion and other adverse impacts in the downstream transport and storage facility, the water content of CO_2 must be kept below 50 ppmv. A dehydration process step using Tri-Ethylene Glycol downstream of compression, is required to meet this specification.

Plant Performance

A number of factors relating to plant performance have been established in the BOD either as absolute requirements or targets to be aimed at through the design process.

JM LCH Technology Performance

The **LCH** technology builds upon the knowledge and experience of JM around the Leading Concept Ammonia (LCA) and Methanol (LCM) commercialised flowsheets, to produce high purity hydrogen with 97% of the CO_2 being captured.

Compared to the counterfactual of SMR with CCS, the **LCH** technology uses a number of technologies that are not commonly used on hydrogen plants in order to maximise conversion efficiency and hence minimise energy consumption. Previously proven in LCA and LCM flowsheets, these include:

- A GHR to recycle heat at the highest possible level as opposed to downgrading to medium pressure steam.
- An oxygen blown ATR to minimise methane slip by operating the ATR at high temperature.
- A high efficiency water cooled Isothermal Shift Converter that recovers medium grade heat as steam.
- A saturator circuit to recycle process condensate and use heat to generate steam.

By utilising a combination of well-established technologies from other industries, leading UK company Johnson Matthey has developed a novel flow scheme for Low Carbon Hydrogen with robust guarantees on its efficiency and carbon capture performance.

Throughput Flexibility

Once the hydrogen distribution network is operational, daily and seasonal fluctuations in the regional hydrogen demand will be met through utilisation of salt cavern storage capacity. However, with Plant 1 in operation before the network and bulk storage have been completed, the Phase 1 hydrogen pipeline will have negligible storage capacity between the plant and the end users. Therefore, Plant 1 will be required to operate at a throughput to match supply to the demand of end users. The plant can automatically respond to fluctuating demand for hydrogen.

To maintain supply during periods of low demand, the plant has been designed to operate at 40% of maximum rate with no detrimental impact to the plant's thermal efficiency or capture rate. To meet demand fluctuations, the plant has been designed to respond quickly to changes in demand. The plant is capable of ramp-up at 1% of design rate per minute, equivalent of turn-up in plant rate from 40% to 100% in one hour. Ramp-down is considerably faster; turn-down from 100% to 40% of design rate can be achieved in as little as 10 minutes, up to 6% of design rate per minute.

Plant Availability

Maximising Plant 1's uptime (availability), is critical to generate the best economic return on investment and consistent decarbonisation for the north west region. FEED was undertaken with a target availability, including planned and unplanned outages, of 95%.

Following conceptual plant design, a preliminary assessment of availability was undertaken, which showed a composite plant availability of ~95-96% between turnarounds. As discussed further in Section 11, the plant requires 30-day outage every 4 years for major maintenance. Combined, this gives an availability of ~94%. At the level of accuracy of this preliminary assessment, 94% is not considered materially below the target of 95%. There are no obvious main contributors to this difference when assessing the availability on a unit-by-unit basis. The target overall availability for the plant remains 95%. A full Reliability, Availability, and Maintainability assessment will be undertaken once sufficient equipment vendor information is available to identify the key contributors to unplanned downtime; any justified improvements will be implemented, to increase plant availability wherever incremental investment is considered proportionate to the benefit.

Plant Performance Summary

Table 9.1 compares Plant 1 design performance versus the BEIS (SMR+CCS) counterfactual.

Parameters	Units	Counterfactual	HyNet	
Feedstock	N/A	Natural Gas	Natural Gas	Natural Gas and ROG
Hydrogen Product Flow Rate	MW_{th} (LHV) / (HHV)	300 / 354	300 / 354	300 / 354
	kNm³/hr	100	100	100
Hydrogen Purity	%	99.9	99.9	99.9
Efficiency (LHV) & (HHV) Basis	%	67.2 / 71.7	80.0 / 85.4	80.3 / 85.8
CO_2 Capture Rate	%	90.1	96.9	96.9
CO_2 Output Stream Purity	%	96.0	99.9	99.9
CO_2 Generated	t/h	82.0	76.8	73.9
CO_2 Captured	t/h	73.9	74.4	71.6
CO_2 Emitted	t/h	8.1	2.3	2.3.0
	kg (CO_2) /kNm³ (H_2)	81.2	23.8	23.0

Table 9.1: Plant Performance

HyNet Hydrogen Production Plant 1 significantly improves on performance metrics given in the BEIS counterfactual. Most importantly, in the context of the project's objectives, the plant can capture 97% of all carbon in the feedstock for geological storage.

Plant Carbon Savings

The purpose of adopting low carbon hydrogen is to deliver material carbon savings. This project has adopted leading edge **LCH** technology in order to optimise performance and maximise carbon savings. The detailed work done during the FEED provides well established engineering data upon which to assess the operation of the plant and the carbon saved through a life cycle analysis. This includes consideration of the direct emissions from the plant as well as the wider emissions associated with upstream feedstock provision and plant construction.

The key parameters are:

- Capture rate and the plant thermal efficiency (these dictate the residual direct emissions).
- Carbon emissions associated with the feedstocks coming into the plant (including natural gas, electricity and oxygen).
- Carbon emissions associated with plant construction (a relatively minor component given the quantum of generation over its life, particularly when compared with more intermittent sources of hydrogen).

Given the importance of minimising upstream emissions, appropriate natural gas sourcing is an important factor in determining Plant 1's overall carbon savings. The project will be sourcing its natural gas from the UK and continental shelf.

The HyNet reference case provides carbon savings for hydrogen relative natural gas (on an HHV basis) of between 85-90%, depending on a number of key assumptions. This carbon saving will be refined once the calculation methodology is confirmed by the BEIS Low Carbon Hydrogen Standard, which is currently issued for consultation.

This is a substantial saving, and one which can deliver operational carbon abatement from 2025, making a material contribution to the 4th and 5th carbon budgets. Plant 1 is saving over 500,000 tonnes per year CO_2 but also unlocks further savings through follow on plants, together saving over 5 million tonnes per year by 2030. This early and material level of carbon savings demonstrates the important role for hydrogen produced in this way, compared with that from renewable electricity.

Operating Window

In order to make meaningful reductions in the CO_2 emissions from Stanlow Refinery, it is critical that Plant 1 is able to process ROG as a feedstock. Plant 1 has therefore been designed to produce hydrogen from a blended feedstock of natural gas and ROG. The proportion of these feedstocks will be managed by the operator, based on the required output of the plant and the energy balance interactions with the Refinery.

Process Safety

Low carbon hydrogen plays an important part in meeting Net Zero. Like the fuels it displaces, it must be produced, distributed and used safely.

During FEED, the identification of hazards has been determined using appropriate industry techniques including hazard (HAZID) and environment identification (ENVID) studies, with subsequent consequence analysis being conducted as part of the QRA to determine the potential scale and effect of these hazards. These include possible fire, blast and gas dispersion impacts. Results from these QRA studies were fed back to the engineering disciplines to drive the design activities, including plant location, layout and separation distances. This was followed with more detailed safety reviews, such as Hazard and Operability Study (HAZOP), Layers of Protection Analysis (LOPA) and dispersion modelling.

External Process Interfaces

In order to turn the core hydrogen and CCS technologies into a fully functional facility, a number of external process interfaces must be designed. Plant 1 design has remained cognisant of the ambitious build out plan outlined in Section 5. Those interfaces that are not easily retrofitted or expanded at a later date have been designed for the best overall value for money; these are shown in Table 9.2.

