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Agricultural Anaerobic Digestion Plant – Carbon Dioxide Vent Emissions Technical Note

Agricultural Anaerobic Digestion Facility – Land East of A162, Home Farm, Bond Ings, Sherburn in Elmet, LS25 6FW

Halstow Energy Limited

SHF.0174.006.AQ.R.003.P02

'Experience and expertise working in union'

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Carbon Dioxide Vent Emissions – Technical Note

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Non-Technical Summary

i. Enzygo Limited was commissioned by Halstow Energy Limited to undertake a CO_2 vent emission analysis for a propsoed AD Facility on agricultural land east of A162, Low Farm, South Milford, Sherburn in Elmet.

ii. This additional technical note has been provided at the request of the Environmental Agency and considers potential CO_2 vent emission impacts from scenarios during normal and emergency operations at off-site human sensitive receptor locations. Following a review the assessment considered scenarios pre and post the CO_2 liquefaction plant being in operation.

iii. Modelling was based on the plant emitting concentrations constantly over 5 assessment years. The maximum predictions showed that the CO_2 concentrations were acceptable at any human sensitive receptor and impacts were considered as negligible and not significant. This shows that the CO_2 vent design is sufficient to ensure adequate dispersion of potential vent gases.

iv. An additional check for plume density and plume grounding was provided to verify that the ADMS model was valid and the modelled results were considered valid.

1.0 Introduction

1.1 Background

1.1.1 Enzygo Limited was commissioned by Halstow Energy Limited to undertake a carbon dioxide (CO_2) vent emission assessment at an Agricultural Anaerobic Digestion (AD) Facility on agricultural land east of A162, Low Farm, South Milford, Sherburn in Elmet, LS25 6FW.

1.1.2 An Air Quality Assessment has been provided to consider emissions from the operation of revised proposals at the facility (Ref. SHF.0174.006.AQ.R.001.P03) and this Technical Note should be read in conjunction with the assessment. This additional technical note has been provided at the request of the Environmental Agency who had stated:

"Concentrated or compressed CO_2 may be required to be vented routinely or in an emergency. Therefore, there is the potential for acute incident related off-site human health impacts and chronic air quality related human health impacts.

- *Provide an assessment of the impact of venting, that includes the following: A description of the different potential venting scenarios including that the whole inventory is vented;*
- *Information that shows how modelling has been or is intended to be used to inform the process design and management of the risks associated with venting of CO_2;*
- *Confirmation that the design is in line with industry best practice such as that from the Energy Institute, or equivalent;*
- *A description of the operating techniques that will be used to minimise the risks;*
- *A vent management plan setting out how the risks from venting of CO_2 will be managed. (If the design is not finalised, the vent management plan can be developed prior to start of operations and a pre-operational condition will be set.)"*

1.1.3 This Technical Note therefore considers potential CO_2 vent emission impacts from scenarios during normal and emergency operation at off-site receptor locations.

2.0 Methodology and Inputs

2.1 Air Quality Assessment Inputs

2.1.1 The following model inputs used in the Air Quality Assessment remain the same for the CO_2 vent assessment:

- ADMS 6.0 Model Software;
- 5 years meteorological data;
- Site layout;
- Building locations and heights;
- Topographical data; and
- Off-site human sensitive receptor locations.

2.1.2 Reference should be made to the AQA for detailed information on these inputs.

2.2 Environmental Standards

2.2.1 The CO_2 vent modelling assessment was undertaken against the relevant environmental standards. There are no defined Environmental Quality Standards (EQSs) in the UK for ambient CO_2 concentrations however CO_2 is classed as a 'substance hazardous to health' under the Control of Substances Hazardous to Health Regulations 2002 (COSHH).

2.2.2 The Health and Safety Executive (HSE) provides long and short term workplace exposure limits (WELs) for CO_2 in their publication 'EH40/2005 Workplace exposure limits'[1]. Whilst these concentrations only apply at workplace locations, they have been used for the purposes of this assessment to consider the acceptability of impacts at off-site sensitive locations and are shown in Table 1.

