Member of the SNC-Lavalin Group

Aldbrough Hydrogen Pathfinder

Feasibility Study Report

SSE Thermal

October 2022

5215677-MD-REP-002

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1. Project Scope

1.1. General project description

SSE Thermal and Equinor, working in collaboration, are developing a portfolio of hydrogen (H_2) projects for deployment within the UK including hydrogen-fired gas turbine applications, hydrogen storage and electrolytic hydrogen production.

The project described within this report is focussed on a concept to be located at the Aldbrough Gas Storage (AGS) facility. The concept consists of the development of an electrolyser system, underground hydrogen storage solution and a hydrogen fired Open Cycle Gas Turbine (OCGT). The existing Aldbrough 1 (ALD 1) cavern will be converted to hydrogen storage. This project will act as proof of concept for potential future development of large-scale hydrogen storage projects which will contribute to the balancing of national supply and demand.

During the Concept Development phase of this project, Atkins has supported SSE Thermal and Equinor in defining the outline design of the project, a cost to execute and schedule as well as an assessment of the feasibility of the projects.

In this feasibility report, Aldbrough Hydrogen Pathfinder is presented along with key findings from the Concept Development phase.

1.2. Definition of location

There are two areas identified for potential siting of equipment that lie within the existing AGS site boundary; the area immediately West of the Aldbrough 1 wellhead that is currently a car park, and the area to the East of wellheads 2-9 that currently houses a warehouse and obsolete blast proof operations cabin.

The West area of land has the advantage of being located close to the wellhead and would ordinarily be an ideal location for high pressure pipework as this would minimise the length required. However, this location is closer to the main road and is more visible to the local community, making it less suitable for large or noisy equipment such as an OCGT or compressor (which are coincidentally also high-pressure components). A high-pressure piping route from West to East is already established on site for the transfer of gas to/from Aldbrough 1 and the process plant. This route would be reused for transfer of high-pressure hydrogen and for transfer of borehole water / saturated brine between East and West. An overview of these areas is illustrated in Figure 1-1 below.

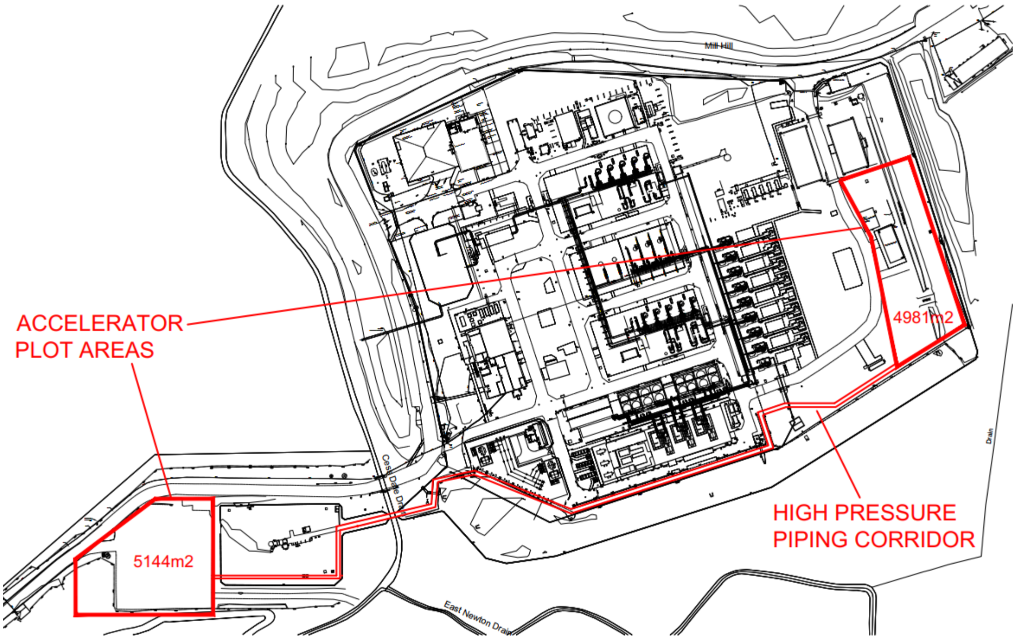

Figure 1-1 - Pathfinder Plot Area Overview

By limiting the Pathfinder plant to these areas, no additional land would be required and the plant would be entirely separate from the Aldbrough Hydrogen Storage (AHS) project. Should the available land in these plots not be sufficient, there is scope to use some of the land directly South of the Aldbrough 1 well area that is currently earmarked for the AHS Central Processing Area (CPA) but this can be used for construction only provided there is no impact on AHS.

1.3. Battery limits, infrastructure, and interfaces

The following diagram provides an outline to the configuration of the Aldbrough Hydrogen Pathfinder.

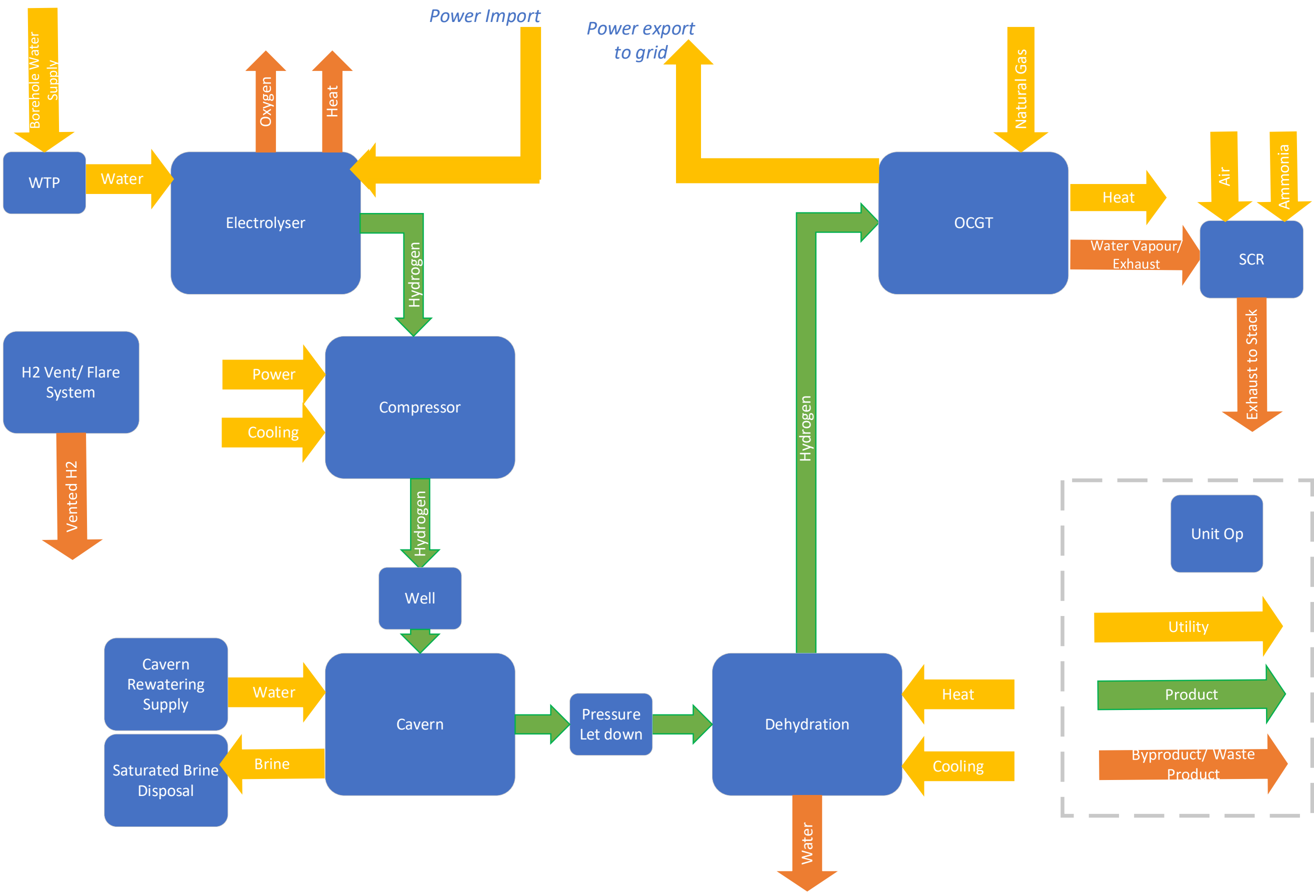

Figure 1-2 - Outline configuration

The outside battery limits (OSBL) and their physical tie-in locations are described in Table 1-1 below:

Table 1-1 - Battery Limit Locations

Battery Limit	Description	Tie-in Location
BL01	Borehole water supply to Electrolyser	Borehole connection, located East of seawater and brine tanks on main site
BL02	O_2 to Vent System	Vent local to West plot
BL03	H_2 to Vent / Flare System	Vent local to East plot
BL04	Borehole Water Supply to ALD 1 rewatering	Borehole connection, located East of seawater and brine tanks on main site
BL05	Saturated Brine produced from ALD 1 for rewatering of ALD 4z	ALD 4z wellhead, with rewatering tree system and associated equipment free issued as part of separate 4z project
BL06	Natural Gas supply to OCGT	Downstream of existing AGS grid connection tie-in (upstream of existing fiscal metering)

Battery Limit	Description	Tie-in Location
BL07	OCGT Exhaust Gas to Stack	Stack to atmosphere
BL08	Aqueous Ammonia for SCR	Storage vessel at West plot local to OCGT exhaust
BL09	Electrical Connection for OCGT	132kV busbars in existing AGS switchyard
BL10	Electrical Connection for Pathfinder Electrical Network	AGS 33kV network (new panel in 33kV Switchroom to new 33/11kV transformer)
BL11	Waste Discharge	[HOLD]

The interface register for the Pathfinder design concept can be found in 5215677-EM-REG-001, and are also shown on the Process Flow Diagram 5215677-PR-PFD-001.

1.4. Description of activities in the area

The proposed site for the SSE Pathfinder project is immediately adjacent to the SSE Hornsea Aldbrough gas storage facility (AGS). The existing AGS facility consists of CPA, wellpad and 9 underground natural gas storage caverns. Additionally, a high pressure 900 mm diameter underground gas transmission pipeline enters the AGS site from the West.

An existing offshore monopile structure, which was utilised for solution mining of the Aldbrough caverns, is located to the East of the existing site, as shown in Figure 1-3. This connects to the site via an underground pipeline which is partially decommissioned.

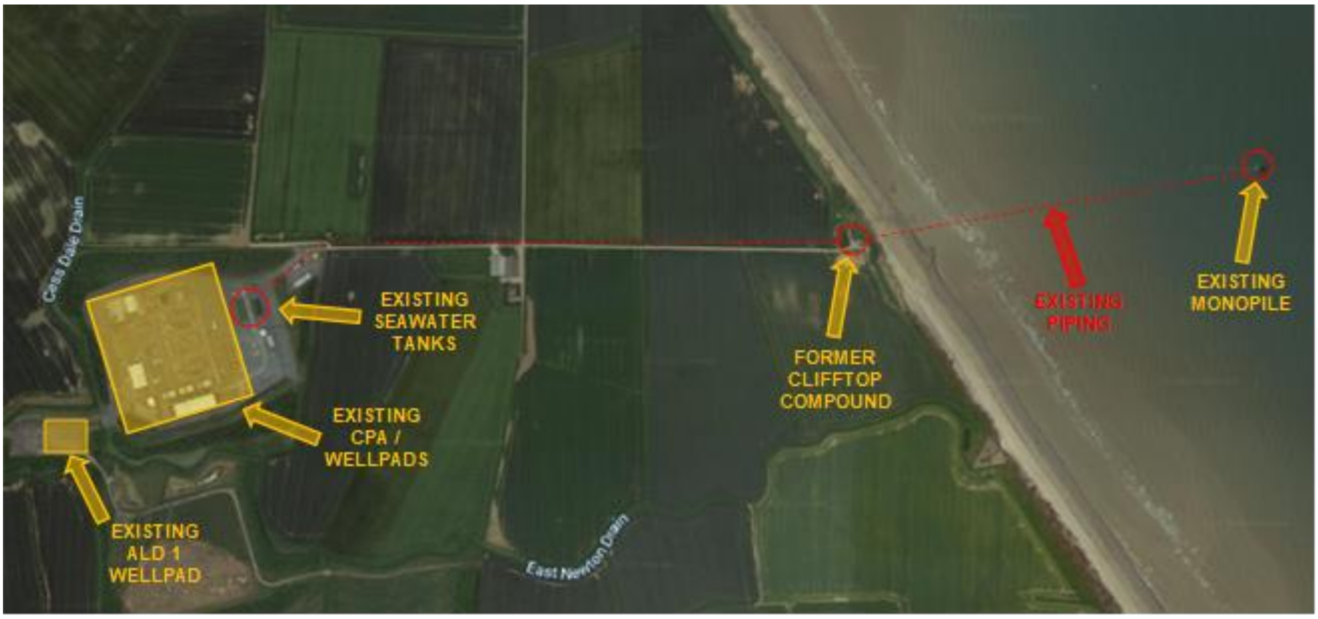

Figure 1-3 - Existing AGS Facilities

There are also plans to develop the Aldbrough Hydrogen Storage (AHS) facility adjacent to the existing AGS facility as part of the wider Keadby and Salt End Hydrogen development projects. The AHS facility would provide an underground storage capacity of 110 million Sm^3 across 5 new hydrogen storage caverns for supplying Keadby 4 Power Station, to be located on the South side of the Humber River, via a hydrogen pipeline provided by National Grid Ventures (NGV). The Aldbrough site will be supplied with the Hydrogen for storage by an additional connecting ~10 km Hydrogen pipeline (the “Aldbrough Hydrogen Pipeline”) running from the NGV pipeline to Aldbrough.

The AHS facility would consist of the Aldbrough Hydrogen Pipeline, compression and drying trains and the storage caverns as well as solution mining facilities for development of the caverns.

1.5. Applicable acts and regulations

The design shall comply, as a minimum, with the Legislation, Codes and Standards listed in Appendix A. Note that the list should not be considered exhaustive and should be updated as the project develops. Other industry standards may be proposed if demonstrable benefits to the project can be shown. The precedence and order of standards are listed below from highest to lowest.

- UK Law
- HSE
- Site Safety Requirements (if applicable)
- Industrial and international standards, including those already identified in Project Standards (e.g. NACE, ASME, etc.)
- Project Specifications
- SSE / Equinor Specifications
- Good engineering practice

Although some industry standards may not be directly applicable to hydrogen service they will be used as a basis on which to develop the design with deviations for H_2 clearly stipulated.

1.6. Design life

The design life of the surface equipment shall be 25 years.

For subsurface infrastructure the design life shall be 40 years [HOLD].

Note: the subsurface design life is assumed 40 years to provide sufficient life beyond the surface facility to permit suspension and abandonment of the cavern. Cavern abandonment may also be aligned with the wider site abandonment requirements or alternatively repurposing (in a similar manner to life extension of other SSE cavern assets beyond 40 years).

1.7. Requirements for abandonment and removal

1.7.1. Subsurface

Abandonment is the final stage of a well and cavern lifecycle and the objectives of any well and cavern abandonment is to:

- Conduct all operations safely without harming people, equipment or environment.
- Permanently plug and abandon the Well and Cavern in line with UK regulations.
- Ensure that the abandonment design complies with the industry best practices and guidelines for well and cavern abandonment, so that "the risk of escape of fluids from the well and cavern are reduced to As Low As Reasonably Practicable (ALARP)".

The Oil & Gas UK "Guidelines for the suspension and abandonment of wells" [1] and the SMRI "Cavern Well Abandonment Techniques Guidelines Manual" [2] have been written by industry and describes the minimum barrier requirements and verification procedures for permanently plugging and abandoning wells and caverns. As a minimum, any program for planned abandonment of a gas storage cavern and well should follow these guidelines.

The Aldbrough 1 well will require to be modified for H_2 service. The modification will be designed and constructed such that it can be abandoned in a safe manner at the end of its service life. Generally, the agreed method of abandonment is cavern rewatering, this is where the stored product, in this case hydrogen, is removed from the cavern by displacing it with fluid (water or brine). After cavern rewatering, the pressure and temperature development in the cavern is assessed, to ensure that the long-term integrity of the abandonment is confirmed. Once the cavern is deemed to be in a stable ALARP state, the cavern shall be permanently abandoned by the installation of bridge plugs in the cavern neck, LCCS or lower completion before plugging the wellbore with cement. With the cavern and well abandoned, surface process plant can safely be removed, and the site reinstated.

1.7.2. Surface Plant

When the wells are permanently plugged and abandoned, the cellar will be filled with concrete to grade to ensure the safety of personal and equipment in future. Following this, the site should be monitored at regular intervals to identify any potential legacy issues. The surface infrastructure shall then be removed, and the site shall be returned to greenfield status, unless any further developments are planned.

1.8. Project milestones

A summary of key project milestones is detailed in Table 1-2. A summary schedule has been developed and is provided in 5215677-PL-SCH-001.

Table 1-2 – Key Project Milestones

Milestone	Date
Project Start Milestone	01-Jun-22
Confirm Red Line Boundary	28-Sep-22
Feasibility Study Complete	07-Oct-22
Brine Disposal Strategy Confirmation	25-Nov-22
Layout Design Freeze (EIA and Planning Application)	26-Jan-23
Pre-FEED Complete	07-Mar-23
Onshore EIA & Planning Application Decision	11-Oct-23
Marine Licence Application Decision (if confirmed to be required)	12-Oct-23
FEED Complete	31-Oct-23
Financial Investment Decision	31-Oct-23
Contract Award of Long Leads and Major Equipment Packages	01-Nov-23
Detailed Engineering Complete	12-Nov-24
Aldbrough 1 Rewatering Facility Construction Complete	14-Jan-25
Aldbrough 1 Rewatering Complete	08-Jul-25
Electrolyser First Operation	07-Oct-25
Cavern Available to Accept Hydrogen	12-Nov-25
Cavern Hydrogen Full	24-Feb-26
Subsurface Execution Complete	24-Feb-26
OCGT Commercial Operation	12-Mar-26
Project Finish Milestone	12-Mar-26

The following assumptions have formed the basis of this programme:

- An accelerated front end development programme has been planned to run in parallel with the SSE Large Capital Projects Governance process to ensure that SSE Gate 3 Approval can be obtained prior to FID.
- A combined pre-FEED & FEED development plan is envisaged through the remainder of 2022 and into 2023 with Pre-FEED planned to commence immediately after Gate 1 Approval and FEED to commence 2 weeks after Gate 2 Approval.
- The project will require an EIA and Planning Application through the Town & Country planning process. This will be submitted in June 2023 with a decision expected by October 2023.
- Detailed Design commences after Gate 3 Approval. The Detailed Design phase is expected to require 12 months, with procurement works and commencement of early execution / site enabling works ongoing in parallel.