Interface	Interface with	Sizing Case	Work undertaken in Phase 2
Natural Gas	National Transmission System (NTS)	Plants 1 and 2, further expansion for Plants 3 and 4 considered	A Gas Connection Feasibility Report studied the options to supply Plants 1 to 4 from the NTS. It was decided to construct an appropriately sized pipeline from a nearby connection point to the plant. This option will supply the gas volumes required by Plants 1 and 2 and enable a later pipeline project to reinforce the NTS to this connection point to unlock capacity for Plants 3 and 4. As the NTS can operate from 26 – 77 barg, a gas receiving facility including let-down and compression has been designed for the plant.
ROG	Stanlow Refinery	Plant 1	ROG is available from a number of sources at Stanlow Refinery, at varying compositions and conditions. The ROG “dry gas” stream from the Stanlow Fluid Catalytic Cracking unit was selected for Plant 1 due to composition stability. ROG is available at pressures of 10 – 14 barg, so compression has been included to deliver the required feedstock pressure. As ROG is a by-product of refinery operations, it is inherently more variable in composition than natural gas; analysis and auto-shut off valves have been design to protect the **LCH** catalysts from degradation by out of specification gas.
Electricity	132 kV District Network	Plants 1 and 2	Feasibility discussions with the District Network Operator, Scottish Power Energy Networks (SPEN), were undertaken based on the Plant 1 and 2 load list. Whilst the preferred approach is direct connection to a low carbon electricity source, a network connection is necessary for resilience. Initial feedback from SPEN was that the installed load for Plant 1 is not available in the local 33 kV grid, therefore a connection to the 132 kV network will be required. The cost of connection is not heavily impacted by the total power, it was deemed sensible to size this connection at the maximum level (99 MVA) for Plants 1 and 2 combined peak load, with some margin for growth during later project development. The connection to the grid and a 132 / 33 kV substation will be installed and operated by SPEN, supplying power to the electrical infrastructure designed by Kent. A formal application to SPEN will be required to confirm and reserve the capacity availability and start the connection design and planning, and this application was made in October 2021.
Water	River Dee Water	Plants 1 and 2, further expansion for Plants 3 and 4 considered	The philosophy for the water system design is to recycle water within the plant and harvest rain water to minimise the imported water requirements. Make up for the system is provided by raw River Dee water. Stanlow Refinery utilises a raw water connection from the River Dee, operated by United Utilities (UU). Investigations undertaken with UU during FEED have confirmed that there is adequate capacity in this system to supply the required water to Plants 1 and 2. River water is treated on site to produce various grades of water for the process: Fire, Cooling, Demineralised.
Effluent	Stanlow Refinery and United Utilities (UU)	Plants 1 and 2	There will be two sources of water emissions: Briny effluent from the demineralisation process and any surplus surface water drainage that is not harvested for the process. Both effluent streams will be handled by the Stanlow Refinery using existing facilities; based on the composition of the steams, it will either be sent off site for water treatment by UU or direct to an outfall.
Air Gases	Industrial Gas Companies	Plant 1, preliminary discussions for Plant 2	Oxygen, nitrogen and compressed air will be provided by a cryogenic ASU. To meet a very high target availability, the ASU package will include back-up liquid oxygen storage and vaporisers in the event of ASU trips. Emergency nitrogen can be generated by the ASU with zero reliance on external utilities, which is essential for inerting the plant in case of loss of utilities. Section 15 discusses the two distinct commercial routes for the supply of air gases.
Hydrogen Off-take	HyNet	Plants 1-4	The plant will compress, analyse the composition of and meter hydrogen leaving the plant. The network will require that hydrogen is delivered at a pressure of 45 barg, and, as per the given composition specification, for distribution to the region. Initially, before the network is available, Plant 1 will have two routes to hydrogen customers: an internal pipeline to Stanlow Refinery and a direct short length pipeline to nearby consumers.
CO_2 Off-take	HyNet	Plants 1-4	The plant will compress, analyse the composition of, and meter the CO_2 stream leaving the plant. HyNet requires that CO_2 is delivered at a pressure of 35 barg and within a specified composition. This will then be in the custody of Liverpool Bay CCS Ltd, for transportation and long-term geological storage.

Table 9.2: External Process Interfaces

10 | PROJECT EXECUTION

Execution

Project Delivery Structure

The Special Purpose Company will deliver Plant 1 in two phases: Pre-Final Investment Decision (Pre-FID) and Execution.

In the Pre-FID phase, separate sub-contracts will be placed with engineering, commercial, financial and legal advisors to conduct the work required to reach FID as well as electricity and gas connection and supply capacity contracts. A Project Management Company (PMC) will be employed in the Pre-FID phase to provide various project management and controls services, and is expected subsequently to manage the Delivery Contractor in the Execution phase.

After FID, Detailed Design, Construction and Commissioning will be managed by the Delivery Contractor in the Execution phase. An entity relationship diagram is shown schematically in Figure 10.1.

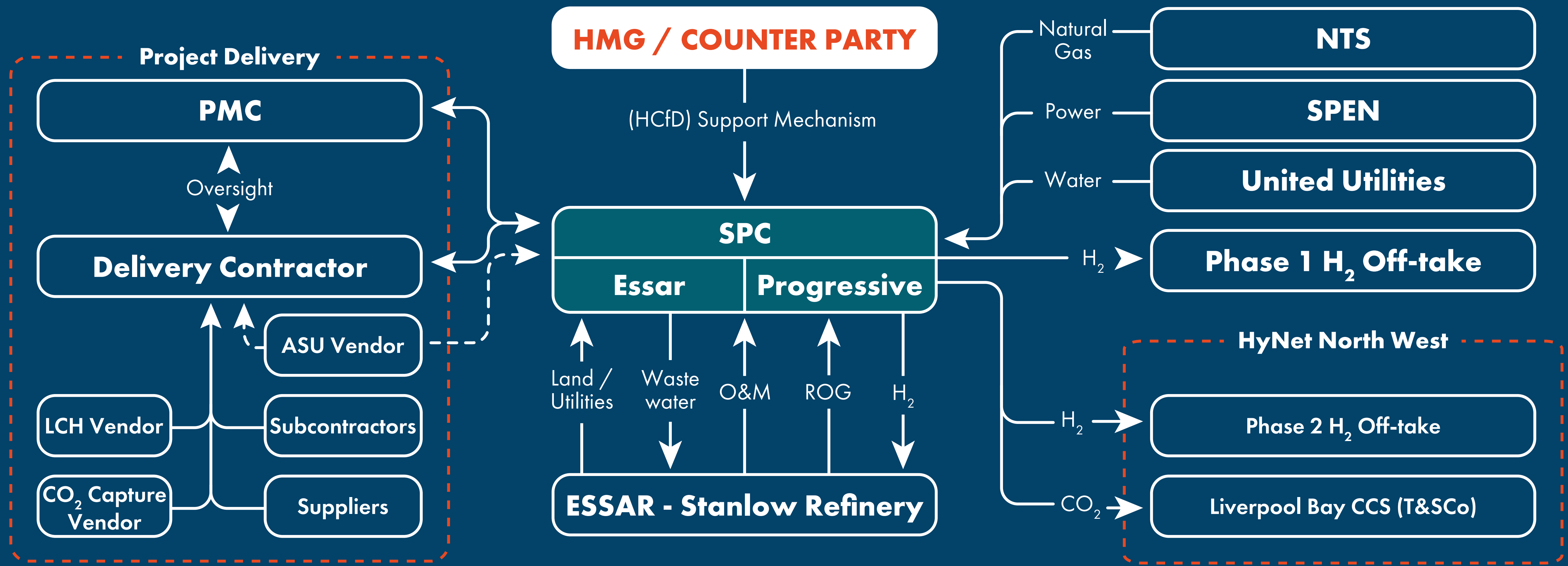


Figure 10.1: Project Delivery Structure

Project Schedule

The Project Schedule has been developed in FEED with two key targets: FID before the end of 2022, subject to implementation and negotiation of the support regime with Government, with first hydrogen by the end of 2025.

Pre-FID schedule

In order to reach FID before the end of 2022, a mixture of commercial, legal and technical works is to be undertaken in a Pre-FID development stage – more details are given in Section 16.

Execution schedule

The execution of Plant 1 will be completed as a series of six consecutive overlapping stages:

Stage 1
Detailed Engineering and Procurement
Finalise the plant design and purchase all equipment and materials

Stage 2
Early Works
The establishment of construction site offices, welfare facilities and internal temporary road systems

Stage 3
Site Preparation
Existing buildings across the site will be demolished, live underground services will be relocated and ground works will be undertaken

Stage 4
Site Access
Modifications required to accommodate the facility

Stage 5
Construction Execution
Construction of the proposed development, where appropriate using pre-constructed modules for cost and quality optimisation

Stage 6
Commissioning and Handover
To deliver Plant 1 hydrogen by end 2025

All stages of work will be required for Plant 1, whilst the construction of Plant 2 is expected to be largely a repeat of Stage 1, 5 and 6 as the enabling works for the plant will have been completed during the preparation for Plant 1. The Plant 1 schedule is shown in Figure 10.2, with an early indication of Plant 2 timing.

