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TECHNICAL MEMORANDUM

TO	Francesco Di Stefano, Environment Agency
FROM	Environmental Resources Management Limited
DATE	11th November 2025
REFERENCE	0792240, Application Reference EPR/CP3225SW/A001
SUBJECT	Aldbrough Hydrogen Pathfinder Permit Application – RFI Response – Temporary Degassing Operations

Response to EA Duly Making – Brine degassing operations

SSE Hornsea Limited (SSE) submitted a bespoke environmental permit application for the Aldbrough Hydrogen Pathfinder (AHP) facility, located at SSE's Albrough Gas Storage Site at Garton Road, East Riding of Yorkshire on 1st July 2025.

Following submission, the Environment Agency issued an information request as part of their duly making checks. Part of the request related to the **temporary brine degassing operations associated with cavern dewatering**. The specific requirements were listed under Point 4 of the request:

- Provide an estimate or assessment of the likely volumes of waste gas produced, including how these volumes may change over time.
- Provide an assessment of BAT with regards to the management of these waste gases, supported by cost-benefit assessment of environmental damage, where warranted (see guidance in the following notes). The limited information suggests that these will be allowed to freely vent from the 'open' tanks, unless H_2S is present. Without understanding the likely gas volumes, it is unclear whether the application meets BAT.
- Air Emissions Risk Assessment for the emissions associated with the degassing and flaring operations, following our guidance Air emissions risk assessment for your environmental permit - GOV.UK.

This technical note has been prepared by ERM using information provided by SSE, to provide the information requested by the Environment Agency.

1. INTRODUCTION

Located at SSE's AGS site, ALD1 is currently an operational natural gas storage cavern. This cavern will be converted to store hydrogen for the proposed AHP installation. This will be achieved by rewatering with abstracted groundwater to displace the existing natural gas contents during for the first 12 months of operation. The natural gas displaced by this water will be exported to the process plant manifold via existing plant systems before being temporarily stored in one of the other operational caverns at the AGS site prior to export to the natural gas grid.

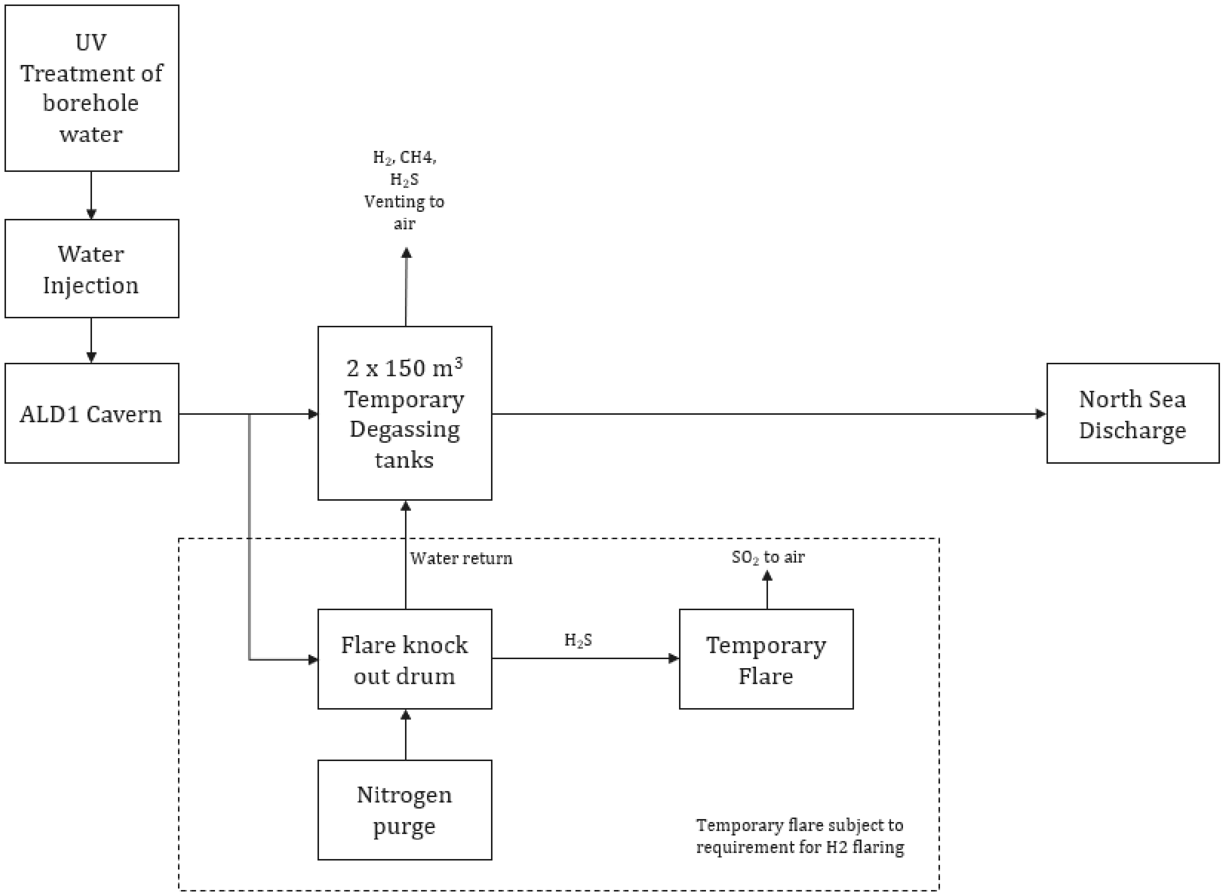
Dewatering will be achieved through the injection of hydrogen to displace water from the cavern. The contents of the cavern (up to 300,000 m^3 water) will be displaced with hydrogen generated from the electrolyser over a period of approximately 12 months.