Table 1: Carbon Dioxide Assessment Concentrations

Pollutant	Environmental Quality Standard		
	WEL Concentration (ppm)	Equivalent Concentration (µg/m³)	Averaging Periods
Carbon dioxide (CO_2)	5,000	9,000,000	8-hour mean (long term)
	15,000	27,000,000	15-minute mean

2.2.3 The conversion from ppm to µg/m^3 was based on a molecular volume at an assumed ambient temperature of 25°C of 24.45 L/mol.

2.3 Assessment Scenarios

Normal Operations

2.3.1 During normal operation the Biomethane Upgrading Plant (BUP) will separate the methane from the carbon dioxide in the raw biogas.

[1] EH40/2005 Workplace exposure limits, Health and Safety Executive, January 2020

2.3.2 The methane will flow to the grid entry unit and then ultimately to the gas network. The carbon dioxide rich stream of gas will flow to the carbon dioxide recovery unit where it is further cleaned and liquified at the plant (CO2L) before being taken off site as a product.

2.3.3 There will be a constant venting of CO_2 from the CO2L unit during normal operation. This off gas will be vented to atmosphere from Vent no. 3 (Appendix B). There will be a period of normal operation prior to the CO2L plant being commissioned or in the event that the carbon dioxide recovery plant is shut down for maintenance purposes where a higher proportion of CO_2 is vented. This off gas will be vented to atmosphere at the vent pipe on the BUP (Vent no. 4 Appendix A).

2.3.4 The following normal operation scenarios have been considered:

- Scenario 1 - upgrading unit in operation and CO2L unit offline. Very low CO_2 recovery and approximately 99% CO_2 by volume emission.
- Scenario 2 - upgrading unit and CO2L unit in operation, tail gas flow less than design flow of liquefaction unit. Residual CO_2 approximately 75% by volume emission.
- Scenario 3 - upgrading unit and CO2L unit in operation, tail gas flow greater than design flow of liquefaction unit. Less CO2 recovered than in Scenario 2. Residual CO_2 approximately 85% CO_2 by volume emission.

2.3.5 As such it was considered to assess Scenario 1 and Scenario 3 as the worst case conditions for normal operation with the CO2L unit offline and online respectively. In all scenarios emissions would be via a single vent.

2.3.6 Appendix A and Appendix B shows the process block diagrams for these scenarios.

Emergency Operation

2.3.7 Following discussions with Halcrow Energy Ltd it is understood that an emergency scenario in which a full tanking would require emptying would not occur. The quality of the plant would be monitored continuously to ensure that the tank would not be compromised. As such this scenario does not require consideration in this Technical Note.

2.4 Modelled Output Scenarios

2.4.1 The modelled output pollutant scenarios considered in the modelling assessment are summarised in Table 2.

Table 2: Modelled Output Scenarios

Pollutant	Modelled As	
	Short Term	Long Term
CO_2	Maximum 15-minute mean	Maximum 8-hour mean

2.5 Emission Process Conditions

2.5.1 The process conditions associated with the CO_2 venting scenarios, as provided by Halstow Energy Limited, are detailed in Table 3. ADMS 6 default values for the emission gas specific heat capacity and molar mass were revised in the model inputs to reflect that the majority of the emission gas would be CO_2 rather than air.

Table 3: Vent Emission Process Conditions

Parameter	Unit	Scenario 1	Scenario 3
Emission Vent Name	-	Vent 4 (Block diagram Appendix A)	CO2L Off gas Vent 3 (Block diagram Appendix B)
Vent Location NGR	m	450479.0, 432093.0	450450.2, 432042.8
Vent Height	m	6.4	11.8
Vent Diameter	m	0.1	0.05
Vent gas Temperature	°C	-22	-22
Normalised Vent Gas Volume Flow (a)	Nm^3/h	647	28
Actual Vent Gas Volume Flow	m^3/s	0.151	0.007
Emission Velocity	m/s	19.27	3.34
CO_2 Specific Heat Capacity	J/°C/kg	800	800
CO_2 Molar Mass	g	44.01	44.01

a: Referenced wet gas flow rate at 25°C

2.6 Vent Mass CO_2 Emissions

2.6.1 Halstow Energy Ltd have provided maximum typical emission concentrations for both scenarios assessed. Scenario 1 will emit a maximum CO_2 concentration of 99% by volume via the BUP vent prior to the CO_2 liquefaction facility becoming operational. Scenario 3 would emit a lower concentrations of approximately 85% by volume via the CO2L off gas vent.