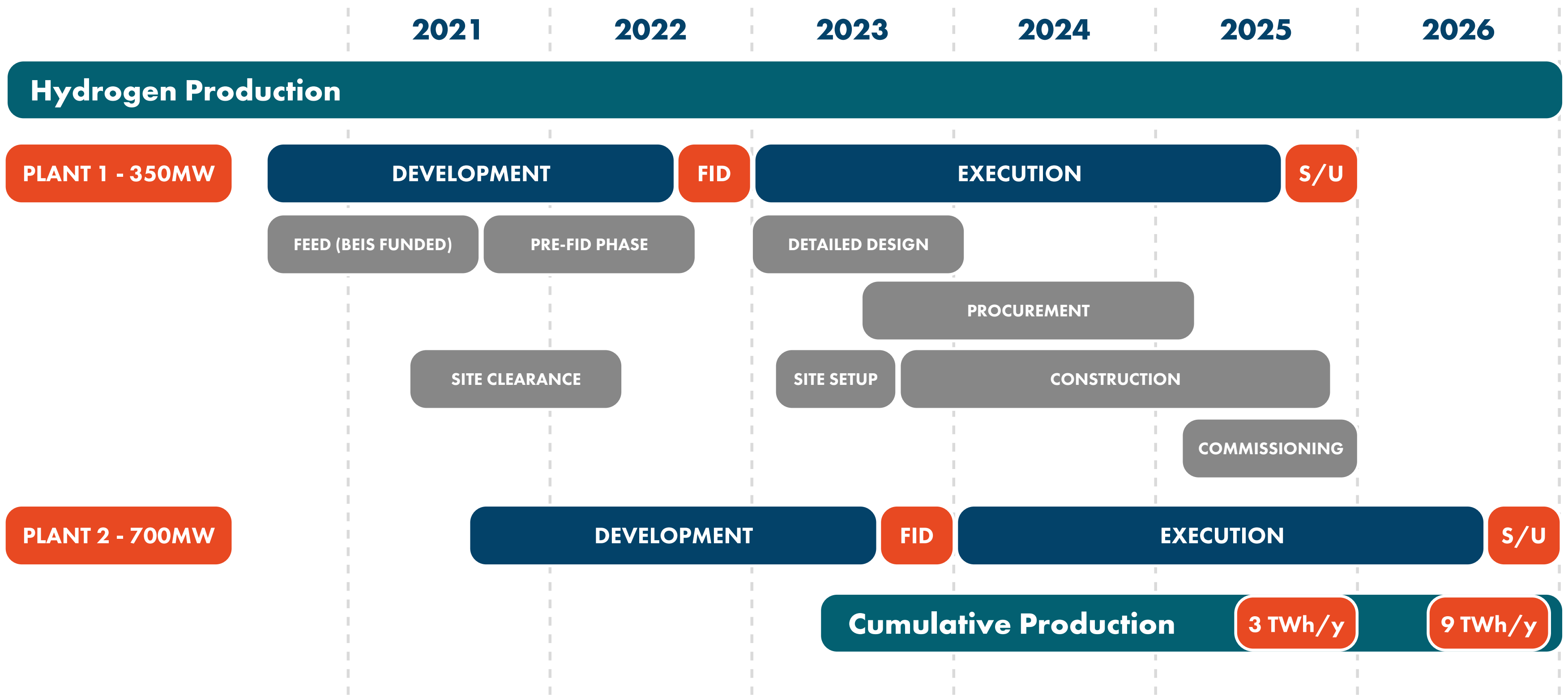


Figure 10.2: Plants 1 & 2 Project Schedule

Managing Project Risks

The project has maintained a FEED and Execution risk register throughout Phase 2, for key risks to be managed through Pre-FID and Execution phases. The top residual project risks which will carry forward to the execution phase are as follows:

1

To reach FID before the end of 2022 requires a regulated support regime agreement in place with Government. If Government is not ready to sign such an agreement before the end of 2022, then start-up of hydrogen production will inevitably be delayed.

2

The construction time of Plant 1 is longer than that for the CO_2 transportation and storage infrastructure. However, the consenting for this CO_2 infrastructure is much longer than Plant 1.

The support regime needs to enable the plant FID to take place before the CO_2 transport and storage infrastructure FID in order to enable hydrogen production by end of 2025 as per the Ten Point Plan.

3

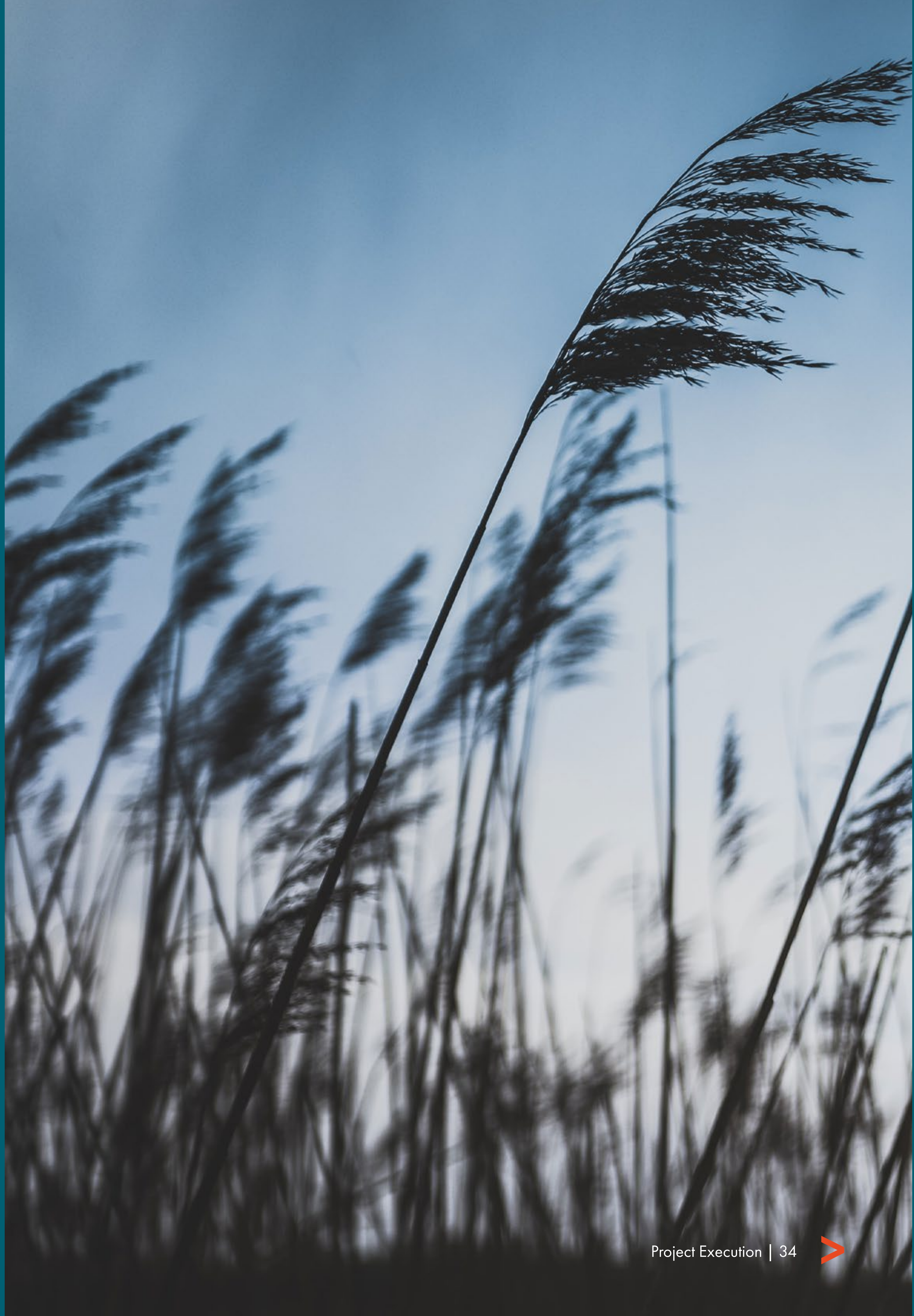
Design has been developed in the absence of a finalised Best Available Techniques (BAT) document leading to a risk during application for the Environmental Permit.

4

Plant performance tests fail to meet the requirement of product specifications, risking the financial viability of the plant; to be managed through performance guarantees from the Delivery Contractor and technology providers.

5

A reduced capacity supply chain as a result of Brexit, presenting a risk of increased delivery cost and timeline.



Plant Constructability

Plant constructability has been incorporated in the FEED package considerations. Constructability reviews have been undertaken throughout FEED to ensure that the plant is safe and efficient to build.

Construction Sequence

The overall construction sequence is included in the detailed execution programme, as described above. The site layout has been developed such that the main pipe racks are located on the perimeter of the plot which enables an efficient construction sequence to be followed. The routing of onsite traffic has been considered, to avoid disruption to the ongoing operations.

Modularisation

The construction methodology is based around reducing risk and cost during the construction phase. To do this the recommended method is to modularise the design where appropriate. A controlled off-site environment allows improved quality control of the fabrication, provides better schedule certainty because it is less influenced by weather conditions and improved safety.

The extent of modularisation and the module design is determined by the type and size of the facilities being constructed in conjunction with constraints of the logistics behind moving the modules to site. FEED design has considered the potential disruption to nearby roads when determining the size and quantity of modules.

Heavy and Critical Lifts

Planning the execution of the heavy and critical lifts for the project is important, as the availability of cranage can impact the construction schedule. A detailed lifting plan will be performed during the execution phase of the project but the equipment requiring critical lifts has been identified during FEED. In addition to this the design has allowed for crane access for construction and maintenance.

Construction Labour Availability

Throughout the construction period it is estimated that there will be an average construction workforce of approximately 300 people with a peak in workforce when module packages are delivered. The majority of the workforce is expected to live within one hour of the plant, thus supporting the regional economy.

Stanlow Refinery has conducted turnaround events hosting upwards of 3,000 personnel in recent years. The construction scheduling of the hydrogen production Plants 1 and 2 will be managed alongside planned refinery turnaround events to ensure the peak labour volume is not exceptional for the site, and that the availability of skilled labour is maximised.

Interactions with Other Projects

Plant 1 has been designated as Work Package 8 (of 11) within the wider HyNet programme. Plant 1 will have project interfaces with multiple adjacent work packages, such as constructing the CO_2 pipeline and hydrogen network pipelines. As a part of their Work Package integration role, Progressive is facilitating communication and information sharing between the HyNet partners, managing the interaction between projects in the best interests of full-chain HyNet delivery.