Hydrogen produced by the electrolyser will be transferred via a new pipeline to the ALD1 cavern. Water displaced from the cavern will discharge to the North Sea using an existing (reinstated) underground pipeline.

The water displaced from ALD1 during the dewatering process may contain dissolved gases (hydrogen, natural gas and potentially H_2S), which will require separation prior to discharge of the water to the North Sea. Interconnected open-top tanks are proposed to allow for degassing of the produced water at atmospheric temperature and pressure.

The following figure illustrates the rewatering and dewatering process, and this is further described in the following sections. The location of the temporary flare and degassing tanks is shown in Attachment A.

FIGURE 1.1 – HIGH LEVEL SCHEMATIC OF REWATERING & DEWATERING PROCESS



2. DEGASSING TANKS

Two 150 m^3 above ground interconnected open top tanks will be installed to provide residence time for degassing of the cavern discharge. The intent is to allow any dissolved gases (hydrogen, methane/natural gas, H_2S) to disperse safely to atmosphere.

2.1 FREQUENCY AND DURATION

The dewatering operation is expected to take place during the first 12 months of operation, as the injection of hydrogen displaces water from the cavern.

2.2 AIR EMISSIONS RISK ASSESSMENT

Sulphate bearing minerals in the cavern have the potential to react with H_2 gas in the presence of bacteria promoting biotic reactions to form methane or H_2S. As such, it has been identified that the water discharge from the cavern may contain dissolved gases, including hydrogen, natural gas, and potentially H_2S. UV treatment of the water used for cavern rewatering is proposed to minimise bacterial activity in the cavern, and therefore minimise formation of methane and H_2S.

Gas solubility levels reduce with an increase in salt concentration in the brine. Industrial experience reports that, typically, withdrawn brine only releases gas towards the end of dewatering. It is anticipated that the levels of dissolved gas produced will be negligible during initial dewatering, and it is entirely likely that there will be negligible dissolved gases for the full duration of the dewatering process.

2.2.1 H_2S EMISSIONS

As noted above, H_2S may be present in the cavern discharge. It is known that several hydrogen storage caverns have been operational for over ~40 years, with no known reported concerns with H_2S production. Therefore, it is credible that no or negligible H_2S formation will occur.