2.6.2 Mass emission rates from venting scenarios were calculated based on these concentrations as shown in Table 4 below.

Table 4: Vent CO_2 Emission Rates

Emission	Scenario 1	Scenario 3
Emission Concentration (% vol)	99%	85%
Emission Concentration (mg/m^3)[a]	2,114,082	1,815,121
Mass Emission Rate (g/s)	320.02	11.89

a: based on a CO_2 molecular volume of 20.61 L/mol at -22°C and molecular weight of 44.01 g/mol

2.7 Background Concentration

2.7.1 The USA National Oceanic and Atmospheric Administration NOAA publishes a monthly global average based on CO_2 measurements by its globally distributed network of air sampling sites Recent data shows that background CO_2 concentrations are approximately 425 ppm. This concentration has been used to represent background CO_2 concentrations in this assessment.

2.8 Time Varied Emissions

2.8.1 Modelling has been undertaken assuming that vents would be emitting constantly under normal and emergency operations. This is assumed for the represents the worst case condition for emergency operation vent emissions would occur over a short if required and therefore a worst case scenario has been considered.

2.9 15-minute CO_2 Conversion

2.9.1 Throughout the assessment, 15-minute mean CO_2 concentrations have been calculated using the following correction factor based upon empirical relationships with the 99.9th percentile of 1-hour means, as described in EA guidance[2]:

99.9th percentile of 15-minute means = 1.34 x 99.9th percentile of 1-hour means

2.10 Significance of Impacts

EA Guidance Criteria

2.10.1 Guidance for assessing the significance of emissions impacts from point sources are also given in the EA's online guidance[2].

2.10.2 Predicted pollutant concentrations are summarised in the following formats:

- Process contribution (PC) - Predicted pollutant concentration as a result of emissions from the site only; and
- Predicted environmental concentration (PEC) - Total predicted pollutant concentration as a result of emissions from the site and existing baseline levels.

2.10.3 The significance of predicted impact has been assessed in accordance with criteria in the EA guidance 'Air emissions risk assessment for your environmental permit[2] and through consideration of likely effects. The EA guidance states that process contributions can be considered insignificant if:

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

2.10.4 If both criteria are met predicted impacts can be considered insignificant and no further analysis is required.

2.10.5 If the above criteria are not met, then a second stage of screening is required to determine the impact of the PEC:

- The short-term PC is less than 20% of the short-term environmental standards minus twice the long-term background concentration; and
- The long-term PEC is less than 70% of the long-term environmental standards.

2.10.6 If both criteria are met during the second stage of screening, then predicted impacts can be considered insignificant. Should these criteria be exceeded then the PEC should be checked against the EQS.

2.11 Plume Assessment Plots and Checks

2.11.1 In addition to providing predictions of concentrations at specific locations ADMS 6 modelling software was used to verify the plume height and density from vent scenario emissions within the vicinity of the site.

2.11.2 The behaviour of the plume is largely related to the stability of the atmosphere. ADMS allows for the manual entry of meteorological conditions As such, the plume centreline height and

[2] Air emissions risk assessment for your environmental permit, Environment Agency, Updated July 2025

density were calculated for meteorological scenarios that correspond approximately with the Pasquill-Gifford stability classes as suggested in the ADMS-6 user guide[3] and shown in Table 5.

Table 5: Meteorological Conditions Modelled for Plume Conditions Assessment

Pasquill-Gifford Stability		Wind Speed (m/s)	Surface Heat Flux (W/m^2)	Boundary Layer Height (m)
Class	Condition			
A	Extremely unstable	1	146	1300
B	Moderately unstable	2	105	900
C	Slightly unstable	5	89	850
D	Neutral	5	0	800
E	Slightly stable	3	-12	400
F	Moderately stable	2	-7	100
G	Extremely Stable	1	-0.8	100

2.11.3 The models were run for 8 wind directions for each 45° segment from N to NW and the predicted plume heights plotted against distance from the vents. This was to further test the validity of the model and likely grounding of plumes, its distance from the source and its density at this point during different conditions.