- Placing contracts for all major plant items / suppliers and long leads is currently scheduled following FID. The initial procurement process for the major plant packages and long lead items will commence during FEED with engagement with vendors and tendering. The project will aim for major project contracts to be ready for signature on FID. This approach brings assurance to the cost for execution to be developed in FEED as well as resilience to the programme.
- Construction durations have been based on experience of similar projects and engagement with SMEs within the Atkins business. The construction sequencing has been designed to ensure that:
    - The plant is ready to produce Hydrogen by November 2025 in line with BEIS funding requirements
    - The Aldbrough 1 cavern is ready to receive Hydrogen in November 2025 requiring the following to be completed in advance:
        - The cavern to be re-watered,
        - the well relined and recompleted
        - the cavern and well proven as Hydrogen gas tight via MIT
    - The OCGT is available to receive Hydrogen in April 2026 once the cavern has been filled with its design operating volume of Hydrogen.

2. Concept Design

2.1. Design Concept

2.1.1. Units and Symbols

All design work shall be undertaken principally using SI units or their derivatives, unless otherwise stated as below:

Table 2-1 – Units and Symbols

Pressure	Bar gauge (barg), atm
Temperature	Degrees centigrade (°C)
Volume	Standard cubic meter (Sm^3), the quantity of Hydrogen Gas contained in a cubic meter at a temperature of 15 °C (288.150 K) and a pressure of 1.01325 bara (1.0 atm), 0% Relative Humidity (RH)
Volume flows of hydrogen	Standard cubic meter per unit time (Sm^3/h)
Diameter	Inches (")
Angle	Degrees (°)
Power	kW, MW or GW
Time	Minutes, hours, days, years
Area	Hectares (ha)
Heat flux density	kW / m^2
Kinematic Viscosity	Centistokes (cSt)

2.2. Process Description

This section includes a process description for the project. This should be read alongside:

- Process Flow Diagram (5215677-PR-PFD-001),
- Heat and Mass Balance (5215677-PR-HMB-001),
- Utility Schedule (5215677-PR-SCH-001).

2.2.1. Demineralised Water Production

The demineralised water shall be produced from the existing Aldbrough borehole (brackish) water supply which shall require treatment in order to produce water of sufficient purity for electrolysis. It is understood that the existing towns water supply is constrained on the AGS site and is therefore not considered as a source.

Pre-treatment of the borehole water shall consist of dechlorination using sodium hypochlorite, pH adjustment using acid and base reactants (NaOH and HCl), clarification using a chemical coagulant and filtering to produce potable water. An offtake of this potable water can be taken to supply any potable water consumers such as workshops, control room, welfare facilities etc.

Demineralisation via reverse osmosis (RO) and polishing via mixed bed ion exchange (MBIEX) shall then be required to produce the required water quality for electrolysis. The water shall be dosed with an anti-scalent prior to RO treatment to avoid mineral contamination of the RO membrane.

2.2.2. Hydrogen Production and Injection

The Aldbrough Hydrogen Pathfinder facility shall be capable of producing 670 kg/h (7,858 Sm^3/h) of hydrogen gas at 100 mbarg and 90°C via 2 x 17.5 MWe PEM electrolysers.

The electrolysers shall use 6,700 kg/h of demineralised water to produce 670 kg/h and 5,330 kg/h of oxygen, which shall be vented to atmosphere.

The hydrogen produced in the electrolyser is expected to be saturated with water and contain traces of oxygen, therefore treatment is required to improve the purity of hydrogen and remove water prior to compression. The wet hydrogen gas shall be passed through a separator vessel, to remove any water in the stream and a deoxidiser vessel which shall remove any oxygen from the gas by catalytic oxidation with hydrogen. The hydrogen shall then be cooled to below 45 °C and any water knocked out by the decrease in temperature shall be separated out from the buffer storage vessel.

In order to inject the hydrogen gas into the underground storage cavern the gas must be compressed to between 120 and 279 barg in line with the allowable cavern pressure envelope. An LP and HP compressor unit shall be used to compress the gas from 100 mbarg to 279 barg, each with 3 to 4 stages of compression. The LP compressor unit [HOLD- technology to be confirmed with vendors] shall compress from 100 mbarg to 30 barg, followed by the HP compressor unit which shall be an API 618 reciprocating compressor that compresses the hydrogen gas up to 279 barg. Each compression stage shall consist of a compressor stage, interstage cooler to reduce the gas temperature back to below 45°C after compression and suction scrubber vessel to remove any liquid present in the gas following compression and cooling.

An after-cooler shall be required downstream of the final compression stage to cool the gas to below 45°C prior to injection into the ALD 1 cavern via the wellhead. This is to avoid exceeding the maximum cavern temperature of 60°C.

Pulsation dampeners shall also be required between LP and HP compressors to reduce flow pulsations caused by the reciprocating compressors.

The HP reciprocating compressor is expected to be oil-lubricated given the high discharge pressures required therefore oil filtration downstream of the final compressor stage shall be required to remove oil contamination from the gas prior to injection into the cavern.

The buffer storage shall be required upstream of the compression unit as the compression ramp-up and -down rates are not expected to align with those of the PEM electrolyser.

2.2.3. Hydrogen Withdrawal and Combustion

The Aldbrough Hydrogen Pathfinder facility shall be capable of withdrawing up to 3,819 kg/h (44,791 Sm^3/h) [3] hydrogen from ALD 1 for supplying the 49.9 MWe OCGT.

The gas leaving the cavern may be saturated with water and may contain some contaminants depending on the chemical composition within the cavern and the chemical and biological reactions that may occur in small quantities within the cavern [HOLD]. Therefore purification, dehydration and dew-pointing will be required to comply with the hydrogen specification of the OCGT [HOLD].

The gas withdrawal system shall comprise of pressure let down, coalescer filter, dehydration columns and gas cooler. An overpressure protection system such as HIPPS (high integrity pressure protection system) shall also be required to protect the downstream equipment from the gas storage pressure in the event of the pressure let-down failing or being driven open.

The pressure shall be let down from the cavern storage pressure and cooled to more optimal conditions for drying. Any liquid water in the gas shall then be removed via the coalescer filter.

Purification and dehydration of the gas shall take place in the dehydration columns. The purpose of the dehydration plant is to reduce the dewpoint of the gas to meet the hydrogen dewpoint specification of the gas turbine (gas supply to OCGT must be above dew point [3]). As described in Atkins technical memo, 5215677-PR-MEM-001 on requirement for dehydration system, there may be opportunity to remove the dehydration plant from the design depending on the OCGT vendor's required water content limits or dewpoint for the hydrogen fuel. This should be considered further in the next phase of design once these requirements are known.

The dehydration columns shall use temperature swing adsorption with molecular sieve desiccant to dry the gas. There shall be a sufficient number of dehydration columns to allow the plant to continuously run whilst regenerating desiccant i.e. there shall be one column in operation whilst one is regenerated. The desiccant shall be regenerated using hydrogen gas from upstream of the forcing valve that is then heated and passed through the regenerating column to remove the moisture from the desiccant. The now wet regeneration gas is then cooled to below dew point and the water removed via a separator. The regeneration gas is then returned to the inlet of the adsorption column. Once the column has cooled it can be returned to operation.

A filter shall be included downstream of the dehydration plant to remove any desiccant particles or dust that may become entrained in the gas leaving the columns.

Prior to the OCGT, the gas shall pass through a metering station which shall also include a moisture analyser to ensure the gas meets the inlet requirements of the OCGT .

The OCGT shall be capable of operating on up to 100% hydrogen and shall generate up to 49.9 MWe (gross power output) for export to grid.

The OCGT shall also be capable of operating on up to 100% natural gas and varying blends of natural gas and hydrogen, therefore a natural gas supply of up to 9,914 kg/h [3] shall be provided.

Fuel specifications for the OCGT are provided in Section 2.12 below.

Given the higher combustion temperature of hydrogen compared to natural gas, there will be higher NOx emissions generated during hydrogen operation of the OCGT. It is expected that a SCR (selective catalytic reduction) system may be required to reduce the excess NOx emissions produced during hydrogen operation. The exhaust gas composition for both natural gas and hydrogen operation are provided below [3]. Along with the other requests for information responses received, this is based on preliminary data provided by SSE Thermal.

Table 2-2 – Exhaust Gas Composition

Parameter	Unit	Natural Gas	Hydrogen
Pressure	Bar	1.03	1.03
Temperature	°C	560	568
Flowrate	Kg/s	128.2	121.1
MW	-	28.4	27.4
N_2	mole%	74.552	72.672
O_2	mole%	12.834	13.483
CO_2	mole%	3.613	0.028
H_2O	mole%	8.103	12.942
Ar	mole%	0.898	0.875

The SCR system shall convert NOx in the turbine exhaust gas to N_2 and O_2 by reacting the NOx with ammonia in the presence of a catalyst. The ammonia is evaporated and mixed with air before injection into the exhaust gas in the SCR reactor. The air shall be preheated using heat from the exhaust gases.

The exhaust is then sent to the stack for release to atmosphere.

2.3. Caverns and Wells

The Aldbrough 1 cavern shall be used to provide the storage volume. To permit this, a number of operations will be required. Table 2-3 shows the key cavern data and Table 2-4 shows withdrawal information. A wells basis of design has been developed for the project and is available in 5215677-WL-BOD-001.

Table 2-3 - Key cavern data of Aldbrough 1 Hydrogen Storage

Last Cemented Casing Shoe (LCCS) depth	1,770	m TVD
Geometrical Volume (Sonar 2018)	273,187.5	m^3
Open cavern volume for H_2 storage (refer to Section 2.3.5)	55,000	m^3
p_{min} (at LCCS)	120	barg
p_{max} (at LCCS) (see Note 1 below)	279	barg
Δp	149	barg
Cushion Gas mass	460,000	kg
Working Gas mass	520,000	kg
Total Gas mass	980,000	kg
Cushion Gas volume	5,800,000	Sm^3

Working Gas volume	5,100,000	Sm^3
Total Gas Volume	10,900,000	Sm^3
Cushion Gas LHV	15,400	MWh
Working Gas LHV	17,400	MWh
Total Gas LHV	32,800	MWh
Cushion Gas HHV	18,200	MWh
Working Gas HHV	20,500	MWh
Total Gas LHV	38,700	MWh

Note 1: the MIT results will determine the allowable Pmax associated with the cavern. It is currently assumed that the previously achieved value of 279 barg at LCCS can be successfully achieved with hydrogen. This Pmax has been considered in determining the total hydrogen volume achievable in the cavern to allow up to 8 days of withdrawal.

Table 2-4 – Withdrawal information

Desired withdrawal rate (mass)	3,819	kg/h
Maximum pressure difference per day	20	bar/day
Maximum hours of withdrawal per day	17	h/day
Hours for complete withdrawal	136	h
Average withdrawal rate per day	65,497	kg/day
Days for complete withdrawal (@ 17 hours per day)	8	day

2.3.1. Rewatering

Aldbrough 1 is currently an operational natural gas storage cavern. The cavern will be rewatered by displacing the existing natural gas contents with brackish water.

- The brackish water source will be the existing site borehole which operates under an existing abstraction licence.
- Natural gas will be exported to the process plant manifold via existing plant systems. It will then require the use of second cavern (ALD 9 [HOLD]) to store the gas prior to export to natural gas grid as it is not possible to export via a single cavern.
- The estimated geometric gas volume of the Aldbrough 1 cavern as defined with the latest Sonar Survey is 259,903 m^3 [4] from 2018. It is recommended to conduct a sonar measurement before start of rewatering operations. Sonar survey data is used to calculate the required amount of brackish water to be injected.
- Aldbrough 1 shall be rewatered using the same well design as has been developed for other SSE caverns Aldbrough 4z, 6 & 9 [SSE Document Reference GG100257]. This shall include the rewatering wellhead, tree and string although it is noted that new equivalent equipment will be required (i.e. will not reuse the ALD 4z equipment).

2.3.2. Preliminary Rock Mechanical Integrity Assessment

A preliminary integrity assessment of Aldbrough 1 was performed by review of 2013 and 2018 sonar survey data. The following was identified:

- The calculated open gas volume of the cavern in 2018 was 259,903.5 m^3, representing a total volume loss of 1.27% compared to 263,252.1 m^3 in 2013. The total volume of the cavern was 273,187.5 m^3 showing a reduction of 1.25% in the same time period, this corresponds to an average convergence rate of 0.27%/year over this period.

- The identified volumetric reduction in the lower part of the cavern (below 1,842m bgl) is related to the intense creep closure typically encountered close to the cavern's sump. Above 1,842 m bgl (below ground level) no significant differences between the 2013 and the 2018 surveys were observed, and the cavern structure is characterized by an essentially uniform mild creep convergence. Most of the cavern surface was subjected to minor changes varying between -6.12 and 1.55m, the nearby cavern's roof by 1.55 and 9.22 m and the sump of the cavern -6.12 m and -13.78 m.
- At the deepest survey depth - 1,858.7 m a small rise of 0.9 m was registered and on the highest point - 1,782.1 m bgl a small shift of 0.3 m was found.

The report concludes that the sonar in 2018 confirmed the Aldbrough 1 cavern to be in a 'Green' category using the Well Integrity Management procedures developed by SSE. A 'Green' categorisation is representative of a cavern which is stable and has no integrity issues of concerns.

Considering the described results of the sonar survey review and the proposed operating scenarios for hydrogen storage that will not differ significantly from today's natural gas operation, it can be assumed that the integrity of the cavern will be maintained during hydrogen operation and from a rock mechanics perspective, the cavern is suitable for the Hydrogen Pathfinder Project. In the next phase of the project, coupled thermal-mechanical analysis will be performed to validate this conclusion.

2.3.3. Mechanical Integrity Test

Post rewatering of the cavern, the gas tightness of the existing casing shoe must be tested by performing a Mechanical Integrity Test (MIT). The hydrogen completion will then be installed, and the cavern can be filled with Hydrogen while brine is withdrawn through a temporary debrining string which will be snubbed out after the cavern is hydrogen filled.

An MIT is a standard procedure for demonstrating the mechanical integrity of the cemented casing, in particular the area around last cemented casing shoe, against the surrounding formation. The test will be completed after the rewatering of the cavern and before the installation of the hydrogen completion.

There are various MIT methods of testing available e.g. In Situ Compensation Method, In Situ Balance Method, Above Ground Balance Method or Sonar Mechanical Integrity Testing. All of those are gas interface tests where a limited volume of gas is injected into the brine-filled cavern until the gas-brine interface is in the open-hole area below the last cemented casing shoe. The monitoring of pressure and temperature allows conclusions on the tightness of the well and verification that leak rates are below a tolerable acceptance criteria as agreed with the regulator.

Although an MIT is a standard part of salt cavern commissioning the test methodology needs to be adapted for hydrogen due to its smaller molecular size. In a recent report Gasunie, SOCON and DEEP.KBB published a successful SoMIT (Sonar MIT) using hydrogen [20]. In the first step the most commonly used test gas - Nitrogen – was used for the MIT. After fulfilling the tightness criterion, the MIT was repeated using Hydrogen. The Hydrogen MIT was successful and proved the ability for cavern for storage of Hydrogen.

Therefore, for Aldbrough 1 the following procedure for an MIT, after removal of the natural gas completion, is recommended:

1. MIT of LCCS using Nitrogen
2. After successful MIT using Nitrogen an MIT of the LCCS should be repeated using Hydrogen as test medium
3. Installation of Hydrogen Gas completion
4. MIT of Hydrogen Gas completion using Hydrogen

2.3.4. Well Remediation

The MIT results will confirm if it is necessary to remediate the existing casing shoe or if it is suitable for hydrogen service. If it is necessary to remediate the existing LCCS section milling will be required to create a new cement bond to the formation. The requirement for section milling of the existing casing is an identified project risk and not considered to be part of the baseline plan.

As a minimum the existing well will require to be relined and recompleted. This will include:

- The well shall be operated under a two-barrier management system; a minimum of two permanent barriers are required to isolate a permeable zone that is hydrocarbon bearing or over pressured and water bearing. The second permanent barrier is a back up to the first.
- In addition, SSE have standard procedures for Well Control, which assure that SSE adhere to the requirements set out in; the Borehole Regulations, the Well (Design & Construction) Regulations [1] and their internal Control of Well Operations procedures [SSE Document Reference RS-SHE-118] [HOLD].
- The new completion shall be designed to allow the use of wireline interventions into the cavern whilst rewatering and during well / cavern operations. The following well interventions will be required as a minimum:
  - Sonar Survey
  - Callipers
  - Plug Installation – Future plugging requirements will be considered in the completion design including provision of sufficient nipple profiles.
  - Cutting tools

Through the development life of the cavern, the well completion will vary in make up; rewatering, debrining and production. The design basis of the completions at each of these stages are outlined in the Wells Basis of Design.

2.3.5. Debrining

Following recompletion, the contents of the cavern will be displaced with hydrogen produced from the electrolyser. Displacement volume shall be commensurate with the ALD 4z contents where it is intended to export the brine from the cavern to ALD 4z as a means of rewatering the ALD 4z cavern.

ALD 4z cavern geometric gas volume is 60,597 m^3 as of 2020 [5]. Due to a back pocket, the required volume to rewater cavern ALD 4z will be reduced to approx. 55,000 m^3. The debrining design is displayed in Table 2-5.

Table 2-5 - De-brining information

Open cavern volume for H_2 storage	55,000	m^3
Required Gas/Brine interface level @ 55,000 m^3	1,795-1,800	m TVD
Required Hydrogen pressure @ 1,795-1,800	approx. 215	bar
Resulting Hydrogen Pressure @ LCCS	approx. 215	bar
Hydrogen mass required for de-brining	780,000	kg
Hydrogen volume required for de-brining	8,675,000	Sm^3
Minimum Duration for de-brining	48	days
Duration to completely fill cavern	61	days

2.4. Grid Connections

The existing 132kV underground cable that connects Aldbrough Gas Storage to Northern Powergrid (NPg) Saltend substation, will remain and supply power to the AGS site and therefore be the grid connection for the Pathfinder electrical network. The cable is rated to 100-120MW. SSE have confidence that the cable can operate with more than 100MW of demand. Existing AGS peak power demand is circa 60MW from the operation of three compressors (circa 22MW each) and circa 1MW baseload.

Electrical demand of Pathfinder is estimated to be 40MW, formed of 35MW from the electrolyser package and approximately 5MW from the compressors and ancillary equipment, including pumps. This demand is to be confirmed at detailed design. Baseload demand will likely be less than 1MW.

SSE have engaged with NPg where an application has been submitted to increase the capacity of the demand connection, and to secure export capacity.

Peak demand of AGS and Pathfinder operating simultaneously is expected to be feasible based on SSE's understanding of the condition of the 132kV cable. Based on the cable rating, the export of 49.9MW from the OCGT is feasible. Power demand of AGS and Pathfinder must be met before export can occur.

An additional demand of circa 5MW is proposed to be connected to the existing AGS electrical network to supply leaching and water extraction pumps as part of the Aldbrough Hydrogen Storage project. This is expected to be operational in Q4 2027. Based on SSE's understanding of the cable condition, there is unlikely to be a constraint to operate AGS and Pathfinder at full capacity. Assessment of the downstream electrical network is required.