Commissioning, Handover and Performance Testing

Commissioning will then be undertaken by the Delivery Contractor, supported by staff from the Operator. Only once all of the process areas have been commissioned will the plant be handed over.

After handover, the Delivery Contractor will then conduct performance testing of the plant, under the supervision of the Operator. Formal completion will be dependent on successful completion of the performance testing and close out of all snagging works.

The average forecast for construction labour is 300 people, with peaks at key points in execution. Stanlow Refinery has experienced up to 3,000 people working on site during major turnarounds.

11 | PLANT OPERATIONS AND MAINTENANCE

Plant Operations and Maintenance

Operations Strategy

Plant 1 will be operated 24 hours a day, 365 days a year. Staff will primarily monitor and operate the plant from within the Stanlow Manufacturing Complex Central Control Room (CCR).

A key benefit of co-locating Plant 1 with the Stanlow Refinery is the highly experienced incumbent workforce; the plant will be operated by a dedicated operations team of suitably qualified and trained Essar personnel, with extensive background in the operations of similar facilities. SPC will contract responsibility for Operations and Maintenance to Essar, through a long-term services agreement, discussed further in Section 15.

To provide continuous operational coverage of the plant, a dedicated operations team, based in the Stanlow Refinery CCR, will operate in line with existing Stanlow practices. This team will be responsible for the operation of the plant and ensuring cohesive operation with Stanlow Refinery and the various other interfacing facilities on a 5-shift basis, each lasting 12 hours, with shift handover between operators. The operations team will be supported by a day shift to cover management and permitting for routine maintenance of the plant.

There are synergies and staffing cost reductions when expanding the site with Plant 2. The operations shift team is expected to increase by one (from 3 to 4 staff), despite producing three times the quantity of hydrogen.

In addition to the core operations staff, the plant will require a number of supporting roles. These roles, such as Finance, Document Control and Human Resources, already exist at Stanlow Manufacturing Complex and it is envisaged that SPC will have a Service Level Agreement with Essar for the provision of these services. This integration will reduce annual operating costs compared to a standalone site.

Essar will provide Operations and Maintenance services to HyNet Hydrogen Production, efficiently leveraging experience of operating similar facilities at Stanlow Refinery.

Maintenance Strategy

Essar will also be responsible for the ongoing inspection and maintenance of Plant 1 to ensure that the plant operates as designed and high levels of availability are achieved. Essar currently utilises a functional group structure for refinery maintenance; departments are split by discipline: Rotating Equipment, Electrical and Instrument and Mechanical. Due to the critical nature of the plant, the technology involved and the expected growth potential, it is practical to set in place a dedicated maintenance team with similar structure. All existing common facilities and workshops will be utilised to minimise costs.

This team will be responsible for maintaining equipment on a routine and preventative basis, as outlined by the manufacturers' recommendations and equipment strategy for that piece of equipment. This maintenance will be executed with the plant in operation, wherever it is feasible and safe to do so. Where this is not possible, maintenance will be carried out during a plant outage (a "turnaround").

Turnarounds

Much of the major work required to inspect and maintain the plant requires a full turnaround. Plant 1 has been designed based on a turnaround frequency of four years. Opportunities to extend the turnaround cycle will be investigated once operating experience and data has been gained (catalyst life, corrosion mechanisms, machine performance etc.). Any equipment that requires maintenance or catalyst change more frequently than four-yearly has been spared to ensure a four-year run length can be achieved.

Plant 1 has been designed such that no planned outage requires more than 20 days of engineering works during a turnaround. Essar has estimated approximately three days to shut down and four days to start-up the plant, based on similar units on the Stanlow site and on JM's experience of GHR/ATR plants elsewhere in the world. Therefore, a total outage of no more than 30 days from hydrogen off to hydrogen on (full load to full load) is anticipated, including a margin for delays due, for instance, to adverse weather or unforeseen maintenance.

12 | INTEGRATION WITH THE STANLOW MANUFACTURING COMPLEX

Integration with the Stanlow Manufacturing Complex

In 2021, six major oil refineries are in operation in the UK, directly employing over 7,600 skilled staff[23].

If the UK is to meet its Net Zero obligations, a significant contraction of the conventional oil sector (offshore and refining) is required; the growth of an alternative, low carbon energy value chain should expand accordingly. In its Net Zero 2050 report[24], the International Energy Agency writes: "While traditional supply activities decline, the expertise of the oil and natural gas industry fits well with technologies such as hydrogen, CCUS and offshore wind that are needed to tackle emissions in sectors where reductions are likely to be most challenging"

HyNet hydrogen production, through deployment at the Stanlow Manufacturing Complex, is a unique early opportunity to demonstrate this initial transition from conventional oil refining to low carbon energy production. This will showcase a low carbon hydrogen plant, benefiting from the available land, skills and infrastructure at the existing refinery. Following successful demonstration at Stanlow, it is envisaged that this model can be replicated at other oil refineries and industrial sites across the UK and abroad. The development of low carbon hydrogen production capacity at the Stanlow Manufacturing Complex complements the wider ambitions to support the energy transition as demonstrated by the recent announcement of the development of sustainable aviation fuel production capacity[25].

The key benefits and challenges of co-locating Plants 1 and 2 with the Stanlow Refinery are outlined in Table 12.1. These opportunities are seen as key benefits to the HyNet cluster, giving confidence that the plant will be delivered safely, cost-competitively, on time and to an excellent standard, as well as expertly operated to ensure emissions reductions are realised for the full life of the plant. Challenges and proposed mitigations are included.

HyNet will demonstrate a transition for UK oil refineries to a low carbon energy alternative, allowing these organisations that are critical to our economy to leverage their skills and experience, whilst protecting our climate.

[23] IBIS World (2021) Petroleum Refining in the UK - Market Research Report https://www.ibisworld.com/united-kingdom/market-research-reports/petroleum-refining-industry/

[24] International Energy Agency (2021) Table 2.7, IEA Net Zero by 2050 – A Roadmap for the Global Energy Sector https://iea.blob.core.windows.net/assets/ad0d4830-bd7e-47b6-838c-40d115733c13/NetZeroby2050-ARoadmapfortheGlobalEnergySector.pdf

[25] Fulcrum BioEnergy and Essar announce plans for waste-to-fuel plant in the North West of England https://www.essaroil.co.uk/news/sustainable-aviation-fuel-plant-set-for-take-off-at-stanlow/

	Opportunities	Challenges	
		Potential Issue	**Project Mitigations**
Consenting	More predictable consenting –existing industrial brownfield site, no use of green belt land, existing COMAH, existing Environmental Permit etc. Established relationships with regulators and neighbours.	Multiple related decarbonisation projects on the site –parallel permit variations may be difficult for Regulators to manage and resource.	Early discussions with Regulatory bodies to ensure adequately resources for multiple variations in parallel. Early community engagement is under way.
Personnel and Systems	Site experience – Staff (O&M, technical, management) with extensive experience operating and risk managing an upper tier COMAH site (including a previous syngas unit). Existing well-established Health, Safety and Environmental Management Systems.	Prioritisation – maintaining the base refinery operation vs. supporting future growth (the plant project development and execution).	Essar staff to be ring-fenced by secondment to SPC and later under an Operations & Maintenance Staffing Agreement. Moreover, the Stanlow site has a trained and capable organisation that has dealt through its history, and in the recent past, with large projects including building new plants whilst simultaneously maintaining operations.
Land	Reutilisation of previously developed plot of land within curtilage of existing industrial site; no additional take of green belt.	Unknown underground conditions of an industrial site. Demolition of existing facilities required.	Civil design has minimised underground works to limit land disturbance. Majority of equipment demolition by Essar, prior to land handover.
Site Infrastructure	Shared infrastructure significantly reduces project CAPEX and OPEX – security, emergency response, waste water management, offices, control room, warehouse etc.	Some existing infrastructure requires relocation to allow the plant to be built (substation migration, central stores, contractor village etc.)	Cost saving due to sharing refinery infrastructure significantly outweighs the additional cost of some relocation works.
Utilities	Potential for shared utilities for CAPEX saving or resilience. Offsite connections (power, natural gas, water) are nearby.	Integration potentially complicates design and operation (e.g. effluent removal).	Initial integrations in FEED, work to select and finalise beneficial integrations to be complete prior to FID. Any potential further integration to be realised is more likely to lead to costs savings, than the opposite.
Construction	Existing supply chain, laydown areas and previously demonstrated large load delivery routes.	Interfacing construction safety considerations may reduce site productivity.	Optimisation of on and off-site execution activities to minimise risk to construction workforce at the Stanlow site. Refinery procedures for safe project execution nearby to operating facilities; typical execution strategy at Stanlow.
Hydrogen Sales	Local to and integrated with the refinery, a significant hydrogen consumer and the largest industrial emitter in the north west. Other industry nearby to Stanlow Manufacturing Complex.	In early stages of operation, the plant's utilisation is heavily dependent on Stanlow Refinery's fuel demand.	Hydrogen distribution network reaching further users rapidly after the start-up of Plant 1. HyNet is already engaged with multiple customers in the region with an appetite to take hydrogen.