The concentration of dissolved gas in the cavern discharge will be dependent on the depth of the brine from the gas/brine interface, the time of exposure, and the degree of mixing within the cavern.

In normal operations, no or negligible H_2S emissions are expected from the degassing tanks. Monitoring of H_2S local to the degassing tanks will be installed. If elevated levels of H_2S (e.g. >1 ppm) are detected, cavern dewatering operation will cease, and the discharge will be rerouted to a rental flare package to route the gases to flare. (See Section 3 for details of flare).

The EA's H1 tool[1] has been used to assess the potential of emissions to air from the degassing tanks (see Attachment B). It has been assumed that the H_2S release concentration is 1.4 mg/m^3 (1 ppm) from each tank. An effective height of 0 m has been used (tanks are expected to be 10 x 5 x 3 m). An operating mode of 100% has been used as a worst case. Since there are two tanks, the Process Contributions (PCs) for each source have been added together. The results of the H1 assessment show that:

- The short-term PC is less than 10% of the short-term environmental standard.
- The long-term PC is less than 1% of the long-term environmental standard.

As such, H_2S emissions from the degassing tanks are considered to be **insignificant** and no further modelling is required.

[1] Air emissions risk assessment for your environmental permit - GOV.UK

The odour threshold[2] for H_2S is approximately 0.011 ppm. Since the H_2S concentration local to the degassing tanks may be up to 1 ppm, there is the potential for odour nuisance off site. As such, an Odour Management Plan has been developed for these operations (see Attachment C) to proactively address and mitigate H_2S emissions. It should be noted that odour emissions are not expected to be continuous and are more likely to occur towards the end of the dewatering operations where there may be a higher probability of H_2S formation.

2.2.2 NATURAL GAS & HYDROGEN EMISSIONS

As hydrogen is stored in the cavern and displaces the brine contents of the cavern, there is the potential for hydrogen gas saturation in the discharge. Hydrogen gas saturation is dependent on the depth of the brine production string and the time for which the gas-brine interface is in contact. It is expected that the quantity of dissolved hydrogen in the produced dewatering stream during the initial stages of dewatering will be negligible due to diffusion limitations of the gas dissolved into the brine.

Small volumes of natural gas may remain trapped in the cavern following the rewatering process, that may become entrained in the discharge. It is expected that the quantities of dissolved natural gas in the produced dewatering stream during the initial stages of dewatering will be negligible due to the diffusion limitations of the gas dissolving into the brine.

Hydrogen and methane do not have Air Quality Standard or Environmental Assessment Levels, therefore are not assessed further.

3. TEMPORARY FLARE

As noted in Section 2.2.1, H_2S monitoring will be installed local to the brine degassing tanks. If elevated levels of H_2S (e.g. >1 ppm) are detected, an Emergency shutdown (ESD) of the dewatering process will take place. This will stop booster and HP pumps, stop the injection of H_2, shut in all wellhead ESD valves and stop the brine discharge pumps to allow a temporary H_2S flare package to be connected and employed.

The purpose of the temporary flare is to prevent venting of H_2S to atmosphere above 1 ppm. Gas to the flare will pass through a Knock Out (KO) drum to remove liquid prior to flaring of the gases. Any liquid collected in the KO drum will be returned to the degassing tank.

It is expected that the flare will maintain a continuous pilot supplied by bottled propane. Bottled nitrogen will be used to purge the KO drum/flare prior to operation. The temporary flare will have manual ignition and will have a local control panel to monitor pilot status.

3.1 FREQUENCY AND DURATION

As noted in Section 2.1 above, it is expected that the levels of dissolved gas produced will be negligible during initial dewatering. Use of the temporary flare is likely limited to the later stages of dewatering when lower boundaries of the cavern are being drawn from.