During construction of the AHS CPA, the existing 132kV cable will be rerouted and therefore unavailable for the duration of the works. This will prevent the operation of the Pathfinder electrolyser, compressors, and OCGT, and the full AGS facility. AGS has a manually switched back-up 6.8MVA 11kV backup feed from the NPg 66kV network. This is connected to the 11kV switchboard, which in normal site operation is fed from the 33/11kV transformer. The back-up grid connection will be used to meet baseload demand of AGS and Pathfinder during this period.

The 11kV backup feed may be technically feasible as an option to export power from the OCGT, however, due to the 6.8MVA capacity only a small proportion of the OCGT 49.9MW output could be exported. Exporting to the NPg 11kV network may have additional constraints compared to exporting to the 132kV network.

Connections between the Pathfinder electrical network, to the existing AGS network, will require outages of some parts of the AGS network. This will reduce the ability to operate the AGS site. Outages should be planned to limit the impact on AGS operations. Outages may also be required during construction of the Pathfinder equipment as electrical cables may require re-routing. Commercial impacts from outages should be assessed.

NPg are operating N-1 active network management (ANM) on their network due to large magnitudes of embedded generation in the region. ANM monitors the available capacity on the network and controls generation outputs accordingly. Generation is only curtailed or disconnected if a fault occurs on a circuit. This restriction may impact the ability for Pathfinder to export generation at certain periods.

2.5. Electrical Systems

The following documents have been produced for the project and should be read in conjunction with this section:

- Single Line Diagram (5215677-EL-SLD-001),
- Electrical Load List (5215677-EL-LST-001).

The existing 132kV cable is routed from Saltend North substation to 132kV busbars in the AGS switchyard. Two existing 90MVA transformers step down the voltage to 33kV.

The initial Pathfinder high voltage (HV) electrical network will be rated at 33kV, preferred to be connected to the existing 33kV network. Options explored to provide a connection included:

- A tertiary connection to an existing 90MVA transformer.
- Connection to the existing 132kV busbars, requiring a new 132/33kV transformer.
- Connection to the existing 33kV switchboard.

From the feasibility investigation and document review the following was determined:

- A tertiary connection to an existing transformer is not feasible as the transformers do not have tertiary windings.
- Connection to the 132kV busbars is unlikely to be achievable due to space limitations in the existing switchyard, would be an expensive option.
- A connection to the existing 33kV switchboard may be feasible.

In the design for the existing switchyard, space was earmarked for an additional 33/11kV transformer to be installed adjacent to the existing 33/11kV transformer, as shown in Figure 2-1.

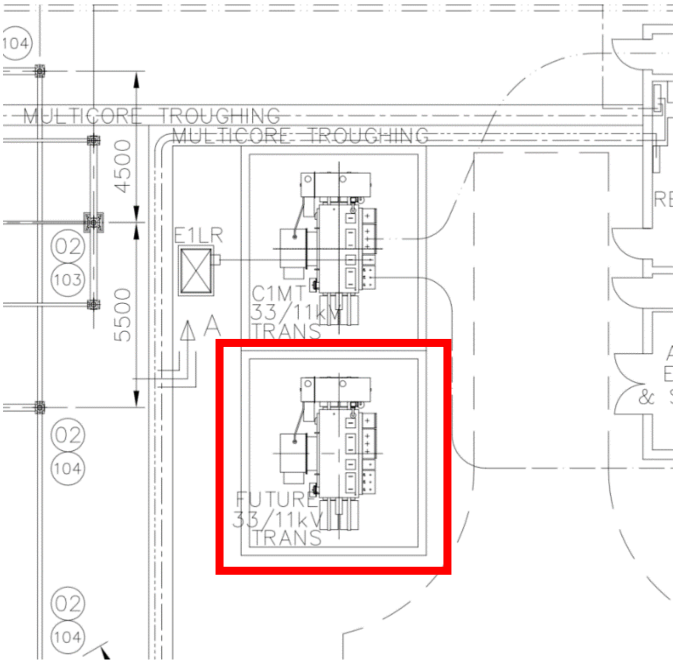

Figure 2-1 – Additional Transformer Space

In designs for the 33kV switchroom, space was allocated for an extension of the 33kV switchboard. Existing single line diagrams also indicate that the only panels in use are those identified as required during design, and no additional panels have been installed or used. Therefore, a connection from a new panel in an extension to the switchboard, to a new 33/11kV transformer will act as a supply for the Pathfinder electrical network.

SSE have advised that the switchboard may not be suitable for a new connection as there are no available spare connections or room for an extension. Verification is required if an extension can be made to the switchboard, in terms of space and considering the voltage and short-circuit current ratings of existing circuit breakers, switchgear busbars, and other electrical equipment. Whether the 33kV switchboard is suitable should be confirmed at the earliest opportunity, or alternative options assessed. This may include the installation of a new switchboard for both AGS and Pathfinder. An outage on the switchboard will be required during the installation of a new panel.

The new 33/11kV transformer will be located in the previously earmarked location, and will be rated to meet the estimated demand of Pathfinder of circa 40MW. A fire damage wall may be required between the existing transformer and new transformer. A fire damage wall may be required between the transformers and the switchyard access road. An outage on the existing transformer may be required during installation of the new transformer.

A new 11kV switchboard will be connected to the 11kV output from the transformer, in which the equipment for Pathfinder will be connected. The switchboard will be located in a new electrical building or within a proposed new building for other services and equipment.

Additional transformers, and associated ancillary equipment, will be used to stepdown the 11kV to low voltages (LV) to supply LV switchboards for the Pathfinder process and mechanical equipment, site services, utilities, and plant protection and control. Transformers and LV switchboards will be located in the East or West plot as required for the equipment they supply. LV supplies should be located as close as possible to the electrical equipment they supply.

An indicative single line diagram of this design is shown in 5215677-EL-SLD-001.

The electrolyser package will include two 17.5MWe units, with a total electrical demand of 35MW. SSE have informed that the electrolyser package will include an HV to 690V transformer, including harmonic filters. The electrolyser will be connected to the new Pathfinder 11kV network.

SSE have assumed the OCGT package will include an 11kV to 132kV transformer. A connection between the OCGT and AGS network will be via a new 132kV cable to the existing 132kV busbars in the AGS switchyard.

The cable is proposed to follow the route of the high-pressure hydrogen pipeline between the switchyard and East plot in which the OCGT will be located. The design for the busbar connection is to be determined at detailed design. Technical feasibility of this option is to be determined at detailed design.

The OCGT will be electrically separate from the other equipment required for the Pathfinder and will not directly power any Pathfinder equipment, however will act as a supply for AGS and therefore Pathfinder indirectly before grid export occurs. Alternative options explored to connect the OCGT to AGS include:

- A tertiary connection to an existing 90MVA transformer.
- Connection to the existing 33kV network.

From the feasibility investigation the following was determined:

- A tertiary connection to an existing transformer is not feasible as the transformers do not have tertiary bushings.
- Connection to the existing 33kV network would require additional transformers not included in the package, and would involve additional stages of voltage stepping up and stepping down before grid export could be achieved. This would increase electrical losses and inefficiency.

The OCGT will operate as a peaking plant with a 49.9MW gross power output. Electrical demand of AGS will be met first, before the OCGT exports power to the grid. If electrical demand cannot be met solely by the OCGT, the remaining demand will be met via the 132kV grid connection. The electrical system will be designed to allow the two feeders to operate simultaneously, with associated synchronising and check relays. Technical feasibility of this option is to be determined at detailed design.

The existing back-up supply feeds the 11kV switchboard, typically fed from the existing 33kV transformer / switchboard. In designs for the 11kV switchroom, space was allocated for an extension of the 11kV switchboard. Existing single line diagrams also indicate that the only panels in use are those identified as required during design, and no additional panels have been installed or used. Therefore, an extension to the switchboard panels, could be used to supply the Pathfinder 11kV electrical network if a fault were to occur on the upstream voltages.

Feasibility of this option is to be determined at detailed design to verify if an extension can be made to the switchboard, due to potential space constraints and ratings of existing electrical equipment.

The backup supply is rated at 6.8MVA, and as AGS baseload demand is <1MW, there is sufficient capacity available to supply the estimated baseload and essential services demand of Pathfinder.

New electrical equipment will be located in new switchyards and within new buildings within the proposed layout for the Pathfinder project. Where equipment is connected to the existing AGS network, relevant equipment will be located within the footprint of the existing AGS switchyard or other appropriate area on the site. Extensions to the existing AGS switchyard or switchroom to locate electrical equipment on the AGS site may be required and identified at detailed design. Electrical equipment required to be housed within a building will be installed within a new bespoke structure, or within other proposed buildings.

Any new switchyard and electrical building, and associated electrical equipment, will be installed above flood levels, or raised to avoid flooding. Appropriate fire safety, including fire damage walls (if required) and fire alarms, will be included.

Electrical cables will be:

- Correctly sized for necessary voltage, power and, short-circuit current withstand requirements.
- Installed in ducts with removable covers.
- Installed with sufficient spacing between one another, and other conductors.

All electrical equipment will be installed to meet minimum safety clearances and adhere to all relevant UK standards, regulations and codes.

All voltages will be to UK frequency specification of 50Hz.

Fiscal metering will be included for the OCGT.

Transformer oily water drainage systems will be integrated with the existing AGS systems. New drainage systems will be created if the existing system does not have sufficient capacity.

Power system studies and detailed design stages are required as future activities to:

- Assess and design the electrical interfaces between the Pathfinder and AGS electrical networks.

- Determine the most feasible and operational connection for new mechanical and process equipment.
- Design the electrical network to identify required electrical assets to supply Pathfinder equipment, and the need for extensions to existing switchyard or switchrooms.
- Identify locations and accurate dimensions for new electrical switchyards or switchrooms, and where electrical equipment can be located in proximity to the mechanical and process equipment.
- Specify all essential design and ratings of transformers and other electrical equipment.

2.6. Control & Instrumentation

2.6.1. Control Philosophy and overall architecture

A control philosophy will be developed to provide a high-level overview and basis of design to assure the safe operation of the plant which includes alarm management, cybersecurity and communication interfaces. The control, monitoring and safeguarding of Aldbrough Hydrogen Pathfinder plant will be by a new and independent Safety and Automation System (SAS). There is no requirement for it to be interfaced with the existing SCADA system at AGS.

2.6.1.1. Package 'Black Box' PLCs

The automation and plant safety of above ground installation (AGI) equipment supplied as a package unit that will be operated by sub-system 'black box' PLCs will be integrated with the SAS. Compressor package unit 'black box' PLCs will interface directly with the Motor Control Centre (MCC). Packages with dedicated PLCs include Electrolyser, LP/HP compression and OCGTs. It is preferable for dedicated equipment PLCs to be of the same manufacturer as the main control system. A vendor should be selected who has demonstrated their system design and package implementation is in accordance with the requirements of IEC 61508 & 61511. Combined Safety and control PLCs should be avoided. Full visibility of Package Unit status in addition to overall plant status shall be available in a new dedicated CCR where new operator stations, control panels and marshalling cabinets will be located.

2.6.2. Automation

2.6.2.1. BPCS

The Basic Process Control System (BPCS) will form part of the overall SAS and be designed to ensure maximum availability with specific redundancy requirements identified at pre-FEED phase. Remote Input/Output (RIO) panels should be utilised and located in the field, interconnected to BPCS controllers within the new CCR. Use of RIO panels will allow for an easier migration process when the control equipment is moved from a temporary location to a permanent control room location. A communication protocol between RIO and BPCS and SIS controllers will be defined at FEED phase based on equipment selection. There will be a requirement for interface to the Hydrogen Flow Import and export Metering System, condition monitoring systems associated with compressor packages, OCGT Electrical metering and plant Motor Control Centre (MCC). Any package units that are supplied as part of a skid and are controlled by the BPCS shall be supplied with instrumentation cables installed and terminated to supplied package boundary edge junction boxes.

2.6.2.2. ESD

An integral part of the SAS is the Safety Instrumented System (SIS). This shall be provided to automatically shut down / isolate discrete equipment, a system, or the plant, in a safe and controlled manner in the event of abnormal operating conditions which could endanger human safety; cause an environmental consequence through loss of containment, or cause mechanical damage to the plant.

The system shall monitor, initiate, and interface with other systems where appropriate, and provide the Safety Integrity Level (SIL) protection requirements determined from the HAZOP/LOPA process. Each safety instrumented function (SIF) shall be adequately segregated from the control functions. The SIS requirement shall meet the probability of failure on demand, determined through a LOPA (or equivalent) SIL determination.

Executive action and inter-trip requirements, e.g., interface with compressor control system, will be identified in preliminary Cause and Effect diagrams, which shall be used to implement the protection requirements of the plant.

The SAS shall be supplied by a Vendor experienced and competent in design, manufacture, testing & installation of systems suitable for process control, monitoring and shutdown applications. The Vendor shall have a proven track record in a similar service that has been used on similar types of projects.

2.6.2.3. Fire & Gas

F&G devices shall be installed in the Aldbrough Pathfinder site and the design will be by a contractor with proven experience in carrying out surveys to determine the precise locations F&G detectors are required and to classify fire zones on site. Any occupied buildings such as Local Equipment Rooms (LERs) shall have fire detection and alarm systems that meet the requirements of BS 5839-1:2017.

SIL rated F&G devices shall be used in plant areas where deemed necessary and be connected to a F&G system that interfaces to the SAS for monitoring and alarming purposes. Manual Alarm Call points (MACs) shall be located in specified plant areas and connected to the F&G system to allow an operator to intervene should they become aware of an emergency situation. MACs shall be end of line monitored so that loop faults are identified.

The F&G monitoring system will carry out executive actions when necessary and defined within the F&G Cause & Effects matrix. If the executive action requires shutdown of equipment connected to the SIS, a F&G Digital Output shall be configured and connected to the ESD system to trigger a shutdown condition. When a device in a specific area initiates an action, the CCTV system should automatically adjust adjacent cameras to the area to give operators visibility.

F&G device technology should be suitable for the specific gas identified as a potential hazard, namely Hydrogen and Natural Gas Detection and specified by a reputable vendor with proven experience in industry.

A high level F&G philosophy will be included in the Control Philosophy. It is anticipated that a specialist vendor would be engaged to determine the type, number and location of detection equipment around the plant. Gas detection and fire suppression equipment shall be required for the OCGT enclosure.

2.6.2.4. HIPPS

Where a High Integrity Pressure Protection System (HIPPS) is deemed necessary following detailed Hazard analysis a vendor experienced and competent in design shall be selected to provide a HIPPS that meets the specific project requirements. A HIPPS is designed and built-in accordance with IEC 61508 and IEC 61511 and shall be designed to meet the required integrity level, typically SIL 3. HIPPS shall be fail-safe in design with valves closing when loss of electrical power, loss of instrument air, loss of hydraulic power or sensor input failure scenario occurs. In the event an overpressure scenario is detected, isolation valves will close to protect lower rated downstream equipment. Pressure Transmitters shall be used to detect pipeline pressure and be in a 1oo2 or 2oo3 voting arrangement. Final element – Valve, actuator and solenoids shall be tested and certified for SIL3. Where SAS logic solvers are SIL3 capable a supplied HIPPS package unit could be incorporated into the SIS system. Where HIPPS vendor supplies the SIL3 capable Logic Solver effort should be made to ensure they are of the same manufacturer as the SAS ESD Logic Solvers and the vendor shall demonstrate that the HIPPS system and associated SIFs meets SIL3 requirements.

2.6.2.5. Field Instruments

Instrument performance/accuracy shall be sufficient to fulfil the plant performance requirements and should be selected to reduce calibration intervals and maintenance to a minimum.

Instruments shall have advanced diagnostics to enhance safety and reduce maintenance. Only industry standard communication protocols such as HART®, HART WIRELESS®, Foundation Fieldbus® or Profibus DP/PA® shall be used.

Variation of instrument types and ranges shall be kept to a minimum.

Analogue instruments shall be used rather than switch functions.

Field Instruments shall be suitable for the environment and the appropriate DSEAR (ATEX) zone requirements.

2.6.2.6. Signal Types

The following signal types shall be used for field measurement, equipment status, and control:

- analogue input/output: 4 mA to 20 mA with superimposed digital signal.
- digital input: potential free contact.
- digital output: 24V d.c.
- signals between control systems and other panels shall be powered from the SAS.
- position: proximity switches with NAMUR interface.
- pneumatic signals: 0.2 barg to 1.0 barg.
- as above, fieldbus type and wireless communications may also be considered, dependant on client approval.

2.6.3. Central Control Room (CCR)

Control room and Equipment rooms required for housing various control system panels, servers/network devices and other associated items including components for human machine interface (HMI) shall be sized and designed to develop a building that satisfies the functional and task requirements for control, monitoring, and safe operation of the Aldbrough Pathfinder project. Human Factors assessments including ergonomic reviews and critical task analysis shall be undertaken to optimise the control room arrangement and layout, number of Operator screens and environmental considerations such as lighting, heating and ventilation, and acoustics.

The Control Room shall be designed to the appropriate standards including ISO 11064 Ergonomic design of control centres, BS EN 6385 Ergonomic principles in the design of work systems and EEMUA 201 - Control rooms: a guide to their specification, design, commissioning, and operation. The Equipment/Rack Room shall be designed to accommodate the SAS Marshalling and Hardware cabinets, System Package Interface Cabinets, and Power Distribution Board(s). If the CCR is located in an area deemed to be within a blast zone, the design of the CCR must be blast-proof and designed by a vendor who has experience in this application.

2.6.3.1. Temporary Control Room

For the initial lifecycle of the project, it would be preferable to have the control equipment located in a temporary modular style control room. At present the carpark in the North-East location of the site has been earmarked as a suitable location. This is an area where a blast proof building would not be required. The intention would be to move the control equipment to a permanent location in a control building potentially cohabited with AHS control equipment during a later lifecycle of the plant(s).

Consideration of building type and design for a temporary modular style control room to house control equipment and control room console will be assessed at pre-FEED. The temporary control room design shall be suitable for the expected staffing levels as per 2.9.1, Table 2-6.

2.6.4. Metering

2.6.4.1. Gas Flow Metering

There is a requirement for flow metering systems to account for Hydrogen produced from the Electrolyser, Hydrogen export to OCGT and Natural Gas import to OCGT. The metering packages shall meet all the contractual and regulatory requirements. The metering packages shall be provided with all necessary bypasses or process connections for in-situ or offsite calibration as determined following meter selection. The flow meter(s) shall, in all cases, be suitable for the process conditions and piping configuration applicable to the measurement location and the environment in which it is mounted and shall be supplied with a calibration certification from an approved laboratory. Ultrasonic Flow Meters (USMs) are a preferred technology for Natural Gas metering. These Flow Meters typically require 20D upstream and 10D downstream of straight lengths in pipe for optimum performance and accuracy. This requirement should be considered in the layout design. Where there is substantial straight lengths in pipe available that exceed these minimum requirements, it is best practice for the USM to be installed with 66.66% of available straight length upstream and 33.33% downstream.