Table 12.1 – Benefits and Mitigated Challenges at the Stanlow Manufacturing Complex

Process Interactions with the Stanlow Refinery

The Stanlow Manufacturing Complex is perfectly positioned to grow as a hydrogen production hub, allowing the site to become a critical part of the nation's low carbon energy infrastructure. The close synergy between HyNet and the Stanlow Refinery offers a deliverable pathway to the UK's first refinery with Net Zero direct emissions by 2030.

This is achieved via two key interfaces with HyNet:

1. The refinery will fuel switch from current fuels (natural gas, ROG and fuel oil) to hydrogen to address CO_2 emissions from on-site fired heaters and power generation. This is represented in Figure 12.1 and discussed further in Section 9.
2. A post combustion capture plant will be installed on the Fluid Catalytic Cracking Unit and the CO_2 sent to the HyNet transport and storage facility.

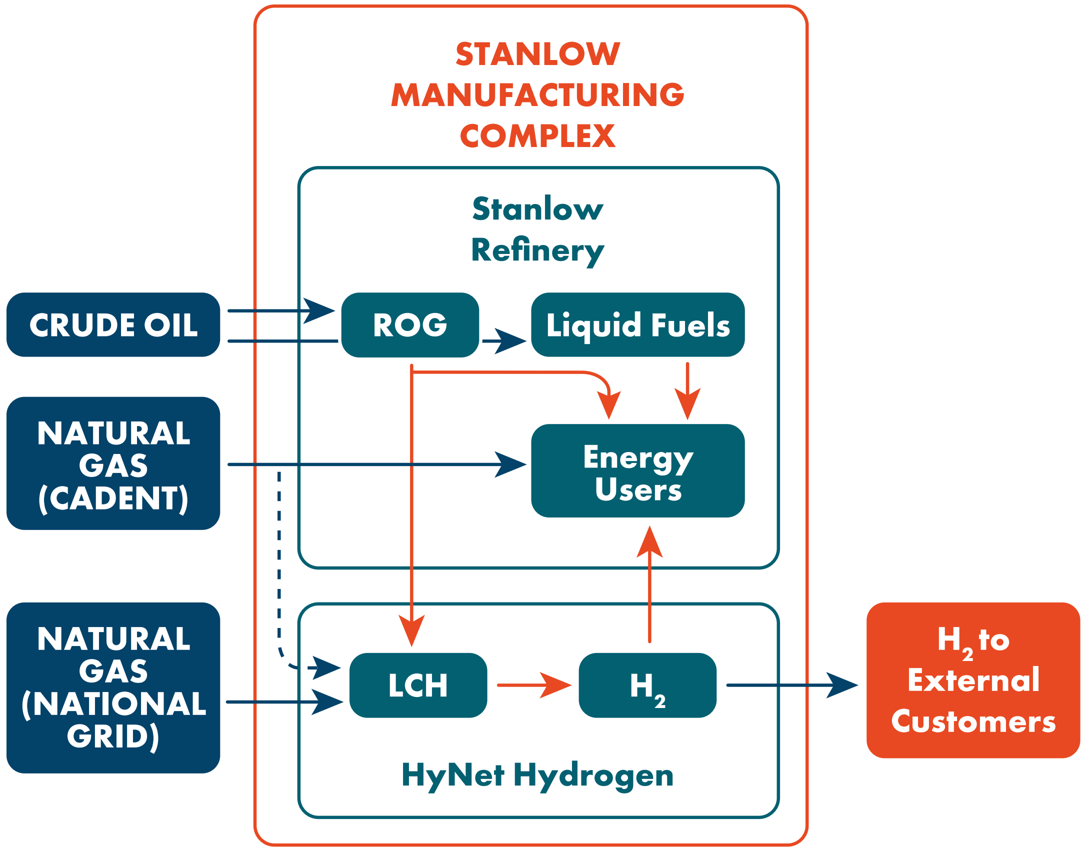


Figure 12.1: HyNet Hydrogen and Stanlow Refinery Interactions

By 2030, HyNet can enable the country's first oil refinery with zero direct CO_2 emissions – dramatically cutting the footprint of conventional fuels in the transition to Net Zero by 2050.

13 | CONSENTING AND PERMITTING

Consenting and Permitting

A detailed consenting strategy for Plant 1 was developed early during FEED, with the overarching objective of submitting or preparing all consents, to the appropriate level for this stage of development.

These consents include Planning Permission, Environmental Permitting Regulations (EPR) operating permit, Hazardous Substance Consent (HSC) and other Health and Safety related permissions necessary to construct and operate the plant. Some of these permits and permissions are standalone for Plant 1, whilst others will form variations to the existing permits held by Essar for the operation of the Stanlow Manufacturing Complex.

Planning Permission

The planning application considered the relevant, National, Regional and Local planning policies to ensure the proposed plant is fully compliant with relevant policies.

The proposed plant is not designated as a Nationally Significant Infrastructure Project as defined in the Planning Act 2008. Consequently, a standalone planning application has been prepared in line with the Town and Country Planning Act 1990 for consideration by Local Planning Authority, Cheshire West and Chester Council (CWaC). The planning application was submitted in October 2021, with an outcome expected by March 2022.

This application consists of a full planning application for the majority of Plant 1 and an outline planning application for Plant 2. The new CO_2 and hydrogen network connecting the plant to the wider HyNet infrastructure will be Nationally Significant Infrastructure Projects and so subject to consenting via Development Consent Order.

Environmental Permit

Throughout the FEED process the project team ensured that the design of Plant 1 minimises the environmental impact of the project and is compliant with major environmental regulatory requirements. The facility requires an Environmental Permit to reach FID.

Following consultation with the Environment Agency (EA), the project submitted an application to the EA to vary the existing Environmental Permit for the Stanlow Manufacturing Complex to accommodate the plant. The details of the emissions associated with Plant 1 were based on the FEED design work and assessed against the appropriate BAT documents issued by the EA. The BAT Guidance for low carbon hydrogen production remained as draft revision 5 and so the submission was made against the latest draft available to the team at the time.

COMAH and Hazardous Substance Consent

COMAH

The Stanlow Manufacturing Complex is a designated an upper tier COMAH establishment. Plants 1 and 2 will introduce additional hazardous substances and operations to the site and thus these will be assessed under COMAH.

Plant 1 will be treated as an integral part of the existing refinery and the existing COMAH safety case and report will be updated to incorporate the hazardous substances and operations. As part of their O&M responsibility to the plant, the COMAH Safety Report will be compiled by Essar after FID in parallel to detailed design and construction. A final draft is required to be in place with no objections from the HSE and EA prior to commissioning – the finalised version is usually submitted after commissioning having been updated as necessary following the commissioning process.

Hazardous Substance Consent

The HSC permits the storage of hazardous substances on the site. The applicant is required to assess the quantities of all scheduled hazardous substances to be stored on the site and then formal application is made to the Local Planning Authority for consent to store them.

The Local Planning Authority will consult with other agencies including the HSE and EA prior to issuing a consent. Receipt of the HSC is a precursor to the planning permission and COMAH submissions. Kent has developed the chemical inventories (type and quantities) and location of these within the site. The application has been submitted by Essar to CWaC as a variation to their existing site HSC.

REACH

Registration, Evaluation, Authorisation and restriction of Chemicals (REACH) requires all chemicals manufactured or imported to the European Union for sale (greater than one tonne per year) to be registered as a means of protecting the safety of the public. It will be necessary for SPC to register its products with the regulator prior to them being sold. Given that the products involved are standard chemicals it is not envisaged that there will be any difficulty in registration, and this work will be undertaken after FID.

Emissions Trading Scheme (ETS)

Production of hydrogen by reforming, in a plant that produces more than 25 tonnes of product per day, falls within the scope of the UK ETS[26]. A Greenhouse Gas permit is taken out by the plant operator with the EA. This is an additional permit to the EPR permit, taken with a different department at the EA. As Essar has an existing permit for Stanlow Refinery, this application will be raised by Essar prior to plant operations.

[26] Legislation.go.uk (2020) Schedule 2 "The Meaning of installation and regulated activity", The Greenhouse Gas Emissions Trading Scheme Order 2020 https://www.legislation.gov.uk/uksi/2020/1265/schedule/2/made

14 | DELIVERING A FINANCEABLE PROJECT

Delivering a Financeable Project

Globally there is increasing recognition that the low carbon transition underpins energy sector investment going forwards. Meeting the UK's Net Zero obligations requires investment in projects and infrastructure. There is a strong track record in the UK of investment in the renewable and low carbon sector. It leads the way globally in offshore wind, and is internationally recognised as a key territory for low carbon investments. The recent Ten Point Plan and Energy White Paper set out ambitious targets for hydrogen production capacity in 2025 and 2030. This provides an important policy backdrop to the investment landscape.