[2] Hydrogen sulphide: toxicological overview - GOV.UK

3.2 AIR EMISSIONS RISK ASSESSMENT

If flaring is required, H_2S in the flare gas will be oxidised primarily to sulphur dioxide (SO_2). The quantity of SO_2 released will depend on:

- The sulphur content of the gas
- The volume of gas flared
- Combustion efficiency

The EA's H1 tool[3] has been used to assess the potential emissions to air from the temporary flare. Given the nature of the release is via a flare rather than a point source such as a stack, the Alberta methodology[4] has been used to calculate gas flow and effective height of the flare.

Gas production rates have been based on information received from industry, based on experience of dewatering caverns. SO_2 emissions have been calculated from these H_2S production rates. Background SO_2 concentrations are derived from APIS[5].

An operating mode of 100% has been used as a worst case.

A summary of the parameters used in the H1 tool is provided in Attachment D. The H1 tool is provided in Attachment B.

The results of the H1 assessment show that:

- The short-term PC is more than 10% of the short-term environmental standard.
- The long-term PC is more than 1% of the long-term environmental standard.

As such, the SO_2 emissions from the temporary flare progressed to the second stage of screening.

In the second stage of screening:

- The short-term PEC is less than 20% of the short-term environmental standard
- The long-term PEC is less than 70% of the long-term environmental standard

As such, the SO_2 emissions from the temporary flare are considered to be **insignificant** and no further modelling is required.

The short-term and long-term PCs are also significantly lower than the Air Quality Standards presented in Table 3.1.

TABLE 3.1 – AIR QUALITY STANDARDS FOR SO_2

Averaging Period	Limit	Permitted Exceedances
Hourly Mean	350 µg/m^3	No more than 24 (1-hour periods) per year
24 Hour Mean	125 µg/m^3	No more than 3 (24-hour periods) per year

[3] Air emissions risk assessment for your environmental permit - GOV.UK
[4] Directive 060: Upstream Petroleum Industry Flaring, Incinerating, and Venting
[5] APIS app | APIS [Accessed 04.11.25]

Concentrations are within the 1-hour and 24-hour mean standards and are therefore not considered to be significant. Although the dewatering activity will take place during the first 12 months of operation, it is not anticipated that the flare will be used until later stages of dewatering, if at all.

SSE proposes to sample the cavern during the detailed design process and analyse the samples for H_2S generating bacteria.

4. BAT ASSESSMENT FOR MANAGEMENT OF WASTE GAS

While not considered an onshore oil and gas site, the EA has suggested reference to the Onshore Oil and Gas guidance for BAT due to the synergies of treatment of produced water and waste gas. As such, the options for reducing waste gas from the temporary dewatering of the ALD1 cavern has been informed by the measures highlighted in:

- Onshore Oil and Gas Sector Guidance and Waste Gas[6].
- Waste Gas Management at onshore oil and gas sites[7]: framework for technique selection

Section 8.5 of the Onshore Oil and Gas Sector guidance states *"You are expected to use BAT to prevent waste gas arising from your processes, or if this is not practicable, to reduce your emissions and impact on the environment. To determine BAT for your site, and demonstrate that you have considered all available options, you should use the methodology in the report Waste gas management at onshore oil and gas sites: framework for technique selection or an equivalent approach. This may result in using a combination of techniques, one of which may be a flaring system to combust any remaining gases."*

4.1 HIGH LEVEL SCREENING EXERCISE

An initial screening exercise has been completed to identify whether any of the potential waste gas reduction options are viable for the site. This screening is summarised in Table 4.1.

[6] Onshore oil and gas sector guidance - 8. Flares at onshore oil and gas sites - Guidance - GOV.UK
[7] Waste gas management at onshore oil and gas sites: framework for technique selection - GOV.UK