Applicable standards include but are not limited to:

- ISO 10012 Measurement Management Systems – requirements for measurement of the metering system
- ISO 10790 Guidance to the selection, installation, and use of Coriolis meters (If selected)
- AGA-9 Measurement of Gas by Multipath Ultrasonic Meters

- API MPMS 5.1 Manual of Petroleum Measurement Standards Chapter 5 – Metering Section 1 – General Considerations for Measurement by Meters
- API MPMS 21.1 Manual of Petroleum Measurement Standards Chapter 21 – Flow Measurement Using Electronic Metering Systems, Section 1 – Electronic Gas Measurement
- Also consider standards within the existing SSE Connection Agreement.

The metering packages shall be supplied by a Vendor experienced in design, manufacture, testing & installation of flow metering systems. The Vendor shall have a proven track record in a similar service that has been used on similar types of projects.

The metering system shall typically consist of the following major sub-systems:

- Primary flow element and associated transmitter (multivariable transmitter for direct mass flow measurement).
- Local field instruments for pressure compensation (if required) and temperature measurement for primary flow element calibration checks if an internal temperature device is included in the primary flow element.
- Flow measurement software package including, calculations, displays and reporting facility to be integrated into the plant control system.

The overall measurement uncertainty shall be better than ± 0.5% for both volumetric flow rate and mass flow rate over full operating conditions (including ambient condition changes).

Further design development will determine the requirements for calibration of the meter(s) in terms of redundancy, proving, in-situ calibration etc.

The following data shall be used in the design of the metering system:

- Fluid properties (molecular weight, specific heat ratio, compressibility etc.).
- Operating and design temperature and pressure.
- Maximum allowable pressure drop across the system at various conditions – this not considered to be critical in this particular application.
- Utilities (electrical UPS power load, instrument air, etc.). Specific utility requirements for the metering skid will be developed during pre-FEED.
- Communication requirements (data hand-off, system interfaces) to be developed as part of the control system specification and design.
- Pipe parameters.
- The rangeability (minimum and maximum) of flow for specified max flows. Requirements for measured flow range and turndown requirements will be developed during pre-FEED.

Continuous compositional gas analysis using an ‘online’ process analyser shall be specified. The gas analysis system shall typically consist of a sample gas conditioning system including pressure reduction equipment in readiness for analysis and an online analyser for gas analysis e.g., thermal conductivity type. An analyser shall have a separate bench calibrated for Oxygen and have a dual output for both gases.

A moisture analyser shall also be specified as part of the metering package to detect condensation in the pipeline which can lead to operational problems (corrosion and erosion) and safety risk such as water slugs.

2.6.4.2. Electrical Metering

Energy meters shall be installed for the measurement of OCGT power generation and meet the requirements of IEC 61850 communications standard. There are around 15 IEC standards for Electrical metering, a vendor should be selected who complies with the applicable standards for the given application. Precise measurements of power transfer points are required to account for accurate revenue transactions for OCGT power export. The energy meters shall interface with the SAS so that data can be presented on a BPCS graphic, stored within a data historian and interface with a settlement system. A communication protocol such as MODBUS should be used and typically an energy meter should have RS232, RS485 and ethernet connection capabilities to interface with the SAS. Current Transformers (CT) and Voltage Transformers (VT) with high accuracy capabilities should be installed within OCGT electrical switchgear and typically the energy meter should have built in dynamic error compensation for CTs and VTs. Measurement parameters shall be further defined at pre-feed and feed. Typically, but not limited to, the below data is measured for settlement purposes:

- Active Energy Consumption (MWh)
- Reactive Energy Consumption (MVArh)
- Active Power (MW)
- Reactive Power (MVAr)
- Hourly Cumulative Energy (KWh)
- Voltage (V)
- Current (A)
- Frequency (Hz)

2.6.5. Telecoms

An independent telecommunication system panel shall be installed on-site for public address and alarm system (PA) that will interface with telecommunication devices such as Loudspeakers and PA flashing lights (beacons) that shall be ATEX rated for the most onerous zonal classification of the site. Telephone systems and CCTV will also be connected to this system. The specific requirements for PA and CCTV device quantity and precise locations shall be determined following a site survey at FEED stage by a specialist vendor and consideration should be given for the new devices and systems to be connected to an existing Telecommunication system at AGS.

2.7. Civil and Drainage

The following documents have been produced for the project and should be read in conjunction with this section:

- Pathfinder Proposed Site Plan (5215677-CV-DWG-001),
- Pathfinder West Plot (5215677-CV-DWG-002)
- Pathfinder East Plot (5215677-CV-DWG-003)
- Pathfinder West Plot – Foundations (5215677-CV-DWG-004)
- Pathfinder East Plot – Foundations (5215677-CV-DWG-005)
- Pathfinder Building / Asset List (5215677-CV-DWG-010)

2.7.1. Site Preparation and Levelling

Site preparation and levelling is to be designed to ensure minimal soil removal. Excavated topsoil, subsoil and existing granular material shall be stored separately, re-used where possible or set aside to form screening bunds and landscaped mounds to screen the works. Broken concrete and asphalt paving will be removed from site.

It is envisaged that construction will begin with:

- The creation of any access road, parking area and/or contractor's compound. All areas on the site are to be plain stone during construction and reshaped and finished in tarmac at the end of construction. Surface water will drain into existing french drains and drainage systems via oil/water separators.
- The installation of wheel wash facilities. An on-site vehicle wheel washing facility and traffic management scheme is to be put in place and complied with before construction starts.
- General site strip, removal and storage of topsoil and subsoil and the general levelling of the site.
- The installation of temporary site perimeter fencing.
- Installation of the contractor's temporary supplies: telecoms, small power and water.
- Diversion of critical infrastructure as required.
- Preparation for incoming power and gas feeds.
- The creation of a working platform, an imported granular sub-base material incorporating geotextile membranes to act as temporary roads, piling platforms and a clean working surface, that may on

completion form the basis of road and ground bearing slab and laydown area formations. The platform level will be chosen to avoid flood risk and similar to Aldbrough1 at between 11.5m and 11.8m AOD.

2.7.2. Below ground installations and services including cable ducts, pipe trenches, culverts etc.

In order to create as tidy and clean an installation as possible, service runs should be located below ground whenever possible. Only those services which require regular inspection or are hazardous to contain below ground are to be carried on above ground pipe racks.

2.7.2.1. Underground Services and Road crossings.

Underground crossings are envisaged beneath roads to connect the process streams. These crossings shall be of reinforced concrete and be designed as culverts to withstand highway and soil loads. Sufficient space for inspection access shall be provided. Precast culvert units shall be utilised wherever possible to reduce on-site operations. Ladders, stairs and platforms shall be incorporated as necessary. All crossings shall fall to one end or be benched to falls and incorporate a drainage sump for dewatering.

2.7.2.2. Cable Ducts

Duct groups shall be laid as required between plant, generally below the working platform or formation level so as not to interfere with drainage and pavement construction. Duct groups will be surrounded in concrete where they are located at shallow depth. Ducts shall rise to ground level in slow bends or terminate in proprietary segmental draw pits.

2.7.2.3. Pipe Trenches

Where possible pipe trenches are to be constructed from precast concrete units, bedded and jointed, with removable covers. Heavy duty covers are to be provided for road crossings. Open mesh covers may be required for those trenches carrying lighter than air gases or to provide improved ventilation.

2.7.3. Roads, ditch crossings, paving and surface drainage.

2.7.3.1. 2.3.1 Foul Drainage

It is NOT envisaged that foul drainage will be required.

2.7.3.2. 2.3.2 Surface Water Drainage

Surface water drainage will be required to the new plant area. A filter drain approach to surface water is suggested, to collect runoff from roads and paved areas as well as unpaved laydown spaces. This follows the existing site drainage philosophy.

The surface water run-off may, where it derives from roads, be slightly contaminated by hydrocarbons. It is therefore envisaged that full retention petrol interceptors will be provided. These will require maintenance and emptying on a periodic basis. Existing interceptors may be reused if present.

It is envisaged that an extension to the existing balancing ponds will be needed to mitigate flows into existing drainage field ditches during high rainfall events.

2.7.3.3. Ditch Crossings

Ditch crossings shall be constructed as culverts and comprise rectangular precast concrete units or large diameter concrete or twin wall polyethylene pipe depending on size.

2.7.3.4. Road Construction

Road construction will typically comprise bitumen macadam surfacing over granular sub-base and capping material. Site ground conditions are thought to comprise clay material and therefore poor ground strength is anticipated with a subsequently deep road construction. Localised areas subject to standing or turning heavy goods vehicles may be constructed in concrete. Initial proposals are for site roads approximately 7.3m wide.

2.7.3.5. Pedestrian Pavements

Pedestrian paving and perimeter paving to buildings etc, will be in-situ concrete to minimise movement and the creation of steps or trip hazards. All paving is to be slip resistant and the concrete is to be frost resistant.

2.7.4. Construction of Buildings / Superstructure

All manned building structures will be considered during the detailed design phase for the provision of passive fire resistance and explosion protection. We anticipate traditional steel framed and lightweight clad constructions. Only manned buildings will be heated.

2.7.4.1. Illumination

Lighting design shall comply with CIBSE Guidelines. Lighting shall be specified for each workplace that requires at least daily access or is critical from a safety point of view. In the design of lighting, the level of illumination and location of lamps shall make it easy to see obstructions, steps, walkways etc.

External low intensity lighting will be utilised where possible and security lighting will be motion activated to reduce the impact on the local environment.

2.7.4.2. Indoor Heating and Ventilation

Adequate indoor climate shall be ensured for each individual room with respect to air demand, draught, humidity, and temperature. The indoor air shall be free of contamination that is damaging to health. Evaluation of natural or mechanical ventilation shall be carried out. Air inlets will be located in open air and in areas not contaminated by exhaust outlets. There will be easy access for internal inspection of the ventilation system and for cleaning of air ducts.

2.7.4.3. Design Working Life and Life to First Maintenance:

Design Working Life = 50 years (Category 4 to BS EN 1990 Table 2.1).

Life to First Maintenance = 25 years for coatings (corrosion protection and intumescent).

It is anticipated that, due to the coastal environment, exposed structural steel will by hot dipped galvanised to achieve this life to first maintenance. High quality cladding systems with a 25 year manufacturers guarantee will be required for any building cladding and high performance aluminium and/or stainless steel systems may need to be considered.

2.7.4.4. Building Class

The building class in terms of disproportionate collapse is category 2A, horizontal tying is necessary for robustness. Other external structures on the site are also category 2A.

2.7.4.5. Blast

Blast is not to be considered for structural design at this stage.

2.7.4.6. Movement:

Primary and secondary movement joints have been determined in accordance with CIRIA Report 'C734 Design for Movement in Buildings'. Further guidance is given in SSE Civil Standard PR-SSE-GEN-SHE-012-003-053

2.7.4.7. Fire Rating

The Building Regulations 2010 (incorporating 2013 Amendments), Approved Document B2, Table A2 = 60 minutes for Purpose Group 6a Sprinklered with no basement and height of top floor above ground not greater than 18m at this stage. To be confirmed at detailed design stage.

2.7.4.8. Thermal Loads

Generally structures shall not be analysed and designed for temperature loads unless thermal stress can be locked in. Movement joints shall be incorporated to avoid this where possible.

Pipe support loads shall be analysed and foundation and supports designed accordingly.

2.7.4.9. Crane Loads

Crane supporting structures shall be designed in accordance with BS EN 1993-6 and BS EN 1991-3. Crane loads will be obtained from the crane supplier. We anticipate that the workshop will have an overhead crane of relatively low capacity, perhaps 5 Tonnes

The overhead crane will operate from a series of runway beams fixed to the underside of the primary steel roof trusses. The load, the class of utilisation, state of loading and corresponding group classification have yet to be determined in accordance with BS 2573-1:1983

Elsewhere there might be isolated lifting davits required to locations in the process plant, subject to an equipment lifting and maintenance plan.

2.7.4.10. Dynamic / Fatigue Loads

Fatigue associated with the use of use of cranes and their intermediate supports will be considered in accordance with BS EN 1993-6 and BS EN 1993-1-9. Dynamic loading with the use of reciprocating or rotating machinery will also be obtained from manufacturers data and assessed.

2.7.4.11. Seismic Loads

Seismic Loads are not considered applicable in the design of the structure.

2.7.4.12. Thrust Loads

As with thermal loads, thrust Loads are to be calculated during pipe analysis and the results passed to the structure and foundation designer.

2.7.4.13. Impact Loads

Design for hostile vehicle loading is not considered in the design for any of the buildings or structures. Standard barriers are to be used to protect plant and structures thought vulnerable to accidental damage.

2.7.4.14. Equivalent Horizontal Loads

Lateral loads as a result of geometric imperfections shall be applied in accordance with the relevant material codes.

2.7.4.15. Construction Loads

Construction loads shall be determined in accordance with BS EN 1991-1-6 and NCCI in order to design members in the temporary condition. The assumed construction live load shall be clearly identified on drawings.

It is assumed that the only permanent works that shall support significant construction loads are concrete ground floors. It is assumed that a telescopic or articulating boom or scissor lift mobile elevated working platform (MEWP) shall be used to install steelwork and cladding. A blanket live load of a minimum of $4kN/m^2$ will be used to allow for the use of such plant. Construction loads should not exceed the combination of superimposed dead loads plus live load provisions. In the event of construction loads exceeding this limit, additional shoring/propping temporary works shall be designed and installed as necessary by the contractor to facilitate construction or the construction methodology revised to ensure that the permanent works are not subject to detrimental effects.

2.7.4.16. Accidental Loads

Accidental Loads are not considered applicable in the design of the structure.

2.7.5. Fences, Gates, Barriers

Permanent high security fencing is to be designed in compliance with SSE/Equinor standards and to blend in with the rural surroundings around the main gas facilities and the wellheads after construction works are complete. SSE standards suggest a Type 3 fence is applicable.

Gates are to be provided to allow traffic and pedestrians to enter the facilities and the wellheads. Emergency personnel gates are to be strategically placed to allow emergency escape. The SSE standard gives guidance on minimum and maximum gate widths.

2.7.6. Landscaping

The plant is located in an environmentally sensitive rural area and is to be designed so as to integrate sympathetically with the surrounding rural landscape character. Details of the location and proposed levels of top soil and sub-soil storage arising from the construction activities, and details of the earthworks, including proposed grading and moulding of land areas, need to be agreed with the Local Authority.

2.7.7. Construction of foundations for external plant and equipment.

2.7.7.1. Generally

Foundations are to be designed to British Standards using concrete piles, slabs and pads as appropriate to ensure minimal settlement of buildings and structures.

The specification for all external concrete shall include air entrainment for frost resistance.

We expect most structures to be piled, with stiffened raft or solid slab construction for the more lightly loaded and less sensitive structures i.e. those slabs supporting equipment that is separated and isolated from the main process plant or connected only by relatively flexible cables and pipes.

Existing drawings suggest piling is adopted throughout Aldbrough Phase 1, typically at around 5m centres, under process slabs. Additional piles are introduced under heavy plant, particularly the reciprocating loads applied to the compressor foundation blocks. Piling is also used to support the service crossings and to support above ground pipework trestles.

We anticipate a myriad of sleeper walls and plinths of various heights to support pipes and small items of plant. Where possible some degree of standardization will be applied.

In the workshop building we expect twin, triple, and quad pile caps to be connected by ground beams and/or a slab edge thickening. In the external process slabs the piles may terminate in the slab thickness or in a slab thickening.

2.7.7.2. Ground Floor Slabs

Ground floor slabs to the workshop are expected to be ground bearing and 200mm thick.

2.7.7.3. Retaining Walls / Embankments

Few retaining walls or embankments are anticipated, though we note SSE specification to limit embankment slopes to 1:3. This will need to be considered when sizing any balancing pond extension and any landscaping works. Retaining walls will comprise precast reinforced concrete or stone filled gabion units.

We assume that the fire water tank is a proprietary sectional glass coated steel tank, constructed off a flat in-situ concrete base. It is anticipated that slabs supporting tanks will have a recess or plinth to seal the first row of the tank to.

2.8. Environmental

2.8.1. Emissions, Discharges & Waste Handling

Various effluent streams that need to be either disposed of off-site or emitted to atmosphere are listed below, in Section 2.8.1.1 (Rewatering Facilities) and Section 2.8.1.2 (CPA). All emissions from the Pathfinder Facility will be disposed of in accordance with Planning Permission requirements and any other permits and consents for the facility.

An atmospheric vent stack is favoured based on its simplicity; however, this is subject to change and will be further defined in Pre-FEED. The vent stack gases may or may not require further treatment prior to venting, dependent on environmental permit conditions [HOLD].

A Waste Management Plan will be developed, and all waste will be disposed of by suitably qualified waste companies. The anticipated quantities and disposal route will be confirmed during development of the plan in detailed design.

2.8.1.1. Rewatering Facilities

- Nitrogen (MIT / potential cavern purge) / hydrogen (dewatering) from the wellhead vents and brine degassing tanks
- Brine discharged to Aldbrough 4z cavern
- Solids including marl, sand, grit, and stones from rewatering,
- Debris surface water drainage screens

2.8.1.2. CPA

- Routine process venting (for maintenance and start-up/ shutdown) and emergency blowdown sequences
- Exhaust gas
- Wastewater drainage
- Concentrated neutralised brine from demineralised water production
- Spent desiccant
- Waste oil and oily water disposal

2.8.2. Chemical Management

The chemical storage and use on the Pathfinder facility shall be approached as follows:

- Use of hazardous chemicals shall be avoided where possible and otherwise minimised
- Quantities of each chemical stored on site shall be minimised
- Handling and transportation of chemicals shall be minimised
- Delivery of chemicals and transport of them across site shall be recorded and controlled by site procedures
- Procedures shall be implemented for dealing with and recording chemical spillages

2.8.3. Use of Area, Water & Resources

The following water uses are anticipated as part of this design:

1. Water will be extracted from the borehole to supply the water treatment plant which shall produce demineralised water supply to the electrolyser. A borehole abstraction license is in place where the flowrate to the electrolyser is within the license agreement limits however the license does not directly refer to electrolysis as a use for the borehole water and therefore this may require an update to planning.
2. Brine that is displaced from Aldbrough 1 during hydrogen filling will be used for the rewatering of the Aldbrough 4z cavern.
3. Wastewater streams from the water treatment plant shall be discharged to the closed drains system and diluted with other wastewater streams. The common wastewater stream is discharged to the waste water treatment system. The waste water shall be sampled prior to disposal to drain. If waste water quality does not meet discharge conditions then alternative disposal shall be required via road tanker.
4. The concentrated neutralised brine, produced as a waste stream from the demineralised water polishing process, shall be disposed of separately (by road tanker) from the other water treatment package waste streams.
5. Knocked out liquid streams from the process (e.g. coalescer filter, separators and suction scrubbers will be collected in a common drain drum. Oily water shall be separated and shall be collected in a storage vessel for disposal via road tanker, as and when required. The water from the drain drum shall be routed to the wastewater treatment system where the wastewater will be treated to ensure the discharged water is consistent with BAT requirements and does not give rise to significant adverse impact on water quality in receiving watercourses. It is to be confirmed if the facility could tie in with the existing wastewater

treatment system within the AGS facility or if a standalone wastewater treatment system shall be required for treatment of the Pathfinder facility wastewater.