To translate this into reaching financial close on projects requires key building blocks to be in place. Primarily this is the underlying business case for investment. In the case of a low carbon project operating in an energy market where the costs of carbon are currently not fully internalised, this requires an appropriate government support framework or 'business model'. This support framework must also be structured recognising the unique challenges for the first projects in the new market, given the risks that sit across the developing hydrogen value-chain. Alongside this the individual project must have all the key elements of a financeable project.

Ultimately an FID can only be made once all these streams are fully in place with sufficient cost, schedule and delivery certainty for funds to be committed.

> **A project will only reach Final Investment Decision, once all the technical and commercial building blocks are in place. Critically, this depends on finalisation of the support regime by Government to allow a Final Investment Decision before the end of 2022.**

Government Support Regime

During FEED, Progressive alongside Linklaters LLP has developed a proposed Heads of Terms for a low carbon Hydrogen Contract for Difference (HCfD). Intended as a non-binding framework for discussions with Her Majesty's Government (HMG) regarding the business model for hydrogen production in the UK, the HCfD sets out proposed core commercial terms for the business model. The UK Hydrogen Strategy provided a minded-to position on the business models, published in August 2021[27].

This will need to translate into fully detailed contractual basis, including appropriate risk allocation between the private sector and government. This will enable the necessary selection/negotiation processes within individual projects, in parallel with any necessary legislative changes required to enact them.

A Contract for Difference support regime is seen as most appropriate because:

- It is a mechanism which is understood and trusted by the financing community.
- It enables reduced support cost over time by driving competition particularly through rounds of negotiations or auctions over time for new projects and by enabling underlying price discovery of the commodity.
- The support is paid directly to the producer bearing the costs which is efficient and bankable, minimising through counterparty risk to investors.
- It can be structured with different 'pots' for different types of hydrogen technologies at different stages of development.

The entity with whom the Contract is held must be a creditworthy and trusted counterparty such as the Low Carbon Contracts Company (LCCC).

Project Specific Activities to Underpin Financeability

The consents and commercial arrangements outlined in Sections 13 and 15 respectively must be in place for a project to be financeable. A number of these flow down from the risk allocation defined in the Support Contract, and so cannot be finalised until this is confirmed.

[27] GOV.UK (2021) UK hydrogen strategy https://www.gov.uk/government/publications/uk-hydrogen-strategy

Financing Approach

The project will reflect the way in which the hydrogen market is expected to develop. Energy projects are typically financed using project finance through a combination of equity and debt. The project has been developed commensurate with the requirements of this structure.

Equity

Against the global and UK demand for low carbon projects, and the role of hydrogen there has been a significant interest in investment in hydrogen projects over the last 12-18 months. There are a range of strategic investors, particularly from the oil and gas sectors, looking to transition towards low carbon investment and activities. There are also an increasing number of private equity and other financial investors looking to enter the space.

Essar is a strategic player, and hence joint venturing in the project with Progressive. This project unlocks a route for it to decarbonise the Stanlow Refinery as well as an opportunity to invest in the energy transition.

Debt

In order to enable build out of hydrogen production capacity required under the Ten Point Plan, and the requirements to meet Net Zero commitment, it is critical that the debt markets engage with the emerging hydrogen sector. This is necessary to provide the financing capacity required and drive down costs.

There is appetite in the market to provide these services and confidence that, with the right government support structures in place, appropriately structured projects should be able to secure project finance. At this stage financing has been assessed on the basis that early projects should conservatively be able to achieve 65% debt.

The Role for Grant Funding

Fundamentally, delivery of hydrogen production facilities requires that both the capital, and also the operational costs of production are covered. In that regard, grant funding alone cannot deliver. With a well-structured revenue support regime, the private sector has an appetite to invest. However, there is a role for grant funding into both development and capital expenditure, such as the £240M Net Zero Hydrogen Fund to manage the transition towards an established revenue support regime, supporting private sector investment, and providing market confidence in government's commitment and policy framework.

15 | COMMERCIAL

Commercial

One of the objectives of the FEED project was to progress the commercial aspects necessary to finance, construct and ultimately operate a hydrogen production plant. The goal was to develop a suite of draft commercial agreements that would exist between the plant owner and the relevant counterparty, with each agreement being developed up to an appropriate stage for FEED.

As well as being an important stage in establishing the overall deliverability of a hydrogen production plant, this workstream also delivered a number of specific benefits for the programme, including:

- Making material progress on specific long-term items that are necessary for FID.
- Gathering improved cost data for economic appraisals.
- Testing and starting to prepare the market for this new technology and energy vector.
- Enabling the boundaries and interfaces between separate commercial arrangements to be identified and considered.

Special Purpose Company

Essar and Progressive announced[28] on 18th January 2021 their intention to form a joint venture company to create the UK's first hydrogen hub at the Stanlow Manufacturing Complex. This company has been structured to deliver Plants 1 and 2 for HyNet.

SPC will seek to complete the remaining technical and commercial activities required to reach FID on Plant 1 before the end of 2022, subject to consenting and a suitable revenue support contract.

> **Essar Oil (UK) Ltd. and Progressive Energy Ltd. have demonstrated commitment to deliver HyNet Hydrogen Production by forming a joint venture to own the facility.**

[28] Essar (2021) Essar and Progressive Energy Join Forces to Deliver the UK's First Low Carbon Hydrogen Production Hub https://www.essaroil.co.uk/news/essar-and-progressive-energy-join-forces-to-deliver-the-uk-s-first-low-carbon-hydrogen-production-hub/

O&M Contracting

The O&M Service Agreement will establish a long-term agreement between the plant "Owner" and plant "Operator" for the provision of O&M services to Plant 1. This agreement has been drafted in FEED as shown in Figure 15.1, will be in place prior to FID and will be on "arms-length" terms.

The Owner will be SPC. The Operator will be Essar - the same organisation that currently owns and operates the Refinery within the Stanlow Manufacturing Complex.

The O&M Service Agreement will seek to ensure that the plant is operated safely and reliably on behalf of SPC to meet the demands of its customers. It is essential that the Operator is incentivised to operate the plant efficiently with high availability and carbon capture rates, whilst maintaining excellent levels of safety and protection for the plant's neighbours and the surrounding environment. The agreement has been drafted to ensure that the Owner provides a strong platform for the Operator to meet their duties successfully, whilst ensuring operational expenses remain under control.

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MEMBER DOC NO: P-1143-HYN-CO-001	REVISION: 02	
DOCUMENT TITLE: **O&M SERVICE AGREEMENT - HEADS OF TERMS**		PAGE: **10 of 37**

APPENDIX 1 – HEADS OF TERMS

Heads of Terms for Operations and Maintenance
(Draft – 30th April 2021)

1. The Parties and the Facility
   a. Plant Owner: Project SPC (the "Owner")
   b. Plant Operator: Essar Oil (UK) Limited (the "Operator")
   c. This Heads of Terms ("HoT") will cover the Operation and Maintenance of the first phase of the HyNet hydrogen project (the "Facility"), located at the Stanlow Manufacturing Complex at Ellesmere Port, Cheshire, CH65 4HB (the "Complex")

Figure 15.1: O&M Heads of Terms Excerpt

Hydrogen Off-take

Over the life of the developing hydrogen production facilities in the region, hydrogen will be supplied to multiple consumers. The initial large industrial customers supplied by Plant 1 will be joined by a much larger number of users as the market and hydrogen network develops, eventually including commercial and domestic users, hydrogen supplied to transport, and blending into the natural gas distribution grid. Plant 1 will contract with local large industrial anchor customers, including the Stanlow Refinery, who will partially replace their use of natural gas and ROG with hydrogen, alongside small-scale early users including hydrogen demonstrations and early deployment such as HyNet Homes and HyDeploy.

Customers face technical and commercial risks in transitioning to hydrogen. To do so they need to see a financial benefit to be 'early adopters'. It is therefore expected that the price for hydrogen will initially be based on natural gas. To the extent that such users are prepared to enter a long-term contract to underpin financing of the plant, then they should benefit from the protection from carbon pricing exposure.

Carbon Dioxide Transport and Storage

A CO_2 stream is isolated and pressurised by the plant, metered and transferred for long-term storage by the Liverpool Bay CCS Transport and Storage company (T&SCo). As this will be the sole CO_2 storage option for the plant, a long-term off-take and supply agreement will be required prior to FID, including an agreed structure for charges to SPC. BEIS is currently working with industry to develop the appropriate model[29].

Under this agreement with T&SCo, it is anticipated that SPC will be required to pay fees to the T&SCo whilst a Government support regime provides additional risk allocation provisions so that the T&SCo is financeable. To support T&SCo to provide smooth operations, it is anticipated that the plant will nominate a quantity of CO_2 to be stored in the following day, based on the forecasted demand for hydrogen. In return, T&SCo will guarantee that, provided the system is available, it would take all CO_2 (up to an agreed contracted amount) produced by the plant during its lifetime.

[29] Gov.uk (2020) Carbon capture, usage and storage (CCUS): business models https://www.gov.uk/government/publications/carbon-capture-usage-and-storage-ccus-business-models

Feedstocks

The primary feedstocks for Phase 1 of the facility are natural gas and ROG, each of which will require long-term commercial arrangements to be in place prior to FID.