2.11.4 Plume is assumed to be too dense to model in ADMS if dense at release and all three of the following conditions are met when the plume reaches the ground:

- The percentage difference in density between the plume and the ambient air > 0.33%;
- The plume reaches the ground less than 250 m from the source; and
- The Richardson number, Ri > 10

2.11.5 The Richardson number can be thought of as the ratio of potential energy and kinetic energy, or the ratio of the buoyancy and inertia and In ADMS 6, it is the densimetric Richardson number, specifically:

$$Ri = \frac{bg(\rho_\rho - \rho_a)}{\rho_a(1.3^2 u_*^2 + 0.4 w_*^2)}$$

2.11.6 ADMS 6 provides the ambient air and plume densities as well as calculating the Richards number when running the model for the standard stability conditions shown in Table 5. These were then checked against the criteria above where the plume was predicted to be grounded.

[3] ADMS 6 User Guide Version 6.0, CERC, 2024

3.0 Results

3.1 Scope

3.1.1 Dispersion modelling was undertaken with the inputs described in Section 2.

3.1.2 As stated previously, maximum concentrations across the five years of meteorological data (2019 - 2023) were utilised to account for varying meteorological conditions.

3.1.3 No warnings or errors were reported in the model runs indicating that the required ground plume density conditions were upheld

3.2 Scenario 1: BUP Vent

8-Hour Mean

3.2.1 Predicted 8-hour mean CO_2 concentrations at sensitive human receptor locations are summarised in Table 6.

Table 6: Predicted 8-Hour CO_2 Concentrations

Receptor		Concentration (µg/m³)		Proportion of EQS (%)	
		PC	PEC	PC	PEC
HR1	Mill Lane, South Millford	74355	1684015	0.8	17.8
HR2	Craglands, South Millford	12879	1622539	0.1	17.1
HR3	Home Lea Cottage	8147	1617807	0.1	17.1
HR4	22 Milford Road/Primary School	5517	1615177	0.1	17.1
HR5	10 Bartlett View, Sherburn in Elmet	8105	1617765	0.1	17.1
HR6	25 Egremont Place, Sherburn in Elmet	9545	1619205	0.1	17.1
HR7	Saxon Mews, Sherburn in Elmet	4662	1614322	0.1	17.1
HR8	Ashfield	2676	1612336	<0.1	17.0
HR9	Lennerton Lodge	3639	1613299	<0.1	17.0
HR10	Norden's Barn Farm	9099	1618759	0.1	17.1

Predicted concentrations were assessed against the relevant EQS: 8-hour mean EQS of 9,000,000 µg/m³.
a: PC proportion of the EQS minus twice the long-term background

3.2.2 As indicated in Table 6, the PC proportion of the relevant EQS does not exceed 1% at all sensitive receptor locations for the 8-hour mean.

3.2.3 Impacts on all 8-hour mean CO_2 concentrations can be screened out as insignificant and negligible according to the criteria detailed in Section 2.10.

15-Minute Mean

3.2.4 Predicted 15-minute mean CO_2 concentrations at sensitive human receptor locations are summarised in Table 7.

Table 7: Predicted 15-minute CO_2 Concentrations

Receptor		Concentration (µg/m³)		Proportion of EQS (%)	
		PC	PEC	PC	PECa
HR1	Mill Lane, South Millford	172611	1782271	0.6	6.3
HR2	Craglands, South Millford	36227	1645887	0.1	5.8
HR3	Home Lea Cottage	24547	1634207	0.1	5.8

Receptor		Concentration (µg/m³)		Proportion of EQS (%)	
		PC	PEC	PC	PECa
HR4	22 Milford Road/Primary School	18162	1627822	0.1	5.7
HR5	10 Bartlett View, Sherburn in Elmet	24687	1634348	0.1	5.8
HR6	25 Egremont Place, Sherburn in Elmet	24464	1634124	0.1	5.8
HR7	Saxon Mews, Sherburn in Elmet	16210	1625870	0.1	5.7
HR8	Ashfield	7612	1617272	<0.1	5.7
HR9	Lennerton Lodge	9197	1618857	<0.1	5.7
HR10	Norden's Barn Farm	22806	1632466	0.1	5.8