6. Surface water will drain into French drains and discharge into the ditches via oil/water separators. The volume and flow rate of the surface water run-off from rainwater will be calculated to meet the requirements of the Environment Agency and any planning conditions, limiting runoff flows to those of the original farmland on which it is built. The surface water run-off may, where it derives from roads, be slightly contaminated by hydrocarbons. It is therefore envisaged that full retention petrol interceptors will be provided, sufficient to treat the maximum site flow. These will require maintenance and emptying on a periodic basis.
7. Foul drainage will be required at:
   - The control building on the process site
   - The welfare cabin at the well pad site
   - The security building on the access road

   Local sewerage connections are not possible therefore an on-site septic tank or mini-commercial treatments plant at each location is required. These will require periodic emptying by tanker.

The Environmental Permit conditions will require a justification for the selection/specification of raw and other materials. The materials proposed for use in the Pathfinder plant shall therefore be reviewed to establish whether alternative less hazardous substances could be used.

2.8.4. Noise

The Pathfinder facility will contain noise generating equipment that is permanently installed and may be operational at any time throughout the day. The guiding principle should be to minimise noise from process plant and equipment, such that the requirements of legislation, regulations, standards, and planning conditions are met.

Noise level limits will typically impact the following areas:

- Local to plant equipment
- In plant rooms or buildings
- In controlled areas e.g. control room

Noise datasheets for all potentially noisy equipment shall be prepared during FEED. The noise level from any item of plant shall be minimised to achieve the planning requirements and to meet the requirements of Control of Noise at Work Regulations, which stipulates a maximum surface noise level of 80 dB(A) at 1m. Where this is not reasonably practicable or in areas where noise from multiple noise sources generates noise levels in excess of 80 dB(A) then personnel access is to be restricted and adequate hearing protection shall be worn.

A noise monitoring system shall be included for both construction and operation of the Pathfinder Facility. The noise data gathered by this system shall be easily accessible (i.e. via the facility network) and have the ability to differentiate between different frequencies (to accurately monitor and analyse noise sources associated with the Pathfinder facility).

2.8.5. Leak Detection and Minimisation

In general, the facility shall be designed in accordance with BS ISO 22734 [11] and NFPA-Hydrogen Technology Codes [12] with the aim of eliminating or minimising the risk of leaks throughout the facility.

The necessity of situational awareness and the use of instrumentation to detect leaks shall be recognised and incorporated into the design. System-wide hydrogen situational awareness is considered the responsibility of the instrumentation system. Instrumentation shall be specifically designed to incorporate hydrogen leak detection, area coverage.

Furthermore, where there is a risk of hydrogen accumulation, both in enclosed indoor and outdoor areas, ventilation and purging of areas shall be used in order to drive hydrogen accumulations below the lower explosion limits (LEL). Emergency and critical systems, including area purging and hydrogen leak sensors shall be included on the UPS.

Details of fugitive emissions sources and mitigations are provided in the Fugitive Emissions Technical Note, 5215677-PR-TCN-001

2.8.6. Best Available Techniques

The Pathfinder plant design shall take account of Best Available Techniques (BAT) i.e. those available techniques which are the best for preventing or minimising emissions and impacts on the environment. “Techniques” include both the technology used and the way the installation is designed, built, maintained, operated and decommissioned. The European Commission produces BAT reference documents (BREF notes) which specify BAT for installations. It also produces ‘BAT conclusion documents’ which contain emission limits associated with BAT (‘BAT AELs’) – which must be complied with – and other key BAT requirements.

The BAT conclusion documents applicable to the Pathfinder plant are as follows:

- BAT reference document for the refining of mineral oil and gas [8]. The BAT conclusions cover the activity of “hydrogen production” which includes hydrogen purification which is applicable to the drying trains.
- Reference Document on the application of BAT to Industrial Cooling Systems [9], applicable to the interstage- and after-coolers required for the compression trains.

The Pathfinder plant shall be designed to be energy efficient using the techniques listed in section 4 of the Reference Document on Best Available Techniques for Energy Efficiency [10]. A record of the techniques employed in the design shall be maintained for inclusion in the Environmental Permit application.

2.9. Operations and Maintenance

2.9.1. Definition of operating model, including manning philosophy

The Hydrogen Pathfinder facility shall be designed to produce hydrogen via electrolysis, provide safe storage and transfer of hydrogen gas to and from the ALD1 cavern and generate electricity via combustion of the hydrogen in an OCGT. Storage of hydrogen in ALD 1 shall allow for asynchronous production and consumption of hydrogen.

The facility shall act as a demonstration for future large-scale hydrogen storage projects which will contribute to the balancing of national hydrogen supply and demand.

It is expected that the system shall be operated intermittently based on the testing operations of the OCGT. The planned operational regime of the OCGT will be developed during the next phase in consultation with the OEM.

The operations team staffing requirements for the Hydrogen Pathfinder facility shall comprise of the following roles as shown in Table 2-6. This assumes a level of operational efficiency with existing operations whereby roles such as security will be shared.

Table 2-6 – Staffing Profile

Role	
Operations	1
Operations Manager	0.5
Shift Superintendent Team 1	1
Plant Engineers Team 1	2
Operators Team 1	2
Security Guard	
Security Guard Team 1	1
Maintenance	
Maintenance Manager	1
Maintenance Technician	2
	10

The above staffing profile assumes two teams of two for:

- Plant Engineers Team 1,

- Operators Team 1,
- Maintenance Technicians.

2.9.2. Integrated operations requirements

The Hydrogen Pathfinder facility shall be independent from the existing Aldbrough Gas Storage (AGS) facility and the proposed Aldbrough Hydrogen Storage (AHS) facility. The exception is the electrical and natural gas supplies to the Hydrogen Pathfinder Facility which shall be provided via a connection from the existing AGS facility.

As stated in Section 2.6.3.1 the Hydrogen Pathfinder facility is expected to share a control room with the proposed AHS facility however will initially be housed in a temporary control room.

It is to be confirmed if the facility could tie in with the existing wastewater treatment system within the AGS facility or if a standalone wastewater treatment system shall be required for treatment of the Pathfinder facility wastewater.

2.9.3. Maintenance requirements

- Equipment shall be designed for cost efficient and safe maintenance and with a layout that provides full access and egress to items of equipment which require routine or frequent attention.
- All systems and equipment shall be prepared for preventive and corrective maintenance. Condition based maintenance is expected to be the preferred preventive maintenance method and shall be conducted in a safe manner without loss of availability.
- Maintenance of process equipment is required on a regular basis. Any routine maintenance requiring a complete shutdown or significant reduction in availability should be no more frequent than annual so that it can be scheduled for the summer months.
- Appropriate isolation facilities (e.g. double block and bleed valves) shall be included to allow routine maintenance of equipment, where necessary, without any need for plant shutdown.
- The facilities shall be designed to the sparing philosophy to be defined [HOLD].
- A maintenance philosophy shall be produced by the designer and will maintain the technical condition for all systems and equipment to achieve
- A planned maintenance schedule shall be provided for the plant which will support the required availability requirements.
- For unplanned maintenance, the design intent shall be that in the event of failure of an item of equipment, the failed item can be removed and replaced whilst the plant is online without impacting on the availability of the rest of the facility.
- A spare parts strategy shall be considered in the design and provided for the plant including parts and equipment and supplier’s lists, replacement rates and lead times and recommended spare list.
- The design shall demonstrate that consideration has been given to the interchangeability of parts / commonality of spares such that stockholding can be minimised.

2.10. Safety, Security and Sustainability (SSU)

The following documents have been produced for the project and should be read in conjunction with this section:

- Hazard Study 1 Report (5215677-PS-REP-001),
- Hazard Study 2 (HAZID) Report (5215677-PS-REP-002).

2.10.1. General

To be developed by SSE Thermal.

2.10.2. Consenting

To be developed by SSE Thermal.

2.10.3. Health and working environment

Existing legislation is in place to effectively regulate the safety of the hydrogen process chain. In particular, the Health and Safety at Work etc. Act 1974 (HSWA) [13] applies to hydrogen processes onshore.

The Health and Safety at Work Act Sections 2 and 3 require employers to ensure the health and safety of their employees and others so far as is reasonably practicable. This means that the operator of the hydrogen storage and processing facility is required to take a proportionate approach to managing the risks from conveying hydrogen at every stage of the facility's lifetime. This should be demonstrated through a comprehensive risk assessment which takes account of the range of risks that arise from the design, commissioning, operation (including maintenance and inspection) and decommissioning of the hydrogen facility.

2.10.4. Human factors

To be developed by SSE Thermal.

2.10.5. Technical Safety

The fundamental principle in the management of HSE risks is to identify and control foreseeable HSE risks during design activities, applying inherent 'safety-in-design' principles in line with the hierarchy of control measures. The first step in risk evaluation and management is to systematically and consistently identify hazards based on the HSE/Safety Engineering risk assessments, suitable mitigation measures and controls will be developed and maintained to ensure that risks are ALARP. The level of detail for formal Hazard Identification and Risk Assessment should be proportionate to each stage of the project. At this stage a Hazard Study 1 and HAZID study have been conducted.

2.10.5.1. Hazard Study 1

A hazard study 1 is a high-level safety and environmental study. The hazard 1 for this project comprised a desktop exercise followed by a multidiscipline workshop, which was held on the 25th August 2022, The purpose of the hazard study 1 was to provide a broad appreciation of the type and scale of hazards associated with the project and ensure that HSSE issues, regulatory permits and compliance requirements are identified early in the project. This will allow appropriate process hazard studies to be planned and allowance to be made to adequately assess or design out risks associated with HSSE in a timely manner. The topics and scope for the review were taken to be in line with those identified by the IChemE and AICHE and considered to be good industry practice. Within the workshop, the following key areas were addressed:

- Process Materials - hazards associated with the materials.
- Chemical Hazard Interaction Matrix
- Incident Review
- Inherent Safety
- Process Hazard Studies/Reviews
- Regulatory Requirements

A terms of reference was issued prior to the workshop to brief attendees and a report was issued to document the process. A total of 18 actions were identified during the review. These actions included responses to incident observed in wider industry and consideration of inherent safety Other, activities were identified which are anticipated to be part of design development, specific actions were not raised for these activities, however the Hazard 1 report records which process hazard studies and regulatory requirements are anticipated as part of the project. These activities and interaction will require to be scheduled in future project phases.

2.10.5.2. HAZID

Following on from the Hazard Study 1 a Hazard Identification (HAZID) workshop was carried out on the 20th of September 2022 to identify risks associated with the proposed Aldbrough Gas Storage (AGS) facility. The objectives of the HAZID workshop were as follows:

- To ensure that the potential hazards are identified and are therefore managed appropriately in the forward design.

- To identify and assess potential hazards, and propose recommendations to eliminate, prevent, control or mitigate hazards as necessary; and,
- To explore the opportunities for Inherently Safer Design (ISD).

Environmental and safety aspects were considered when performing risk ranking for severity. However, as the HAZID was carried out at an early stage of design, the likelihood of risks materialising was not assessed due to the level of information available. Appropriate actions were assigned accordingly to deliver that information and inform future design. The workshop identified 40 actions and identified numerous initiating events which were assessed for severity resulting in the distribution summarised in Table 2-7.

Table 2-7 - Distribution of Initiating Event Severities from HAZID Study

Environment	Safety		Severity Level	Distribution of Identified Risks	
	Public	Worker		H&S	Environment
MATTE- CAT D	>1 Fatality	Multiple Fatalities (11-50)	E	0	0
MATTE- CAT C	1 Fatality/ multiple injuries	Multiple Fatalities (2-10)	D	6	5
MATTE- CAT B	1-4 Major injuries	1 Fatality / multiple injuries	C	18	15
MATTE- CAT A	Minor Injury/ first aid	1-4 Major injuries	B	6	3
Sub-MATTE	No impact	Minor Injury/ first aid	A	2	9

2.10.6. Security

The overall requirement is for a system that principally comprises of a permanent high security fence, CCTV system, access control and security lighting. The design shall integrate the CCTV, intercoms, remotely operated gates, access control, security fence and their subsystem components to form an Integrated Security System (ISS). The CCTV System shall be designed to meet the requirements of DIN EN 62676 – Video surveillance systems for use in security applications [6]. Security lighting will be motion activated to reduce the impact on the local environment. The security fence shall be designed in compliance with SSE Thermal standards [HOLD].

The control and safety system design shall incorporate cybersecurity countermeasures to prevent external attacks through external network connections and through attacks from inside the facility. The design shall incorporate network segregation and shall be provided to enable backup and recovery of the systems in the event of compromise to any system.

2.10.7. Sustainability

To be developed by SSE Thermal.

2.11. Reference Conditions

2.11.1. Site Reference Ambient Conditions

Table 2-8 – Meteorological Data

Title	Reference
Ambient Temperatures	Maximum +40°C Minimum -20°C
Wind @ 10m above LAT, 100 year return period	3 second gust 46 m/s, 1 hour mean 35 m/s

Rainfall, 50 year return period	18.2 mm/h
Relative Humidity	Minimum 40% Maximum 100%
Snow Load	Snow Load 1.5 kN/m² (Not necessarily the site snow load, but the minimum roof load that should be considered)
Specific atmospheric conditions at site that may cause corrosion	Saliferous air, coastal environment to be considered for coating / paint / cladding systems
Design Frost Affected Zone	A UK standard 0.45m frost affected zone shall be considered, note foundation minimum depth within clay soils of average shrinkability is greater at 1.050m.

In addition to the meteorological data in Table 2-8, the design shall consider implications of climate change based on the contents of client standards [HOLD].

2.11.2. Operating Modes

The facility shall be capable of operating in either hydrogen production and injection mode or hydrogen withdrawal and combustion mode or in standby mode. The facility shall not be designed to allow for simultaneously operation of both injection and withdrawal from the cavern.

2.11.2.1. Hydrogen production and injection mode

Production of up to 670 t/h of 99.99% H_2 via 2 x 17.5 MWe PEM electrolysers. The hydrogen gas shall be compressed from 100mbarg to 279 barg and cooled for injection into the ALD 1 cavern.

2.11.2.2. Hydrogen withdrawal and combustion mode

Saturated hydrogen gas is withdrawn from ALD 1, let down to ~40barg and cooled to remove moisture. Gas is conditioned to meet requirements of the OCGT. Hydrogen is combusted in the OCGT to generate electricity. The OCGT shall be capable of running on 100% hydrogen, 100% natural gas or a range of hydrogen/ natural gas blends.

2.11.2.3. Standby mode

The facility shall be in hot standby mode ready to swich to either hydrogen production or hydrogen withdrawal mode.

2.11.2.4. Shutdown mode

Systems are isolated and purged with nitrogen to avoid hydrogen inventory accumulation above LEL.

2.12. Fuel & Product Specifications

The composition of the gas exiting the electrolyser package (after separation of water and oxygen) shall be as follows [3]:

Table 2-9 – Electrolyser Outlet Gas Composition

Component	% (by mass)
Hydrogen	99.99
Oxygen	0.005
Water	0.005

The required hydrogen composition of the gas turbine and the required inlet conditions are to be confirmed by the OCGT vendor.

Table 2-10 – Gas Turbine Required Hydrogen Inlet Conditions

Component	mol%
Hydrogen	HOLD
Oxygen	HOLD
Hydrocarbons	HOLD
Water	HOLD
Energy Content	HOLD
Pressure	HOLD
Temperature	HOLD
Water Dewpoint	HOLD

The required natural gas composition for the gas turbine shall be in line with the National Grid gas specification and the Gas Safety Management Regs (1996) where the typical gas composition is defined below. The OCGT incoming gas conditions are to be confirmed by the OCGT vendor.

Table 2-11 – Aldbrough Typical Gas Composition*

Component	mol%
Methane	89.7195
Ethane	5.6325
Propane	1.4230
n-Butane	0.2175
i-Butane	0.2205
n-Pentane	0.0370
i- Pentane	0.0515
neo-Pentane	0.0000
C6+	0.0585
Nitrogen	1.1650
Carbon Dioxide	1.4750
Total Sulphur Content	HOLD

** based on the average composition taken from the Aldbrough Surface Plant Study Basis, 5138580-600-RPT-0002 from 2015 [19]*

The OCGT shall be capable of operating on 100% hydrogen fuel and 100% natural gas fuel as well as the range of hydrogen/ natural gas blends in between. The table below provides some details of the fuel under a range of blend concentrations.

The required natural gas inlet conditions to the OCGT are as shown in Table 2-12. It is expected the AGS composition shall meet the requirements of the OCGT vendor [HOLD].