Natural gas will be sourced, via the NTS, most probably from a single supplier, under a long-term, market standard, flexible contract for the supply to an industrial facility. SPC will seek gas suppliers from lower carbon footprint gas sources to minimise emissions from the project's upstream supply chain.

ROG will be supplied to SPC from the Stanlow Refinery, under a long-term contract with Essar negotiated at arms-length. For technical reasons, the operating modes of the refinery and seasonal variations will give fluctuations in the available supply and composition of this ROG. Where ROG is available and meets the technical specification, it will be delivered to the **LCH** facility by Essar and used preferentially as a feedstock to produce hydrogen. The ROG will be priced, according to its energy content (p/kWh), with the price indexed to a market gas index, with appropriate adjustments for transportation and additional compression.

Air Gases

As part of FEED, two separate contracting strategies were investigated:

1. The 'design and build' of an ASU by SPC as an integral part of the plant.
2. Long-term over-the-fence gas supply direct from an industrial gas company who then builds, owns and operates the ASU.

Prior to FID, SPC will compare these options (with respect to life-time cost, flexibility, and financial and risk management) and make a decision as to which way to proceed.

Catalysts and Solvents

A catalyst and chemicals supply strategy is important to ensure that Plant 1 has a robust plan for provision of consumables to the plant, to support ongoing operations. The strategy for each of these consumables will reflect the balance between the need for secure supplies against a desire for competitive pricing for these products.

The use of specific JM **LCH** catalysts and proprietary carbon capture solvent are expected to be required for the life of the plant to ensure that performance guarantees remain valid. Therefore, SPC will seek to establish long-term supply guarantees for these consumables, with an agreed pricing structure indexed to relevant industry markers, prior to FID. SPC will, however, reserve the right to tender these consumables competitively during the lifetime of the plant, if higher performing or better value-for-money alternatives are identified.

For all other "common" consumables, it is expected that these could be sourced from a number of suppliers and that Essar, as Operator, will establish short-term, periodically re-negotiated, supply contracts for these.

Water and Effluent

The existing Stanlow connection for raw water is into a common header and so the performance characteristics of this connection is well understood and the volumetric price known.

Liquid effluent will be metered or measured at the point of transfer to the existing refinery effluent system and off-site treatment costs passed through to SPC via Essar's existing commercial effluent charging contracts.

Insurance

The project engaged the services of a global leader in insurance broking and risk management to understand and identify the appropriate insurances that would be required at the various stages of the development, construction and operation of this sort of plant.

Relevant construction and operational metrics for Plant 1 were provided to the broker, which were used to create budget annual premium estimates for Business Interruption, Erection All Risk, Delayed Start Up, Operational All Risk covers, as well as Employer's and Public liability insurance

Financial Model

A detailed financial model was produced based on the inputs developed through this programme in order to inform delivery of the project. The output of this assessment shows a Levelised Cost of Hydrogen that broadly consistent with the range of hydrogen costs developed by BEIS in the Hydrogen Strategy.

Subject to finalising the hydrogen business models, the project will be building upon this model to engage with government to enable FID and project delivery.

16 | PATH FORWARD – SECURING FID

Path Forward – Securing FID

Building Confidence for Financial Sanction

In order to achieve FID, there are a range of activities that need to be undertaken to take the project forward, as defined and consented, both technically and commercially, and deliver a suite of fully-engrossed contracts that will form the basis of the FID. This is work that has to be delivered by SPC on behalf of its investors. As part of FEED, a Delivery Plan was developed, which defines the scope of that work and the mechanisms to be established and used to deliver it.

This plan covers all work activities required, beyond the completion of the BEIS funded FEED, to deliver all aspects of the agreed business case required to allow FID to be taken. This plan covers technical, consenting, commercial and financial work packages.

The timing of FID will depend on the recently introduced BEIS Cluster Sequencing process, and the completion of the work identified in the Delivery Plan with the current target before the end of 2022. It is identified that the activities listed below could be on the project critical path and will therefore be addressed as a priority, prior to FID:

- Completion of contract negotiations with BEIS (or other nominated counterparty) for the support mechanism that enables low carbon hydrogen production.
- Design, consenting and securing land access rights for the offsite natural gas and hydrogen pipelines.
- The delivery timeline for the electrical connection from SPEN, the local District Network Operator.

During the period leading up to FID, SPC will also be required to determine the timeline for Plant 2 and the resulting necessary interaction with the construction of Plant 1, given that both are being built on the same site with shared utilities.

Business Framework

HMG's Ten Point Plan commits to finalising business models for low carbon hydrogen in 2022[30]. SPC will continue to work closely with BEIS and LCCC through 2021 and 2022 to support the development of a balanced framework which provides the confidence needed for private entities to invest in Plant 1, whilst ensuring that HMG receives value for money carbon abatement. The model requires protection for investors if external issues prevent the plant from operating at maximum capacity and a route to reducing support payments for HMG, as the value of hydrogen increases.

Once finalised in 2022, SPC will negotiate with LCCC an appropriate support framework and strike price for Plant 1. Completion of this contract before the end of 2022 is required to enable production of hydrogen from Plant 1 in 2025.

[30] HM Government (2020) The Ten Point Plan for a Green Industrial Revolution https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/936567/10_POINT_PLAN_BOOKLET.pdf

Site Integration

Plant 1 has been designed to be as self-supporting as possible in order to deliver a FEED that could be replicated elsewhere with minimal localisation. It is likely that the business case for the plant, and thus the levelised cost of hydrogen, can be optimised by incorporating additional integration to the existing refinery. A number of discrete value engineering exercises will be undertaken pre-FID.

Once the value engineering decisions have been made then it may be necessary to update the FEED documentation to accommodate any changes agreed. An exhaustive list of identified value engineering site integration activities is in the Pre-FID Delivery Plan: an example would be the potential to integrate with the existing Stanlow Manufacturing Complex fire-fighting infrastructure for both Plants 1 and 2.

Engineering Optimisations

In addition to site integration, further optimisation opportunities were identified in the FEED. These will be investigated as value engineering activities and implemented where an improvement to the business case or environmental credentials of the plant is identified. An example would be establishing whether investment in natural gas compression is justified, once further confidence in NTS delivery pressure is gained from National Grid Gas Transmission.

Securing Connections

Given the criticality of these connections and in order to produce hydrogen by 2025, SPC will be required to commit to and fund its major external connections prior to FID. These are considered to be development costs, at risk prior to FID, and a key part of the commitment shown by SPC to the project. These connections include: Water, Power, Natural Gas, a hydrogen pipeline to external customers and any turnaround-critical tie-ins to the Stanlow Refinery.

Consenting

SPC will continue to progress the consents and permissions with the relevant regulatory bodies, as discussed in Section 13; approved Planning Permission, Environmental Permit and Hazardous Substance Consent are required prior to FID.

Commercial Contracts

Section 15 outlines the commercial framework required to deliver Plant 1. Where a contract is required prior to FID, SPC will be responsible for negotiating these with their respective counterparties ready for signature prior to or alongside the FID suite of contracts.

17 | LESSONS LEARNED

Lessons Learned

At the close of the Phase 2 work, the consortium undertook a lessons learned workshop to provide learnings to take forward into the next phase of the project at Stanlow and also to inform others undertaking similar projects.

These lessons, alongside the project more widely, were shared externally through a number of knowledge transfer activities:

- The publishing of this report.
- A public knowledge dissemination webinar in September 2021; 500 delegates signed up to attend and the stream was published online for later viewing.
- A public presentation at the IChemE Global Energy Awards 2021, for which the project was awarded "Highly Commended". The **LCH** core technology also won this award in 2020.
- Knowledge sharing events throughout the project with: public bodies (national and local); key market influencers including trade bodies and consultants; industry including multiple potential hydrogen users and the supply chain to support development of the hydrogen market; the finance community; engineering institutions and regulatory bodies.
- The HyNet website was updated during the programme and Progressive led technical hydrogen economy publications (such as in The Chemical Engineer Magazine) and presentations, to enable targeted dissemination to a technical audience.

The key learnings to date for external projects are described below. As the project further develops, the project team will continue to seek opportunities to promote and share the work completed and lessons learnt.

Consortium Working

The team found that working as a consortium with a collaboration agreement rather than in a formal client-contractors mode with contracts allowed for better collaborative working, communication and problem solving. All partners were empowered to raise issues as they saw them without going through formal communication channels. This was particularly helpful in the development of a first of a kind application of the core technology in what is a nascent industry.

Use of Decision & Assumption Register

FEED work inevitably involves design iteration and this is particularly true of a first of a kind application of the core technology. The use of a live Decision and Assumptions Register reviewed regularly by the cross-consortium team allowed decisions and current assumptions to be agreed, maintained, tracked and now passed to the next phase of the project.