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TABLE 4.1 – SCREENING ASSESSMENT FOR WASTE GAS MANAGEMENT

Option Description	Technology/process	Description	Viable?	Comments
Combustion	**Shrouded Flares**	Piloted single piped flare housed within a larger pipe (shroud) assembly of suitable size and configuration to hide the flame and reduce thermal radiation effects	No	Low gas flow is expected resulting in low combustion efficiencies and not suitable for H_2S presence due to health and safety considerations.
	Enclosed ground flares	Piloted multiple burner system housed within a thermally insulated enclosure that will prevent local thermal radiation effects and hide the flame.	Yes	See Section 4.2 for choice of temporary flare.
Power Generation	**Spark Engines**	Combustion of gas in a reciprocating engine driving an electrical generator	No	Degassing tanks will be temporary and generate insufficient gas flow for onsite power generation.
	Gas Turbine	Combustion of gas in a gas turbine driving an electrical generator	No	Degassing tanks will be temporary and generate insufficient gas flow for onsite power generation.
Collection and reinjection/ recycling	**Recycling of waste gases**	Recovery of vented gases for injection into a separate processing step or feed recycling	No	Recovery of waste gases is not considered feasible given the low quantities of gases and temporary nature

Option Description	Technology/process	Description	Viable?	Comments
				of the activity, and cost of installing recovery systems. Since waste gases could comprise a mixture of natural gas, hydrogen and H_2S, there is no route for the recovered gas to be recycled in the process.
	Export via pipeline	Recompression of vented waste gas to supplement export flow	No	Recovery of waste gases is not considered feasible due to temporary nature of degassing, insufficient flow of gas and low concentration.
Zero Emission Technologies	**Valve actuators**	Electric/ electrohydraulic/ compressed air valve actuators	No	Not applicable as this relates to emissions from valves. In this case, emissions arise from dewatering effluent, not valve emissions.

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4.2 COST BENEFIT ANALYSIS

BAT option: flare

A rental flare package, if required, is proposed to prevent venting of high levels of H_2S from the degassing tanks to atmosphere during dewatering operations. It is currently anticipated that an open flare system designed for temporary deployment will be used, standing at 8 meters tall. The flare will be designed for smokeless operation, reducing visible emissions, and with high combustion efficiency to minimise release of harmful pollutants. Noise levels are typically below 60 dB, which is considered low for industrial applications. The choice of flare has been considered for the following reasons:

- The flare is only to be used for short-term operation.
- The flare will be smokeless and generate low noise levels.

The use of an enclosed ground flare is not technically or economically feasible for the duration and nature of the operation.

Flaring of gases from the degassing tanks for the whole duration of the dewatering process has been considered, however this is deemed excessive for the anticipated emissions. Temporary flares are designed for intermittent, high-volume releases. Continuous, low-volume emissions are likely to result in poor combustion efficiency. Routing all waste gases to flare also increases the risk of flame instability, backflow and ignition hazards, particularly when dealing with variable gas compositions. Operation of a flare when not required would also result in unnecessary combustion of pilot gas.

Based on total dewatering volume of 300,000 m^3, and natural gas production rate of 12.06 g/m^3 in brine, the maximum quantity of natural gas generated is expected to be 3.6 tonnes. Using the EA's Air Quality Damage Cost Appraisal Toolkit[8], assuming a VOC reduction of 3.6 tonnes, the central damage cost is £622 (£376 - £1,118) (see Attachment E). The cost of flaring for the full duration of one year has been estimated at circa £1.16 million ex VAT for equipment and an engineer to support/control. This cost is not justified based on the damage costs.

Emissions of carbon dioxide equivalent (CO2e) from venting/flaring of natural gas and hydrogen have also been considered. Based on the gas production rates in Attachment D, up to 3.6 tonnes of natural gas and 0.9 tonnes of hydrogen may be vented/flared, which equates to 118 tonnes CO2e, if vented. Using the central carbon values[9] for 2027 of £281 per tonne CO2e, the cost is £33,207. It should be noted that this is based on carbon values, rather than a damage cost.

Selected option: Open-Top Tanks

The use of two open top tanks has been selected to vent waste gases in normal operation. Open top tanks, when designed and operated to minimise hazardous gas accumulation, offer a passive, low-risk solution.

[8] Assess the impact of air quality - GOV.UK
[9] DESNEZ Green Book Supplementary Guidance - Table 3

1. Sufficient ventilation (either natural or forced) will be provided to ensure the gases are not present above their lower explosive limits.