Table 2-12 – Gas Turbine Required Natural Gas Inlet Conditions

Parameter	
Total Sulphur Content	HOLD
Energy Content	HOLD
Pressure	HOLD
Temperature	HOLD
Water Dewpoint	HOLD

Table 2-13 – Fuel Blending Specifications

H_2 (%vol)	100%	90%	80%	70%	60%	50%	40%	30%	20%	10%	0%
NG (%vol)	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Molecular Weight	2.02	2.81	3.68	4.65	5.72	6.93	8.28	9.83	11.6	13.6	16.0
LHV (kJ/kg)	120,000	97,360	83,760	74,660	68,150	63,250	59,440	56,390	53,890	51,800	50,030
HHV (kJ/kg)	141,800	114,100	97,270	86,020	77,960	71,910	67,200	63,420	60,330	57,760	55,570
Wobbe Index (MJ/m^3)	45.88	42.69	42.22	42.69	43.55	44.62	45.79	47.0	48.24	49.48	50.72
Exhaust Temperature (°C)	568	HOLD	HOLD	HOLD	HOLD	HOLD	HOLD	HOLD	HOLD	HOLD	560
NOx content	HOLD	HOLD	HOLD	HOLD	HOLD	HOLD	HOLD	HOLD	HOLD	HOLD	HOLD

2.13. Process Performance and Interfaces

2.13.1. Process Performance Requirements

The Hydrogen Pathfinder shall be capable of achieving the full range of design conditions, operating modes and functions required by the project. These will include, but not limited to, the following:

- Production of hydrogen within the defined specification and capacity range
- Combustion of hydrogen within the defined specification and capacity range
- Operate caverns within and not exceed the defined pressure envelope
- The facility shall be designed to stably meet, but not exceed the following maximum flowrates
    - Total hydrogen production flowrate 670 kg/h
    - Total hydrogen combustion flowrate 3,819 kg/h
- The facility shall be designed to stably meet the following turndown requirements (request for information response includes preliminary data provided by SSE Thermal):
    - Minimum hydrogen production flowrate 67 kg/h (in line with expected 10% turndown of electrolyser capacity) [7]
    - Minimum hydrogen combustion flowrate 0 kg/h (in line with expected 0 to 100% OCGT load based on the expected turndown, start-up / shutdown hydrogen rates of the OCGT as well as requirements of blended fuel operation of the OCGT) [7]
- The process equipment design shall achieve the required availability and reliability by inclusion of sufficient redundancy for key equipment [HOLD] [7]
- The facility shall be designed to accommodate the start-up and shutdown rates of the electrolyser and OCGT [HOLD];
- Hydrogen compressors shall be capable of matching start up rates of electrolyser or sufficient buffer storage shall be sized accordingly as an intermediary whilst compressors are brought online;
- Oil contamination of the gas injected into the cavern shall be minimised by inclusion of an oil filter downstream of compressors;
- Cooling systems shall be capable of reducing hydrogen temperatures to within defined range, even during maximum ambient temperatures;
- Storage capacity of 55,000 m^3 H_2 shall be provided by ALD 1 cavern
- Maximum rate of pressure change of the cavern shall be limited to 20 bar/day

- Cavern shall be capable of switched from injection to withdrawal mode within 1 hour
- Combustion of hydrogen shall be achieved within the defined ramp up rates of the OCGT
- The OCGT shall be capable of combusting hydrogen up the to the maximum capacity.
- The OCGT shall be supplied with hydrogen from the cavern only.
- The withdrawal train and wellhead shall be capable of achieving up to the maximum OCGT capacity
- The withdrawal train and wellhead shall be capable of achieving the full range of OCGT capacity and meet the OCGT ramp rates.
- The OCGT shall start up using 100% natural gas and hydrogen shall be blended in up to 100%. The system shall be capable of running on both extremes and blends in between.
- The hydrogen shall be dried, let-down and cooled to meet the required inlet condition of the OCGT.
- The dehydration train shall be capable of regenerating the desiccant whilst operating continuously i.e. a column can be offline and regenerating whilst other column(s) are in operation.
- Hydrogen shall be used as the regeneration gas for the adsorption dryers.
- Monitoring of hydrogen composition and conditions shall be included to ensure gas supply to OCGT is on-spec.
- Brine displaced from ALD 1 during hydrogen injection shall be re-used for rewatering ALD 4z
- A brine degassing and settlement tank shall be required to allow gas bubbles in the brine to be released to atmosphere during rewatering of ALD 1
- During normal operation of ALD 1 the displaced brine shall be bypassed around the brine degassing & settlement tank and sent to ALD 4z
- A vent system will be required for the Pathfinder facility
- Sizing of the vent system and sterile zone shall be designed for worst case relief rates, blowdown rates and manual depressurisation rates.
- Venting system shall be designed to be safe while minimising environmental impact and impact to neighbours.
- Wastewater streams shall be sent to a wastewater treatment system prior to disposal to drain.
- Velocity limits:
    - Maximum pipeline velocity – liquids 5 m/s
    - Maximum velocity – single phase
        - gas 20 m/s for NB 600mm and above
        - 25 m/s for NB 300 to 600 mm
        - 30 m/s for NB 300 or less

2.13.2. Process Consumables

The facility shall require the following process utilities:

- Power – electrolyser, compressors, pumps and cooling & heating systems shall require a power supply in order to operate
- UPS – to provide back-up power supply to critical loads when the input power source or mains power fails
- Cooling Water- circulating water / glycol mix to provide cooling to electrolyser, compression train and withdrawal trains. Heat rejected via fin fan coolers.
- Natural Gas
- Borehole (Brackish) Water – supply of water to WTP to produce demineralised & potable water for supplying electrolyser and ancillary consumers (workshop, control room, welfare facilities etc.) respectively. Borehole water shall also be used to rewater ALD 1 cavern.

- Instrument Air – compressed clean air system to supply various pneumatic equipment, valves & electrical controls
- Process Air – ambient air supply required for the OCGT and SCR packages
- Nitrogen- for purging of systems between operations
- Lubricating Oil- rotating machinery such as gas turbine and high pressure reciprocating compressors shall require lubricating oil supply
- Water treatment chemicals- ferric sulphate, sodium hypochlorite as well as pH adjustment (NaOH & HCl) and anti-scalent salts shall be required by WTP in treating the borehole water
- Ammonia – supply of aqueous ammonia solution for NOx reduction from the OCGT exhaust gas via the selective catalytic reduction (SCR) system, if required.

These utilities are defined and quantified in the utility schedule, 5215677-PR-SCH-001.

2.14. Codes and Standards

The design shall comply, as a minimum, with the Legislation, Codes and Standards listed in Appendix A. Note that the list should not be considered exhaustive and should be updated as the project develops. Other industry standards may be proposed if demonstrable benefits to the project can be shown. The precedence and order of standards are listed below from highest to lowest.

- UK Law
- HSE
- Site Safety Requirements (if applicable)
- Industrial and international standards, including those already identified in Project Standards (e.g. NACE, ASME, etc.)
- Project Specifications
- SSE/Equinor Specifications
- Good engineering practice

Although some industry standards may not be directly applicable to hydrogen service they will be used as a basis on which to develop the design with deviations for H_2 clearly stipulated.

2.14.1. DSEAR / ATEX

DSEAR, the Dangerous Substances and Explosive Atmospheres Regulations, 2002, is the United Kingdom's implementation of the European Union-wide ATEX directive. The intention of the Regulations is to reduce the risk of a fatality or serious injury resulting from a "dangerous substance" igniting and potentially exploding.

As part of the Hazard 1 study which assessed the hazardous properties of the substances anticipated to be present those substances which are flammable or have the potential to cause a vapour cloud explosion were identified. A DSEAR assessment will be carried out in further stages of the design.

2.14.1.1. Hazardous Area Classification

The DSEAR regulations require measures to be taken to eliminate and control risk this includes zoning and hazardous area classification. The industry standard Hazardous Area Classification of Natural Gas installations, IGEM/SR/25 Edition 2 [15] is concerned solely with natural gas, there is a Hydrogen Supplement being produced, which is currently in draft to address hazardous area classification using Hydrogen (IGEM/TSP/21/480) [16]. Another widely used industry standard for hazardous area classification is the Energy Institute Model Code of Safe Practice Part 15 [17], which contains information based on refinery hydrogen. The information from both the hydrogen supplement to IGEM and the published EI Part 15 were reviewed to establish a reasonable value for hazardous area zoning. There are small differences between the two documents for this application, the published EI document was used rather than the draft IGEM, which may be subject to change.

- Based on a freely vented outdoor location applying EI Part 15 and conservatively assuming a Level II release source and associated 2mm hole size for valves a hazardous area of 2m is an appropriate distance to assume for zoning associated with valves and connections up to 100 barg at this concept stage.
- At this stage it is assumed that any vents will be designed such that the discharges are at sufficient height and orientation to allow safe dispersion and to not represent a significant hazard to either personnel or equipment in the event of inadvertent ignition.
- Due to the very low ignition energy of hydrogen the electrical equipment selection will require to be based on the gas group categorisation of IIC.

2.14.2. COMAH

COMAH aims to prevent and mitigate the effects of major accidents involving dangerous substances which can cause serious damage / harm to people and / or the environment. COMAH treats risks to the environment as seriously as those to people. COMAH mainly affects the chemical industry, but also some storage activities and other industries, where threshold (and above) quantities of dangerous substances identified in the regulations are kept or used.

Schedule 1 of the regulations lists the dangerous substances or the categories of dangerous substances which cause the duties to apply and the quantities which set the two thresholds for application – at 'lower tier' and 'upper tier'. Operators of sites holding larger quantities of dangerous substances and notifying as upper tier sites are subject to more requirements than lower tier sites. Several of the substances that are anticipated to be present are categorised as dangerous substances under COMAH: Hydrogen, Natural Gas and Aqueous ammonia, there will also be small quantities of other hazardous substances.

Schedule 1 Part 2 of the COMAH Regulations lists Hydrogen as a “Named Dangerous Substance”. The relevant qualifying amounts are:

- 5 tonnes for the application of “lower tier” requirements
- above 50 tonnes the “upper tier” requirements.

It is anticipated that the proposed pressurised hydrogen storage will exceed the 50 tonnes threshold and as such meets the criteria for an upper tier COMAH site. Other dangerous substances, although below the relevant threshold for their category will need to be taken account of when considering the hazard at site.

All operators of upper-tier establishments are required to prepare a safety report. Its purpose is to show that you have put in place arrangements for the control of major accident hazards and to limit the consequences to people and the environment of any that do occur. The purposes and minimum content of a safety report are set out in Regulations 8 and 9 and Schedule 3 to the regulations. Prior to operation and through the project lifecycle there will be a requirement for the following:

- Operator submit a COMAH notification
- Develop and Operator submit a preconstruction safety report
- Develop and Operator submit a pre-operation safety report.

It is yet to be determined whether this will be a new standalone upper tier COMAH site or an amendment to the existing Aldborough upper tier COMAH site. Early dialogue with the competent authority to develop and a agree a timeline for these activities is anticipated.

2.14.2.1. Hazardous Substances Consent

Consent is needed if hazardous substances are stored or used at or above the specified controlled quantities listed in Schedule 1 of the Planning (Hazardous Substances) Regulation 2015 [14]. Hydrogen is listed as a named hazardous substance in Part 2 of Schedule 1 with an associated controlled quantity of 2 tonnes, therefore this proposed facility would require a hazardous substances consent to be applied for. Responsibility for checking claims for deemed consent rests with the hazardous substances authorities (HAS). This is typically the same body that would act as the local planning authority for the site. The HAS will consult the Health and Safety Executive on such applications.

3. Site Feasibility

The following documents have been produced for the project and should be read in conjunction with this section:

- Plot Plan (5215677-ME-PLP-001),
- Materials Design Philosophy (5215677-ME-REP-001).
- Mechanical Equipment List (5215677-ME-LST-001).

3.1. Site assessment

The existing AGS facility has 8 directionally drilled wells arranged in a line and one remote wellpad (ALD 1) that has been identified as the potential storage cavern. Available land areas within the existing plot are limited to the area to the East of the existing wellhead laydown area, the car park area to the west of ALD 1 and various smaller areas within the footprint that may require modification (e.g. the earth berm between the main CPA and the construction village area). The potential plot areas are illustrated in Figure 3-1 below.

Figure 3-1 - Potential Plot Areas

Areas A-J illustrated in the figure are discussed in the section below.

3.1.1. Site location selection

The potential areas for locating equipment are:

A- The existing car park adjacent to ALD 1

B- The semi-prepared land area to the North of the access road

C- Land on the East of CPA plot that currently houses a warehouse, blast cabin and brine settlement tank

D- Available area in construction village area

E- Small parcel of grassed land between ALD 1 and Cess Dale Drain

F- Parcel of wooded land between ALD 1 and Cess Dale Drain

G- Land to North of methanol and utilities plot on AGS

H- Berm between CPA and construction village

I- Semi-prepared land designated for AHS

J- Field area to East of CPA, not currently inside AGS plot or AHS planning application area

The proposed plot areas to be utilised are highlighted in orange in the figure, areas considered sub-optimal but within SSEs land ownership are highlighted red, and alternative areas outside of SSEs current ownership are highlighted blue.

Area A (~4140m^2) is a useful area as it is located close to the proposed hydrogen well, is inside the SSE boundary and has some existing vegetation screening from the main road. It does not have enough space to host the required equipment and therefore must be combined with other areas to provide sufficient footprint.

Area B (~1480m^2) is also a useful area adjacent to ALD 1 and is already semi-prepared, level ground without significant vegetation. It is bounded to the North by a landscaped berm.

Area C (~6860m^2) is located inside the CPA and is screened from the surrounding farmland by existing landscaped berms to the East and South, and by the main CPA to the West. Like area A, this does not have sufficient footprint for the equipment on its own but could be combined with other areas to provide sufficient space. The existing equipment within the area would require demolition and, in the case of the warehouse, the contents would require to be relocated to the existing warehouse / stores on site. This area also contains a drainage channel that will require to be filled in. It accommodates catastrophic failure of the brine and seawater settlement tanks; although the brine tank will be demolished, the seawater tank will remain and drainage for this will need to be accounted for.

Area D (~730m^2) is available for location of equipment that would benefit for being remote from operational plant, such as a control room or workshop / store.

Area E (~330m^2) is a small portion of land that would be available for use. It is grassed but is relatively small.

Area F (~780m^2) has a mixture of trees and grass but could be made available if required. The land is located next to ALD 1 and can also be accessed from the future AHS access road.

Area G (~1275m^2) is located inside the CPA but the hazardous area zones associated with the methanol tank are likely to rule this area out.

Area H (~2375m^2) currently has a berm that protects the construction village area from the main CPA. If this area was to be used, significant earthworks to create a retaining wall could be required and it is likely that the blast protection offered by the berm would have to be investigated.

Area I (~49,700m^2) is the main CPA area identified for the AHS project.

Area J (~83,900m^2) is the adjacent field to the East of the AGS site. This is a very large area that could accommodate the Pathfinder equipment but is outside of any current planning application and would require purchase.

3.1.2. Scheme description and layout

As stated in section above, four of the areas listed were selected for layout development.

The west plot (designated A above) will house the electrolysers and the plant associated with them, including water treatment plant, demineralised water storage, low pressure compression (to take the electrolyser output of circa 0.1barg up to circa 30barg), hydrogen buffer vessel (for storage of hydrogen produced by electrolysers while the compression plant is starting up and for the collection of hydrogen vented from other equipment items) and other utilities such as nitrogen and compressed air. The additional area to the North of the road (‘B’ above) will host an electrical compound for the Pathfinder project and a vehicle holding area that can be used for rig transport etc., in place of the car park area which will house the items listed here.

The East plot (designated C above) will house the high pressure compression plant, the Pathfinder cooling system, the dehydration & letdown plant and the OCGT. This will locate the majority of the high pressure, high noise equipment as far from the main road and Aldbrough village as possible, and the adjacent farmland will be screened by existing landscaping and earth berm walls. The construction village to the northeast of the site (Area D) can house a control room and workshop. These may be relocated at a later date to be collocated with the AHS project if this is desirable but equally, they are capable of permanent location in this area.

Each of the plot areas also contains access roads and laydown areas that allow access to all equipment plots. Significant temporary laydown for construction activities is available on the site of the proposed AHS plot (Area I), provided that there is no overlap between Pathfinder construction and AHS enabling works.

In addition to the equipment housed on each of the plots, rewatering equipment will be temporarily located on the ALD 1 wellpad during rewatering operations. This is a well understood operation and sufficient space is available for the rental equipment on the wellpad. An additional brine degassing and settlement tank will require to be located adjacent to the ALD 1 wellhead during first fill of the cavern with hydrogen. There is adequate space to house this on the wellpad, bearing in mind that this is not required at the same time as the rewatering equipment.

3.1.3. Pipeline routing

The division of equipment into East and west plots requires a high pressure pipe route between the East plot and ALD 1 for supply of compressed hydrogen from the HP compressors to the cavern (and vice versa for the supply to the OCGT from the cavern). A lower pressure hydrogen line from the LP compressor in the west to the HP compressor in East will also be required, as will cooling water and other utility lines. It is proposed that the route of the current above ground, high pressure natural gas line that feeds to/from ALD 1 is followed, subject to detailed engineering assessment of the routing.

In addition, a route is required for the supply of water from the borehole at the northeast of the site to the electrolysers (and ALD 1 during rewatering) at the southwest. There is also a requirement to connect ALD 1 to ALD 4z for the disposal of brine displaced by hydrogen filling of ALD 1.

The OCGT will also require a natural gas supply; it is envisaged that this will be taken from the existing plant gas pipeline reception facilities to the North of the existing control building and workshop.

3.1.4. Sensitive environmental features

To be developed by SSE Thermal.

3.1.5. Site assessment (topology, hydrology, flood, archaeology)

To be developed by SSE Thermal.

3.1.6. Planning Consenting Strategy

To be developed by SSE Thermal.

3.1.7. Laydown and site establishment

A site establishment plan will be developed in the next phase of the project.

The plan will include details of the site accommodation proposed including site offices and welfare units, hardstanding, access routes, parking, security and safe routes to/from and between the various worksites for use by all personnel involved in the project including visitors. The plan will also detail routing for deliveries and laydown areas for temporary storage to segregate materials and equipment.

The plan will be set out to minimise inconvenience to neighbours and minimise disruption to the ongoing operations of AGS. Typically, there should be dedicated, surfaced, permanently lit walkways around all areas normally accessible to pedestrians. In addition, the vehicular and working areas should be segregated from pedestrian areas by way of traffic control, barriers and fencing. It is expected that a traffic management plan will be established which will clearly display all walkways, which will also be included as part of the induction process. The traffic management plan shall be reviewed regularly and as any change occurs, this will be communicated to the workforce as part of the morning briefs.

Control of parking is a consideration as the planned work sites either do not have space for parking in the case of the wellsite or the access is not suitable for private vehicles for example along the hydrogen pipeline corridor. For this reason, a centralising parking policy supported by shuttle minibuses to take staff and operatives to and from the worksite will be considered.

As an existing operational site, much of the enabling infrastructure (e.g. roads and access) is already present but there is a requirement to clear existing plant areas to establish construction, fabrication & laydown areas and site welfare. Laydown will be established in the West and East of the site as well as a temporary facility in adjacent SSE owned land.

3.2. Site transport infrastructure

3.2.1. Construction phase

A Transportation, Shipping and Lifting Plan will be prepared in order that all deliveries to Pathfinder are adequately managed. This will set out the standard requirements to be met by all contractors and vendors and captured in their scope of supply.

A Construction Phase Traffic Management plan will be developed and submitted to the Planning Authority prior to the commencement of works on site.

It is expected that the selected Contractor will have overall responsibility for all aspects associated with Transportation, Shipping (for all deliveries likely to arrive via Hull) and Lifting such as: fastening design, calculations, fastening installation and coordination with shipping vessels. It is however, acceptable for this to be delegated to one specialist contractor who will transport and manage all packages from any fabrication facilities to the site location. This will be considered during FEED.

All vendor information will be reviewed thoroughly to ensure that the correct level and standard of information is present, and findings are embedded into the project design and that this is made available to the Transportation Contractor. This will enable comprehensive lifting studies detailing the weight of items to be lifted, weight distribution findings, capacity and reach of crane, size of attachments and lifting devices to be used, ground loading, maximum wind speeds, necessary exclusion zones. Activities involving all lifting works shall comply to the provisions of LOLER.

Regarding the general logistics of handling materials to the site, the project will consider various options of transport directly to the site. A key aim during FEED will be to establish what elements of the plant are proposed to be modularised and limit overall size to enable transport by road.

The base strategy for any shipping (likely to Hull) will be that goods and materials, including prefabricated equipment will be carried by road haulage to the site. The contractor will be required to develop transport routes from the port to site within the Transport Management Plan

3.2.2. Operations phase

The existing AGS site transport procedures and processes will be reviewed and revised to accommodate the introduction of the Hydrogen Pathfinder project.

There is currently a safe system of work in operation which is likely to be extended to incorporate the Pathfinder plant. This will be considered in detail during FEED.

3.3. Site Services and Utilities

3.3.1. Electrical & Grid Connection

AGS is supplied via an existing 132kV cable between the site and NPg Saltend substation. SSE have identified the cable will have sufficient capacity to meet both AGS and Pathfinder. This connection will remain, and no new grid connection is required. SSE have submitted an application to increase the capacity of the connection agreement with NPg.