Risk Management

The project used separate risk registers covering the Phase 2 (FEED) work and the later execution/ operation of the project. These were reviewed quarterly by the full consortium team. The use of separate registers allowed specific foci to be applied to what might prevent the FEED work being successfully completed, on the one hand, and what might impact later execution and so could possibly be mitigated through the scope of the FEED, on the other. The use of consortium-wide teams in the review allowed the greatest cross-industry expertise to be used in assessing and planning the mitigation of the risks identified.

Appropriate Standards

At this point with a new industry, certain standards are yet to be finalised (e.g. hydrogen distribution pipeline standards, CO_2 fiscal metering standards and application of ETS). The project has to make and record key assumptions so that these elements can be easily revisited at a later date.

Hazard of CO_2

Managing large volumes or pressurised CO_2, including with its inherent toxicity is different from other flammable and explosive substances. This affects the required safety separation distances. Early dispersion modelling and QRA work should be undertaken to understand the impacts.

Hazards of Oxygen Storage

Many different low carbon technologies, including **LCH**, require oxygen and, therefore, significant liquid oxygen storage to maintain plant availability. Standard approaches to assessing safety separation distances used within the industrial gas industry are no longer acceptable to the HSE for new build facilities and COMAH implications must be understood. Early interaction with the HSE and appropriate dispersion modelling and QRA should be undertaken to assess plant layout.

Clarity of Business Models

This project had to be undertaken ahead of the commercial frameworks for delivery being developed. This presents challenges in terms of defining and optimising the plant functional requirements. Delivery of a project such as this, relies on a suite of support regimes coming together. It is imperative that government continues to deliver across these in a timely manner in order for a project to reach a successful FID.

Ongoing Project Development

Inevitably with a CCUS project there are multiple interacting projects that form the whole cluster. As a result of the timing of available funding, the FEED for Plant 1 was undertaken ahead of the FEED for other interacting elements of the wider HyNet project. This led to external project development impacting upon the FEED work for Plant 1. To minimise the impact of these changes, good communication and change management processes are required across all elements of the cluster. This was aided on the project by the same company, Progressive, being involved in all the elements of the wider cluster.

As with other projects undertaken in 2020-21 the team has also learnt much about collaborative working when team members are isolated and remote. The team trust that this learning will not need to be redeployed in the near future.

18 | THE FUTURE UNLOCKED BY THIS PROJECT

The Future Unlocked By This Project

HyNet hydrogen production Plant 1 is only the first step towards establishing a hydrogen economy in the north west of England and north of Wales. HyNet's ambition is to become a key part of the region's low carbon energy infrastructure, enabling the area to thrive in a low emission landscape.

Delivery at Pace to Support North West Ambition

The north west has set some of the country's most aggressive emission reduction targets:

- CWaC has announced its Climate Emergency response plan, targeting Net Zero no later than 2045. As a result of the concentration of industry in the north of the Borough, CWaC is the fourth highest emitting of all local authorities in the UK. CWaC have labelled this "a challenge, a responsibility, and an opportunity[31]". HyNet is a critical part of CWaC's strategy; quoted from the strategy: "Of all the interventions set out in the Climate Emergency Response Plan, HyNet is the most transformative and offers the greatest potential for carbon reduction".
- Greater Manchester City Region has also announced a pathway to carbon neutrality by 2038, citing the requirement for deployment of hydrogen trains to meet this target[32]. A need for substantial quantities of hydrogen, and specifically HyNet, is also identified in the Greater Manchester decarbonisation pathway[33].
- Liverpool City Region has announced a Net Zero target by 2040[34].

HyNet's delivery schedule, supported by rapid deployment of hydrogen production capacity, the repurposing of gas infrastructure to CO_2 transport and storage assets, co-location with the Stanlow Refinery and utilisation of a previously-consented salt cavern storage development for hydrogen, will facilitate the region meeting these ambitious local targets.

HyNet, through the delivery of a low carbon supply of energy, provides the best opportunity for north west England and north Wales to meet their highly ambitious climate goals.

Supporting Government's Ten Point Plan

Section 4 discusses the steps required to unlock the UK's hydrogen economy.

The Ten Point Plan sets out an ambition to deliver 1 GW of low carbon hydrogen production capacity by 2025. As the first major target for the UK's deployment of the hydrogen economy, these early stages will provide the momentum for the later stages of roll-out. HyNet hydrogen production Plant 1 is uniquely positioned to support this Ten Point Plan target, by delivering 35% of this total capacity. Without the delivery of Plant 1 on time, this critical interim commitment will be missed. HyNet can also provide up to 75% of the 5 GW low carbon hydrogen UK target by 2030.

HyNet Hydrogen by 2030

By 2030, HyNet can supply consumers with 30 TWh per annum of low carbon hydrogen. This is an ambitious but achievable goal, which relies on HMG policy supporting customer switching to hydrogen. It also takes into consideration that the demand for hydrogen is nascent but growing rapidly, and that hydrogen production and delivery (distribution network and storage) infrastructure is planned but not yet built. By this stage, hydrogen production, distribution and storage infrastructure will be in place across a wide part of Liverpool City Region, Great Manchester, Cheshire, Warrington, Wrexham, Flintshire and parts of Lancashire.

While ambitious, HyNet has been deliberately planned in discrete, achievable stages to ensure that the first phase is delivered as soon as 2025, with expansion happening shortly thereafter to deliver widespread decarbonisation of the local economy by 2030.

HyNet in 2040

By 2040, the north west of the UK is expected to be a thriving, Net Zero, industrial cluster. HyNet expansion opportunities are being investigated by Work Package 4 of the HyNet North West's IDC project. These will align with other decarbonisation projects across the region being explored within the North West Industrial Cluster Plan, under the leadership of Net Zero North West.

Initial modelling by Progressive has also considered a "Western Mega Cluster", extending to serve a large proportion of western England and Wales. The anticipated demand for low carbon hydrogen for this area is expected to be ~130TWh per year; the foundation of this capacity is expected to be low carbon hydrogen produced from natural gas or other fossil feedstock, which will be the core supply that enables the creation of the hydrogen distribution infrastructure. Hydrogen produced electrolytically using renewable electricity and from nuclear sources is expected to make an increasing contribution, and will be able to 'plug' into the HyNet pipeline, once cost of production by this route is supportive of the required scale-up.

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[31] Cheshire West and Cheshire (2020) Climate Emergency Response Plan https://www.cheshirewestandchester.gov.uk/your-council/councillors-and-committees/the-climate-emergency/documents/climate-emergency-response-plan.pdf

[32] Greater Manchester City Region (2019) 5 Year Environment Plan for Greater Manchester https://greatermanchester-ca.gov.uk/media/1975/5_year_plan_exec_summ_digital.pdf

[33] Cadent Gas et al (2020) Greater Manchester 2038 – A Decarbonisation Pathway https://www.enwl.co.uk/globalassets/go-net-zero/net-zero/de-carbonisation-pathways/greater-manchester-decarbonisation-pathway-.pdf

[34] Liverpool City Region (2021) One-year climate plan reveals immediate action to be taken as Liverpool City Region strives to be zero-carbon by 2040 https://www.liverpoolcityregion-ca.gov.uk/one-year-climate-plan-reveals-immediate-action-to-be-taken-as-liverpool-city-region-strives-to-be-zero-carbon-by-2040/

19 | GLOSSARY

Glossary

Acronym	Definition
AGI	Above Ground Installations
API	American Petroleum Institute
ASU	Air Separation Unit
ATR	Autothermal Reformer
BAT	Best Available Techniques
BEIS	Dept. for Business, Energy and Industrial Strategy
BOD	Basis of Design
CAPEX	Capital Expense
CCC	Committee on Climate Change
CCR	Central Control Room
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilisation and Storage
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
COMAH	Control of Major Accident Hazards
CWaC	Cheshire West and Chester Council
EA	Environment Agency
ENVID	Environment Identification
EPR	Environmental Permitting Regulations
ETS	Emissions Trading Scheme
FEED	Front-End Engineering Design
FID	Final Investment Decision
GHR	Gas Heated Reformer
HAZID	Hazard Identification
HAZOP	Hazard and Operability Study
HCfD	Hydrogen Contract for Difference
HHV	Higher Heating Value

Acronym	Definition
HMG	Her Majesty's Government
HSC	Hazardous Substance Consent
HSE	Health & Safety Executive
JM	Johnson Matthey plc
LCA	Leading Concept Ammonia
LCCC	Low Carbon Contracts Company
LCH	Low Carbon Hydrogen
LCM	Leading Concept Methanol
LHV	Lower Heating Value
LOPA	Layers of Protection Analysis
NTS	National Transmission System
O&M	Operations and Maintenance
OPEX	Operating Expense
PMC	Project Management Consultant
PSA	Pressure Swing Adsorption
QRA	Quantitative Risk Assessment
REACH	Registration, Evaluation, Authorisation and restriction of Chemicals
ROG	Refinery Off Gas
SMR	Steam Methane Reforming
SPC	Special Purpose Company
SPEN	Scottish Power Energy Networks
S/U	Start-up
T&S	Transport and Storage
T&SCo	Transport and Storage Company
UK	United Kingdom
UU	United Utilities

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