This approach will minimise the potential for gas accumulation in enclosed spaces. This approach is considered to meet standards for environmental protection while prioritising site safety and operational reliability.

As such, the preference is to vent natural gas and hydrogen gas dissolved due to the low levels expected to be produced, and temporary nature of the process.

5. CONCLUSIONS

The water displaced from the ALD1 cavern may contain dissolved gases (hydrogen, natural gas and potentially H_2S). UV treatment of the borehole water for cavern rewatering is proposed to minimise bacterial activity in the cavern and therefore minimise formation of methane and H_2S.

Two open top tanks are proposed to provide residence time for degassing the cavern discharge. Monitoring of H_2S will be installed local to the degassing tanks. If elevated levels of H_2S are detected, dewatering will be stopped to allow a temporary flare to be connected.

The EA's H1 tool has been used to assess emissions of H_2S from the degassing tanks, and SO_2 emissions (from combustion of H_2S) from the flare. The H1 assessment showed that H_2S emissions and SO_2 emissions are considered to be insignificant.

As assessment of BAT for management of waste gas has concluded that the proposed solution is appropriate, given the temporary and low-volume nature of the operation. Continuous flaring for the duration of the degassing operation is considered to be excessive and is not economically justified.

ATTACHMENT A WELLPAD AREA AND INDICATIVE LOCATION OF TEMPORARY FLARE

DO NOT SCALE

NOTES:

1. ALL DIMENSIONS IN METRES UNLESS STATED OTHERWISE.
2. HIGH TEMPERATURE PIPING WILL REQUIRE HEAT CONSERVATION INSULATION.
3. SURVEILLANCE CAMERA TO BE ISOLATED DURING VENTING OPERATIONS.
4. NITROGEN INJECTION NOT CURRENTLY PROPOSED AS A REQUIREMENT. HOWEVER, PROVISION OF N2 INJECTION POINTS HAVE BEEN PROVIDED IN ANTICIPATION OF FUTURE REQUIREMENTS.
5. CAR PARK 1 TO BE USED AS DEWATERING ENGINEERING LAYDOWN AREA.
6. REQUIREMENT FOR RENTAL FLARE PACKAGE TO BE SPECIFIED BY VENDOR BASED ON RISK OF H2S.

KEY:

- FLUSHING & DILUTION SUPPLY PIPING & EQUIPMENT
- BRINE DISCHARGE PIPING & EQUIPMENT
- UTILITIES & INSTRUMENTATION
- HIGH PRESSURE PIPING & EQUIPMENT
- HIGH PRESSURE HYDROGEN PIPING

REFERENCE DRAWINGS:

1. 5221963-ATK-ZZ-DW-DDRW-M-000001 PATHFINDER DEWATERING GENERAL ARRANGEMENT DRAWING OVERALL SITE
2. A1000-02-00-00-0001-000-01 - PLOT PLAN

Rev.	Date	Description	By	Chk'd	App'd
C01	07.06.24	APPROVED FOR DESIGN	JO	GM	KM
P03	16.02.24	ISSUED FOR APPROVAL	RP	GM	KM
P02	13.11.23	ISSUED FOR CLIENT COMMENT	GM	RM	KM
P01	13.10.23	FIRST DRAFT FOR COMMENT	RP	GM	-

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Project Title

PATHFINDER DEWATERING ENGINEERING

Drawing Title

PATHFINDER DEWATERING GENERAL ARRANGEMENT DRAWING ALD 1 WELLPAD AREA

Scale	Designed	Drawn	Checked	Authorised
1:500	GM	RP	GM	-
Original Size	Date	Date	Date	Date
A3	13.10.2023	13.10.2023	13.10.2023	-

Drawing Number	Revision
5221963-ATK-ZZ-DW-DDRW-M-000003	C01

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ATTACHMENT B H1 TOOL TO AIR – DEGASSING OPERATIONS

ATTACHMENT C ODOUR MANAGEMENT PLAN

ATTACHMENT D H1 TOOL TO AIR – INPUT CALCUATIONS

ATTACHMENT E DAMAGE COST TOOL