Electrical supply for Pathfinder will be via a connection to the AGS 33kV electrical network, via an extension to the existing 33kV switchboard connected to a new 33/11kV transformer installed in an earmarked location within the existing switchyard. Technical feasibility of this option is to be confirmed [HOLD].

An 11kV switchboard will be supplied from the new 33/11kV transformer, in which the electrically powered process and mechanical equipment, and electrolysers, will be connected. Transformers will be used to step down the voltage to appropriate ratings for the equipment, and ancillary services. A connection between the existing 11kV switchboard to the new switchboard will allow the 6.8MVA backup supply to feed the Pathfinder essential services. There is sufficient capacity for this, however technical feasibility of this option is to be confirmed.

The OCGT will be connected to the existing 132kV busbars in the switchyard of AGS, allowing onsite demand to be met and for power to be exported to the grid.

Technical feasibility of the interface between AGS and Pathfinder, and Pathfinder electrical designs are to be determined at detailed design.

Leaching and water extraction pumps for AHS will be connected to the AGS network and may add an additional 5MW of demand. Based on the SSE assessment, this is not perceived as an issue.

The 132kV underground cable will be rerouted during the construction of the AHS CPA. During this relocation, the AGS site will only be supplied via the back-up grid connection and cannot be used to operate the electrolyser, OCGT, or other high power demand equipment. Outages will also be present during the interfacing of Pathfinder and AGS, and if cables are rerouted during construction of Pathfinder equipment.

3.3.2. Gas Connection

A supply of up to 9,914 kg/h of natural gas shall be required to run the OCGT on up to 100% natural gas.

The gas shall be supplied from the National Grid network. The connection to the Pathfinder facility shall tie-in between the existing AGS grid connection and it's dedicated fiscal metering. Fiscal metering and isolation shall also be required on the Pathfinder gas connection line.

Note, that if the AGS facility undergoes an outage, the natural gas supply to Pathfinder shall also undergo outage therefore impacting the ability of the OCGT to run on natural gas. This should be considered further in the design development.

3.3.3. Water supply

The Pathfinder facility shall be operated with a borehole water supply. The borehole water shall be used for rewatering of ALD 1 cavern as well as supplying the electrolysers, once treated and purified. Based on the rewatering design for ALD 4z, 144 m^3/h of borehole water shall be required for rewatering of ALD 1.

During normal operation, up to 9,967 m^3/h of borehole water shall be required by the water treatment plant in order to produce demineralised water to meet the maximum demand the electrolyser.

The borehole water quality analysis from Aldbrough Borehole Pump Specification [18] is provided in Appendix B.

Potable water, for supply to ancillary services such as welfare facilities, shall be produced by pre-treatment of borehole water. A nominal supply of up to 10 m^3/h potable water is currently assumed. Potable water demand shall be defined during the design of the facility [HOLD].

3.3.4. Waste and Discharges Management

New electrical transformers for Pathfinder will require a connection to an oily water drainage system. As there are operational transformers for AGS, connection to an existing system is the preferred option. If the system does not have sufficient capacity, a new system will be required. This is to be determined at detailed design.

3.4. Ground Conditions

3.4.1. Existing Site Knowledge and Further Investigation.

3.4.1.1. Site description

The site is located 2.5 km southeast of the village of Aldbrough, Hull and inside the existing SSE Hornsea facility (approximate National Grid Reference E:526468, N:436473). The planning boundary area is approximately 200 ha and within this area two zones have been identified, to the West an existing carpark, and to the East an existing stone surfaced laydown area. The zones are linked by an existing pipe corridor. A site visit was not undertaken by a geotechnical engineer for this report, a site visit is recommended prior to a specific intrusive Ground Investigation (GI).

3.4.1.2. Ground Conditions

There is limited GI data available across and surrounding the site. The BGS hold records of eighteen boreholes located within 500 m of the site boundary, but only three of these are publicly accessible. Two additional borehole records were provided to Atkins by the BGS on request. The boreholes generally confirm the BGS viewer mapped geology, recording Glacial Till deposits comprising a mixture of boulder clay and gravel and sand layers, overlying chalk bedrock. In addition, the BGS records an area of Alluvium overlying the Glacial Till in a band under the central part the existing SSE Hornsea site. The Alluvium may extend to some of the proposed development area.

A small site-specific GI is proposed, with in situ and laboratory testing, to classify the superficial deposits (and underlying bedrock if required) and determine geotechnical parameter values for foundation design of the proposed surface infrastructure. Specifically, any Alluvium recorded on site may present a risk if it is found to be highly compressible, as well as potentially representing a source of ground gas. The ground conditions present on site are typical of the area. Whilst ground risks will need to be managed through the engineering design, they are unlikely to have a significant impact on the feasibility of the project. Full utility plans will be required when planning the investigation. A geophysical survey may be also required to help identify drain locations prior to an intrusive GI. The service plans will also be required to design the proposed construction and site layouts.

3.4.1.3. Groundwater conditions

According to the Groundsure report the Glacial Till has been classified as a secondary undifferentiated aquifer and the Alluvium has been classified as a secondary A aquifer. The Rowe Chalk Formation is a principal aquifer.

The Groundsure report identified one groundwater abstraction from the underlying bedrock aquifer associated with the SSE Hornsea site. This abstraction has an annual volume of 500,000m^3. No potable groundwater abstractions or source protection zones were recorded within 500m of the site.

It is proposed that further assessment is undertaken prior to site development and that any subsurface engineering activities (including ground investigation) should be carried out in a way that avoids potential impact on these aquifers. In addition, a piling risk assessment should be carried out if any piling is likely to intercept the underlying chalk bedrock. Groundwater monitoring is recommended to be undertaken as part of an intrusive investigation to understand seasonal fluctuation and inform foundation design. Whilst groundwater risks will need to be managed through engineering design, they are unlikely to have a significant impact on the feasibility of the project.

3.4.1.4. Surface waters

A network of field drains crossing the site area can be seen on Ordnance Survey mapping. The site is also adjacent to the North Sea. No surface water abstractions were identified within 2km of the site. Care should be taken during construction (including pre-construction investigation etc.) and operation to avoid any potential impact on surface waters. Whilst surface water drains will need to be considered through the engineering design, at this stage it is considered unlikely that the surface waters identified at and around the site will have an impact on the feasibility of the project.

3.4.1.5. Flood risk

The Groundsure report does not indicate that the site proposed for surface development in is within a river or coastal flood zone.

The Groundsure report shows moderate groundwater flood risk for the wider site boundary area, with areas of high and moderate-high risk in the northwest of the site within the zone proposed for surface development.

The highest risk of surface water flooding (as a result of extreme rainfall events) across the site is recorded as 1 in 30 years, with a depth of greater than 1.0m. In addition, a spring is noted on the Groundsure report to the north-east of the site in close proximity to Ringbrough Farm.

If not already carried out, and subject to regulatory requirements, a flood risk assessment should be undertaken to determine any related potential constraints, as preliminary data indicates this to be a potential risk.

3.4.1.6. Historic land uses

Based on historical maps provided in the Groundsure report, most of the site has been used as farmland since at least 1854. However, the following potential sources of contamination have been identified:

- Three “unspecified tanks” shown on Aldbrough Sands beach (on site) near Ringbrough Farm.
- Ringbrough Farm was the historic location of an artillery battery during WWII. The battery and farm included barracks, guardroom, engine room, ammunition and the farm. Most of the buildings on site have either been lost to coastal erosion (approx. 2012) or demolished.

It is proposed that a detailed desk top study should be undertaken prior to site development to better define the risks posed by these potential sources. In addition, no geo-environmental testing has been reported for the site so it is advised that any GI should include consideration of potential contamination sources and receptors.

Based on the historical data provided within the Groundsure report, the historical sources of contamination that have been identified on the site are currently considered unlikely to negatively impact the overall feasibility of the project.

3.4.1.7. Unexploded Ordnance (UXO)

The Groundsure preliminary UXO risk assessment gives a high UXO risk across the wider site area. It is thought that this is due to a bombing decoy site which is mapped by Zetica to be located immediately to the North of the existing SSE site. The Groundsure preliminary UXO risk assessment recommends that a detailed UXO threat assessment desk top study is undertaken for the site. This is recommended prior to any ground-breaking activities on the site, including GI. Given that both development areas are within the existing developed site boundary, UXO is considered unlikely to impact the feasibility of the project.

3.4.2. General basis for foundation design

The foundation type selected in design will depend on a number of factors including the ground parameter values, applied loads and required settlement performance. It is understood that piled foundations were used for the larger structures on the existing SSE site.

The Alluvium, which may be present beneath the proposed development areas, poses a risk to be explored with site specific ground investigation. It may be that piled foundations or excavate and replace may be required if Alluvium is proved to be present. However, unless loads or foundation performance requirements are extremely onerous, the design of shallow or piled foundations would be routine in these ground conditions.

The presence of Alluvium and Glacial Till at the ground surface may impact trafficability of the site during GI or construction, particularly in wet weather or the winter months, due to its cohesive nature. Therefore, granular material may be required to construct temporary access roads during site works.

It is deemed unlikely that with our current understanding of the site and site conditions, that the geotechnical factors highlighted above will negatively impact the overall feasibility of the project. It is expected that the ground risks can be readily managed through the engineering design process.

3.5. Construction, Commissioning and Decommissioning

3.5.1. Constructability

An efficient and effective construction function is fundamental to the success of the Pathfinder project and the following key features need to be addressed:

- Safety of all aspects of onsite work.
- Construction work must minimise the impact to residents local to the project works.
- Construction work must be coordinated to ensure there is no disruption to the operation of the existing AGS plant with detailed consideration of potential SIMOPs. An initial SIMOPs assessment was carried out during the Layout Review and is included in Appendix C.
- Construction work must be planned to ensure that the completion date and commercial management of the project within agreed budgets is achieved.
- Supervisory ratio to be kept efficient and manageable.

To meet these main objectives, planning for construction will proceed during the next phase of work. With the preparatory works and the Aldbrough 1 cavern rewatering operation being critical to ensuring the facility is ready to operate in November 2025, the construction strategy and plan must be fully developed during FEED in readiness for the project execution phase.

Key issues, listed below have been identified as important to the success of the construction phase of this project:

- A target of zero health, safety and environmental impact approach to all aspects of the project.

- Early involvement of construction personnel for input into the FEED, ensuring a safe and considered approach to the implementation phase.
- All off-site works shall be completed and pre-commissioned as far as is possible / practical prior to delivery to site. For any remaining items a clearly defined scope of the completion work must be compiled and formally issued to the site team, prior to delivery.
- Ensuring that engineering continuity and support is always available to the fabrication and construction team.

A detailed analysis of the full scope of transportation from fabricators yards to site installation will be undertaken during FEED when a complete equipment scope of supply is determined and vendor packages decided. This will ensure that equipment and vehicles required to transport, lift and manoeuvre the fabricated items are suitable, available, checked prior to use, and capable of all the various operations that will need to be undertaken to safely and successfully deliver all module elements into their final positions.

Where practicable, construction will be modular, with as much off-site fabrication as possible. This is particularly important when considering both SIMOPs with the existing gas storage facility as well as construction activities such as welded piping, as shop fabricated welds in a controlled environment are preferrable to site welds where it is more difficult to control the conditions during welding.

3.5.1.1. Sequencing

Equipment is required at different times throughout the construction of the Hydrogen Pathfinder project; certain infrastructure needs to be in place and operational to allow for further site development to occur.

Priority will be given to establishing the Aldbrough 1 cavern rewatering system. This is to enable the Aldbrough 1 Cavern to be fully rewatered and ready to receive hydrogen from the electrolyser by November 2025. Natural gas will be exported from the cavern through existing AGS infrastructure. Natural gas connections from Aldbrough 1 to AGS will be removed once the cavern is fully rewatered. The wellpad area for Aldbrough 1 is sufficient to contain all temporary rewatering plant. The wellpad area will generally be maintained exclusively for all subsurface works throughout the project with construction of the Pathfinder plant in areas identified in the West and East of the site.

The construction sequencing for the surface infrastructure will be assessed in detail during the next phase of work, however generally the following is considered.

Pathfinder West Plot: Water Treatment, Electrolysis and compression plant

The water treatment, electrolysis and compression plant will likely be located within a vendor supplied package and enclosed in buildings adjacent to the Aldbrough 1 wellpad.

The packages will likely be brought into the site pre-assembled and installed in its proposed location. The connecting pipework will be installed once the other plant items are in place. Access to the equipment for component removal will be required; this is likely to require laydown and vehicular access to the front of the enclosures. The plot area for the electrolysis and compression plant is currently a car park facility and therefore it will require foundation preparation. This is likely to commence in parallel with cavern rewatering operations.

Construction of the West Plot will proceed alongside the rewatering of Aldbrough 1. The primary aim is to ensure that Hydrogen is available for injection into the cavern by November 2025.

Prior to connection of the hydrogen supply to the cavern, the existing gas well will be relined and recompleted for hydrogen operation. Final connections of hydrogen supply will be made once the rewatering facilities are cleared and well workover rigs and equipment are removed.

Given the potential for simultaneous construction operations. A detailed construction sequence for this area of plant will be developed during the next phase of work. This will be developed alongside the detailed rewatering plan accounting for the assembly and connection of the temporary rewatering facilities

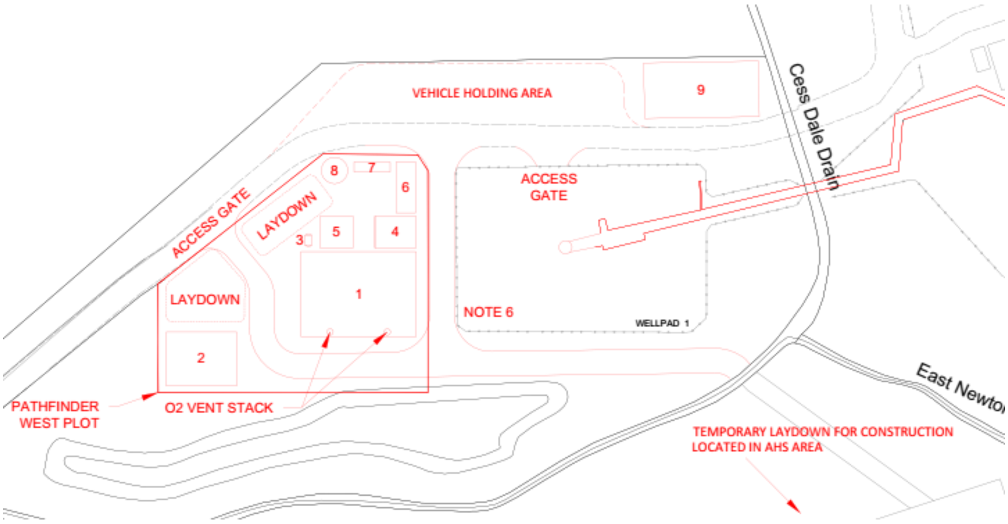

Figure 3-2 – Pathfinder West Plot

Pathfinder East Plot: Hydrogen Conditioning and Hydrogen OCGT

The hydrogen conditioning and hydrogen OCGT plant will likely be located within vendor supplied packages and enclosed in buildings adjacent to the existing gas cavern wellhead systems.

The packages will likely be brought into the site pre-assembled and installed in its proposed location. Hydrogen will be transported west to East through a new HP pipe corridor. The connecting pipework will be established prior to commissioning of the conditioning plant and OCGT. The Pathfinder East plot is currently spare land and used as a temporary facility for gas storage well workovers and therefore it will require clearing and foundation preparation.

Construction of the East Plot will proceed alongside the rewatering of Aldbrough 1 and construction of the West Plot. The primary aim is to ensure that the OCGT is ready to receive hydrogen from the cavern by April 2026.

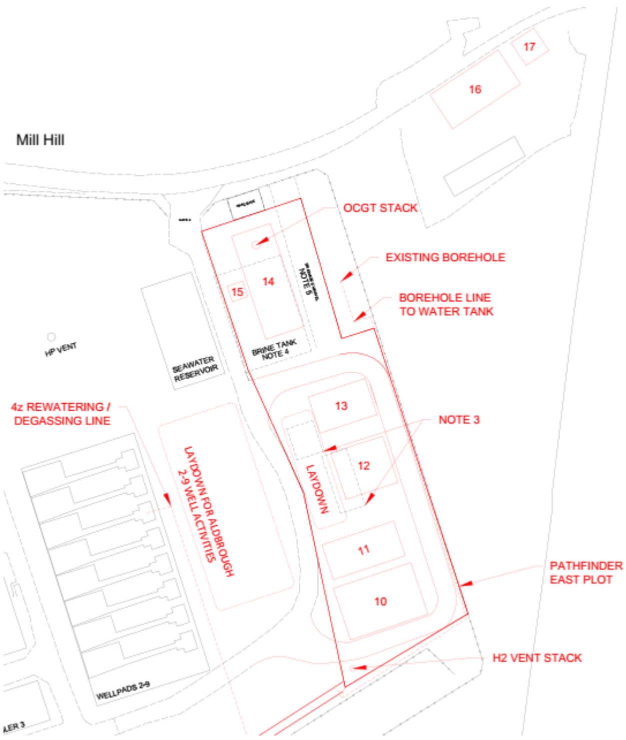

Figure 3-3 – Pathfinder East Plot

3.5.2. Commissioning

All plant will be commissioned to OEM guidelines and specifications. The Commissioning strategy will be developed further during the next phases of the project and key activities detailed in the project schedule. However, the following key works have been identified during the Concept Development.

3.5.2.1. Commissioning of Aldbrough 1 for Hydrogen Storage

The Aldbrough 1 well will be relined and recompleted to ensure its suitability to transfer hydrogen to the cavern. The key commissioning works for the cavern will be the performance of a Mechanical Integrity Test (MIT) as defined in Section 2.3.3 of this report as this will confirm suitability of the cavern / LCCS to permit hydrogen injection.

3.5.2.2. OCGT Hydrogen Commissioning

The OCGT will undergo commissioning and performance testing as per OEM requirements. Typically for development of an OCGT, a series of performance and reliability tests would be completed to verify the plant is capable of achieving its commercial and contractual obligations. Consideration during the next phase of the project will be given to the requirement for further testing bespoke to firing on various blends (up to 100%) of hydrogen.

3.5.3. Decommissioning

A decommissioning strategy will be developed in the next phase of the project. The decommissioning approach will be in line with the existing plans for the Aldbrough Gas Storage facility. Particular attention will be given to the requirements for monitoring of the cavern in a post operation, rewatered state.

4. References

[1]	Oil and Gas UK, “Guidelines for the Suspension & Abandonment of Wells, Issue 5,” Oil and Gas UK, 2015
[2]	F. a. K. J. Crotogino, “Cavern Well Abandonment Techniques Guidelines Manual,” KBB Underground Technologies / SMRI, Hannover, 2006.
[3]	5215677-MD-TCQ-001, Request for Information - Electrolyser and OCGT, 20/07/2022.
[4]	Aldbrough_1_84308, ECHO-LOG Aldbrough 1, 16-5-2018, SOCON
[5]	Aldbrough_4z_204309, ECHO-LOG Aldbrough 4z, SOCON
[6]	DIN, “DIN EN 62676 Video surveillance systems for use in security applications,” 2016.
[7]	5215677-MD-TCQ-004, Request for Information –Availability & Turndown Requirements, 14/09/2022
[8]	“Commission Implementing Decision of 9 October 2014 establishing best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions, for the refining of mineral oil and gas”.
[9]	European Commission, “Reference Document on the application of BAT to Industrial Cooling Systems,” 2001.
[10]	European Commisson, “Reference Document on Best Available Techniques for Energy Efficiency,” 2009.
[11]	ISO 22734-1 Hydrogen Generators using Water Electrolysis Process-Part 1:Industrial and commercial applications
[12]	NFPA 2 Hydrogen Technologies Code
[13]	“Health and Safety at Work etc Act 1974,” [Online]. Available: https://www.hse.gov.uk/legislation/hswa.htm. [Accessed 2022].
[14]	The Planning (Hazardous Substances) Regulations 2015, U.K. Government.
[15]	The industry standard Hazardous Area Classification of Natural Gas installations, IGEM/SR/25 Edition 2
[16]	Hazardous area classification of installations using Hydrogen or blends up to 20% by volume Hydrogen in Natural Gas, IGEM/SR/25 Hydrogen supplement, IGEM/TSP/21/480, Draft for comment 2022.
[17]	“Model code of safe practice, Part 15, Area classification for installations handling flammable fluids, 4th Edition,” Energy Institute.
[18]	SSE-5182233-601-SPC-001, Aldbrough Borehole Pump Supply and Installation Specification (2019)
[19]	SSE-5138580-600-RPT-0002 Rev P0, Aldbrough Surface Plant Study, Study Basis (2015)
[20]	Haselkuss et al., “Combined MIT – Nachweis der Gasdichtheit der Bohrung Zuidwending A8A im Rahmen des Demonstrationsprojektes zur Wasserstoffspeicherung,” 2022.

Appendix A. Applicable Codes, Standards and Guidance Documents

Standards – General

Title	Reference
Hydrogen Technologies Code	NFPA 2
Hydrogen Piping and Pipelines	ASME B31-12
Evaluation of Pipeline and Pressure Vessel Steels for Resistance to Hydrogen Induced Cracking	NACE TM0284
	API RP 934-C
Basic Considerations for the safety of Hydrogen systems	PD ISO/TR 15916:2015
Gas Safety (Management) Regs	UK Statutory Instruments 1996 No. 551

Standards – General

Title	Reference
BASIS OF STRUCTURAL DESIGN	BS EN 1990:2002+A1:2005 Incorporating corrigenda December 2008 and April 2010

Standards – Client Standards

Title	Reference
DESIGN STANDARD FOR CIVIL AND STRUCTURAL ENGINEERING (SSE)	PR-SSE-GEN-SHE-012-003-053
FIRE PROTECTION	PR-GEN-SHE-012-003-061
CORROSION PROTECTION OF STEELWORK	PR-GEN-SHE-012-003-05 BS EN ISO 14713-1
SECURITY FENCING	SP-NET-CIV-505

Standards – Civil Standards

Title	Reference

FENCES	BS 1722 (ALL PARTS)
SHW	Highway Agency Manual of Contract Documents for Highways Works Volume 1
DMRB	Highways Agency Design Manual for Roads and Bridges.

Standards – Concrete

Title	Reference
DESIGN OF CONCRETE STRUCTURES Part 1-1: General rules and rules for buildings	BS EN 1992-1-1:2004+A1:2014 Incorporating corrigenda January 2008, November 2010 and January 2014
DESIGN OF CONCRETE STRUCTURES Part 1-2: General rules — Structural fire design	BS EN 1992-1-2:2004 Incorporating corrigendum July 2008
DESIGN OF CONCRETE STRUCTURES Part 3: Liquid retaining and containment structures	BS EN 1992-3:2006
	NA to BS EN 1992-3:2006
CODE OF PRACTICE for protection of below ground structures against water from the ground	BS 8102:2009
Design of Concrete Structures for retaining aqueous liquids, Section 9	BS 8007
CONCRETE – COMPLEMENTARY BRITISH STANDARD TO BS EN 206 Part 1: Method of specifying and guidance for the specifier	BS 8500-1:2015+A1:2016 Incorporating corrigendum No. 1
CONCRETE – COMPLEMENTARY BRITISH STANDARD TO BS EN 206 Part 2: Specification for constituent materials and concrete	BS 8500-2:2015+A1:2016
Scheduling, dimensioning, bending and cutting of steel reinforcement for concrete — Specification	BS 8666:2005 Incorporating Amendment No. 1
Concrete — Specification, performance, production and conformity	BS EN 206:2013 Incorporating corrigendum May 2014
Concrete Society. Concrete Industrial Ground Floors: A guide to design and construction.	CS TR 34
Construct: National Structural Concrete Specification	NSCS

Standards – Steel

Title	Reference
DESIGN OF STEEL STRUCTURES Part 1-1: General rules and rules for buildings	BS EN 1993-1-1:2005+A1:2014 Incorporating corrigenda February 2006 and April 2009
	NA+A1:2014 to BS EN 1993-1-1:2005+A1:2014

DESIGN OF STEEL STRUCTURES Part 1-2: General rules — Structural fire design	BS EN 1993-1-2:2005 Incorporating corrigenda December 2005, September 2006 and March 2009
DESIGN OF STEEL STRUCTURES Part 1-3: General rules — Supplementary rules for cold-formed members and sheeting	BS EN 1993-1-3:2006 Incorporating corrigendum November 2009
DESIGN OF STEEL STRUCTURES Part 1-8: Design of joints	BS EN 1993-1-8:2005 Incorporating corrigenda December 2005, September 2006, July 2009 and August 2010
DESIGN OF STEEL STRUCTURES Part 1-9: Fatigue	BS EN 1993-1-9:2005 Incorporating corrigenda December 2005, September 2006 and April 2009
DESIGN OF STEEL STRUCTURES Part 1-10: Material toughness and through-thickness properties	BS EN 1993-1-10:2005 Incorporating corrigenda December 2005, September 2006 and March 2009
	NA to BS EN 1993-1-10:2005
DESIGN OF STEEL STRUCTURES Part 1-11: Design of structures with tension components	BS EN 1993-1-11:2006 Incorporating corrigendum April 2009
DESIGN OF STEEL STRUCTURES Part 6: Crane supporting structures	BS EN 1993-6:2007 Incorporating corrigendum July 2009
Hot rolled products of structural steels — Part 2: Technical delivery conditions for non-alloy structural steels	BS EN 10025-2:2004
Hot finished structural hollow sections of non-alloy and fine grain steels — Part 1: Technical delivery conditions	BS EN 10210-1:2006
Paints and varnishes. Corrosion protection of steel structures by protective paint systems	BS EN ISO 12944
Zinc Coatings. Guidelines and recommendations for the protection against corrosion of iron and steel in structures.	BS EN ISO 14713
Hot dip galvanised coatings on fabricated iron and steel articles	BS EN ISO 1461
BCSA National Structural Steelwork Specification	NSSS

Standards - Geotechnical / Foundations

Title	Reference
GEOTECHNICAL DESIGN Part 1: General rules	BS EN 1997-1:2004+A1:2013 Incorporating corrigendum February 2009
Code of practice for earth retaining structures	BS 8002:2015

	Incorporating Amendments, No 1 and 2 and Corrigendum No 1
Code of practice for foundations	BS 8004:2015
Code of Practice for foundations for machinery. Foundations for reciprocating machines	CP 2012
Machine Foundations: Flexible structures that support machines with rotating elements.	DIN 4024
Code of practice for protection of below ground structures against water from the ground	BS 8102:2009
Concrete in Aggressive Ground	BRE Special Digest 1
Code of practice for earthworks	BS 6031
Characterization of waste. Sampling	BS 14899
Characterization of Waste. Terminology	BS 13965
Control of water pollution from construction sites	CIRIA C648
Institution of Civil Engineers Specification for Piling and Embedded Retaining Walls	ICE SPERW

Standards – Highways and Drainage

Title	Reference
Foul Drainage	Sewers for Adoption, Latest Edition
Surface and Roof Drainage	MCHW Volume 1 SHW, Series 500
Design Manual for Roads and Bridges	Highways Agency DMRB.
Specification of Highway Works	Highways Agency SHW
The SuDS Manual	CIRIA C753
Separator Systems for light liquids	BS EN 858
Drain and sewer systems outside buildings	BS EN 752

Standards – Pipelines

Title	Reference

Steel pipelines for high pressure gas transmission	IGEM/TD/1 Edition 6
High pressure Hydrogen pipelines	IGEM/TD/1 Edition 6 Supplement 2
Pipeline systems. Steel pipelines on land - code of practice	PD 8010-1:2015 + A1:2016
Hydrogen Pipeline Systems	EIGA IGC Doc 121/14
Hydrogen Piping and Pipelines	ASME B31:12

Standards – Electrical

Title	Reference
IET Wiring Regulations – Requirements for Electrical Installations	BS 7671
Earthing Standards	BS 7430
Operation of Electrical Installations	BS EN 50110
Electromagnetic Compatibility (EMC)	BS EN 61000
Lightning Protection	BS EN/IEC 62305
Uninterruptible Power Systems	IEC 62040
Explosive Atmospheres - Equipment. General Requirements	BS EN IEC 60079-0:2018

Standards – Wells

Title	Reference
Specification for Wellhead and Christmas Tree Equipment	API 6A
Specification for casing and tubing	API 5CT
Downhole equipment – packers and bridge plugs	BS EN ISO 14310
Downhole equipment – lock mandrels and landing nipples	BS EN ISO 16070
Design, installation, repair and operation of Subsurface Safety Valve Systems.	API RP 14B

Although some standards may not be directly applicable to hydrogen service they will be used as a basis on which to develop the design with deviations for H2 clearly stipulated.

Appendix B. Borehole Water Quality

Analytical Parameter (Water Analysis)	Units	LOD	Sample 1	Sample 2	Sample 3
pH	pH Units	N/A	7.2	7.2	7.4
Electrical Conductivity at 20 °C	µS/cm	10	3800	3900	3900
Total Cyanide	µg/l	10	< 10	< 10	< 10
Sulphate as SO4	mg/l	0.045	640	575	703
Chloride	mg/l	0.15	820	830	840
Total Phosphate as PO4	µg/l	62	86	80	86
Ammonium as NH4	µg/l	15	1300	1200	1400
Dissolved Organic Carbon (DOC)	mg/l	0.1	2.61	1.86	1.85
Total Organic Carbon (TOC)	mg/l	0.1	2.45	3	2.37
Nitrate as N	mg/l	0.01	0.51	0.43	0.48
Nitrate as NO3	mg/l	0.05	2.24	1.92	2.13
Nitrite as N	µg/l	1	5	1.1	4.9
Nitrite as NO2	µg/l	5	16	< 5.0	16
Alkalinity	mgCaCO3/l	3	480	210	52
Alkalinity	mgCaCO3/l	3	500	170	53
Total Suspended Solids	mg/l	2	25	< 2.0	5
Bromine	mg/l	0.05	0.27	0.31	< 0.05
Bicarbonate	mgHCO3/l	10	< 10	< 10	< 10
Lithium (dissolved)	µg/l	1	22	22	19
Aluminium (dissolved)	µg/l	1	4.5	3.2	< 1.0
Arsenic (dissolved)	µg/l	0.15	1.02	0.7	0.54
Barium (dissolved)	µg/l	0.06	11	12	10
Boron (dissolved)	µg/l	10	500	510	520
Cadmium (dissolved)	µg/l	0.02	< 0.02	< 0.02	< 0.02
Calcium (dissolved)	mg/l	0.012	150	190	140
Chromium (dissolved)	µg/l	0.2	< 0.2	0.3	< 0.2
Copper (dissolved)	µg/l	0.5	8.1	6.4	2.4
Iron (dissolved)	mg/l	0.004	1	0.088	0.022
Lead (dissolved)	µg/l	0.2	0.2	< 0.2	< 0.2

Magnesium (dissolved)	mg/l	0.005	82	95	86
Manganese (dissolved)	µg/l	0.05	20	32	16
Mercury (dissolved)	µg/l	0.05	< 0.05	< 0.05	< 0.05
Molybdenum (dissolved)	µg/l	0.05	1.4	1.1	1.2
Nickel (dissolved)	µg/l	0.5	0.7	1.4	1.1
Potassium (dissolved)	mg/l	0.025	32	32	30
Selenium (dissolved)	µg/l	0.6	10	16	16
Sodium (dissolved)	mg/l	0.01	550	550	570
Strontium (dissolved)	µg/l	1	6900	8300	10000
Tin (dissolved)	µg/l	0.2	< 0.20	< 0.20	< 0.20
Zinc (dissolved)	µg/l	0.5	44	62	51

Appendix C. SIMOPS

Aldbrough Pathfinder Project SIMOPS Matrix

Key:

X - Simultaneous activities NOT permitted.
C - Activity permitted with caveats / limitations (e.g. additional controls)
P - Activities can continue subject to normal RA & PTW controls.
ER - Emergency Response Plan applies.
N/A - Simultaneous activities not applicable/possible.

Note: A specific Risk Assessment must also be undertaken and its findings implemented.

Project Activity	Operating Asset	Operations Related Activities	General Operation duties and checks in Ald 1 area (1)	General Maintenance (e.g. ESD checks) (2)	General Operation duties and checks in Ald 2-9 area (3)	Routine Workover on Ald 1 [NOTE 1] (4)	Live Process Equipment (5)	Vehicle Access (6)	Site Evacuation (7)	Project activities not related to Accelerator Project in vicinity [NOTE 2] (8)	AHS Project activities (9)	Dry recompletion on well (10)	end of life rewatering (11)	Routine Workover on Ald 2-9 (12)	Snubbing in of Ald 1rewatering equipment (13)	Ald 1 rewatering (14)	COMMENTS
Electrolyser & Compressor Construction on West Plot																	
Pile driving for new buildings	A		P	P	P	N/A	P	C1	ER	P	N/A	C1	P	P	X	C2	Check exisitng equipment for sensitivity to vibration / vibration trips
Civil construction of pile caps	B		P	P	P	N/A	P	C1	ER	P	N/A	C1	P	P	X	C2	Check exisitng equipment for sensitivity to vibration / vibration trips
Foundation construction	C		P	P	P	N/A	P	C1	ER	P	N/A	C1	P	P	X	C2	Check exisitng equipment for sensitivity to vibration / vibration trips
Mechanical erection, lifting activities	D		P	P	P	N/A	P	C1	ER	P	N/A	C1	P	P	X	C2	
Pipe installation - hot work/ field welds	E		P	P	P	N/A	P	C1	ER	P	N/A	C1	P	P	X	C2	
OCGT & Compressor Construction on East Plot																	
Pile driving for new buildings	F		P	P	P	N/A	C3	C1	C4	P	N/A	X	X	P	P	C5	Check exisitng equipment for sensitivity to vibration / vibration trips
Civil construction of pile caps	G		P	P	P	N/A	C3	C1	C4	P	N/A	X	X	P	P	C5	Check exisitng equipment for sensitivity to vibration / vibration trips
Foundation construction	H		P	P	P	N/A	C3	C1	C4	P	N/A	X	X	P	P	P	Check exisitng equipment for sensitivity to vibration / vibration trips
Mechanical erection, lifting activities	I		P	P	P	N/A	C3	C1	C4	P	N/A	X	X	P	P	C6	
Pipe installation - hot work/ field welds	J		P	P	P	N/A	C3	C1	C4	P	N/A	X	X	P	P	P	Check if hot work prohibition map ends at access road rather than fenc line
HP Piping Corridor Construction																	
Existing Piping Destruct - Cold cut & remvove	K		P	P	P	N/A	P	P	ER	P	N/A	P	P	P	N/A	N/A	SIMOPS with Ald1 rewatering not possible - existing equip required for rewatering
Pipe support steelwork erection	L		P	P	P	N/A	P	P	ER	P	N/A	P	P	P	N/A	N/A	SIMOPS with Ald1 rewatering not possible - existing equip required for rewatering
Pipe installation - lifting	M		P	P	P	N/A	P	P	ER	P	N/A	P	P	P	N/A	N/A	SIMOPS with Ald1 rewatering not possible - existing equip required for rewatering
Pipe installation - hot work/ field welds	N		P	P	P	N/A	P	P	ER	P	N/A	P	P	P	N/A	N/A	SIMOPS with Ald1 rewatering not possible - existing equip required for rewatering
Interface with Existing Plant																	
Aldbrough #1 Rewatering equipment (inc. borehole tie-in)	O		N/A	P	P	N/A	P	P	P	P	N/A	P	X	P	N/A	N/A	
Aldbrough #1 dewatering equipment (inc. 4z tie-in)	P		N/A	P	P	N/A	P	P	P	P	N/A	P	P	P	N/A	N/A	
Utilities tie-ins	Q		P	P	P	N/A	P	P	P	P	N/A	P	P	P	N/A	N/A	
NG tie-in for OCGT supply	R		X	P	X	N/A	P	C7	P	P	N/A	P	X	P	N/A	N/A	
Electrical tie- ins	S		C8	P	C8	N/A	P	P	P	P	N/A	P	P	P	N/A	N/A	
Venting of O2 (Electrolyser), H2 or NG (during rewatering)	T		P	C9	P	N/A	P	P	P	C9	N/A	P	P	P	N/A	P	
General Project Activities																	
Radiography	U		X	X	X	N/A	P	X	ER	X	N/A	X	X	X	X	X	
Hydrotesting new piping	V		X	X	X	N/A	P	X	ER	X	N/A	X	X	X	X	X	
Excavations	W		P	P	P	N/A	P	P	ER	P	N/A	P	P	P	P	P	
Cable pulling activities	X		P	P	P	N/A	P	P	ER	P	N/A	P	P	P	P	P	
Electrical equipment installation	Y		P	P	P	N/A	P	P	ER	P	N/A	P	P	P	P	P	
I&C installation	Z		P	P	P	N/A	P	P	ER	P	N/A	P	P	P	P	P	
Secondary steel installation - lifting activities	AA		P	P	P	N/A	C6	P	ER	P	N/A	P	P	P	P	P	
Vehicle Movements	AB		P	P	P	N/A	P	P	ER	P	N/A	P	P	P	P	P	

Notes	
C1	Consideration of provision for long vehicle turning circle and access required
C2	Permitted except for interventions / certain activities which would cause halts to operations
C3	Potential for reroute of electrical equipment
C4	Ensure adequate escape routes from main site remain during construction activities
C5	Borehole water piping & supports would require qualification for piling loads
C6	Limitations on lifting over live plant; additional safeguards anticipated
C7	Limitations on vehicular access anticipated in area
C8	Outages likely required for tie-ins, limiting general operation
C9	Exclusion zones created by vents may prohibt access where it was previously permitted
1	Aldbrough 1 will not be in natural gas operation as part of this project
2	Upgrading of DCS & ESD system in May '24 may require site hibernation period of approx 2-3 wks

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