Predicted concentrations were assessed against the relevant EQS: 15-minute mean EQS of 27,000,000 µg/m³.
a: PC proportion of the EQS minus twice the long-term background

3.2.5 As indicated in Table 7, the PC proportion of the relevant EQS does not exceed 10% at all sensitive receptor locations for the 15-minute mean.

3.2.6 Impacts on all 15-minute CO_2 concentrations can be screened out as insignificant and negligible according to the criteria detailed in Section 2.10.

3.2.7 All predicted CO_2 concentrations are **not significant** for Scenario 1.

3.3 Scenario 3: CO2L Vent

8-Hour Mean

3.3.1 Predicted 8-hour mean CO_2 concentrations at sensitive human receptor locations are summarised in Table 8.

Table 8: Predicted 8-Hour CO_2 Concentrations

Receptor		Concentration (µg/m³)		Proportion of EQS (%)	
		PC	PEC	PC	PEC
HR1	Mill Lane, South Millford	3074	807904	0.03	8.5
HR2	Craglands, South Millford	445	805275	<0.01	8.5
HR3	Home Lea Cottage	308	805138	<0.01	8.5
HR4	22 Milford Road/Primary School	247	805077	<0.01	8.5
HR5	10 Bartlett View, Sherburn in Elmet	333	805164	<0.01	8.5
HR6	25 Egremont Place, Sherburn in Elmet	335	805165	<0.01	8.5
HR7	Saxon Mews, Sherburn in Elmet	125	804955	<0.01	8.5
HR8	Ashfield	103	804933	<0.01	8.5
HR9	Lennerton Lodge	97	804927	<0.01	8.5
HR10	Norden's Barn Farm	241	805071	<0.01	8.5

Predicted concentrations were assessed against the relevant EQS: 8-hour mean EQS of 27,000,000 µg/m³.
a: PC proportion of the EQS minus twice the long-term background

3.3.2 As indicated in Table 8, the PC proportion of the relevant EQS does not exceed 1% at all sensitive receptor locations for the 8-hour mean.

3.3.3 All 8-hour mean CO_2 impacts can be screened out as insignificant and negligible according to the criteria detailed in Section 2.10.

15-Minute Mean

3.3.4 Predicted 15-minute mean CO_2 concentrations at sensitive human receptor locations are summarised in Table 9.

Table 9: Predicted 15-minute CO_2 Concentrations

Receptor		Concentration (µg/m³)		Proportion of EQS (%)	
		PC	PEC	PC	PEC[a]
HR1	Mill Lane, South Millford	6621	1616281	0.02	2489.1
HR2	Craglands, South Millford	1191	1610851	<0.01	447.9
HR3	Home Lea Cottage	904	1610564	<0.01	339.9
HR4	22 Milford Road/Primary School	742	1610402	<0.01	278.9
HR5	10 Bartlett View, Sherburn in Elmet	766	1610426	<0.01	287.8
HR6	25 Egremont Place, Sherburn in Elmet	935	1610595	<0.01	351.6
HR7	Saxon Mews, Sherburn in Elmet	415	1610075	<0.01	156.0
HR8	Ashfield	277	1609937	<0.01	104.2
HR9	Lennerton Lodge	350	1610010	<0.01	131.5
HR10	Norden's Barn Farm	647	1610307	<0.01	243.4

Predicted concentrations were assessed against the relevant EQS: 15-minute mean EQS of 28,405,766 µg/m³.
a: PC proportion of the EQS minus twice the long-term background

3.3.5 As indicated in Table 9, the PC proportion of the relevant EQS does not exceed 10% at all sensitive receptor locations for the 15-minute mean.

3.3.6 Impacts on all 15-minute CO_2 concentrations can be screened out as insignificant and negligible according to the criteria detailed in Section 2.10.

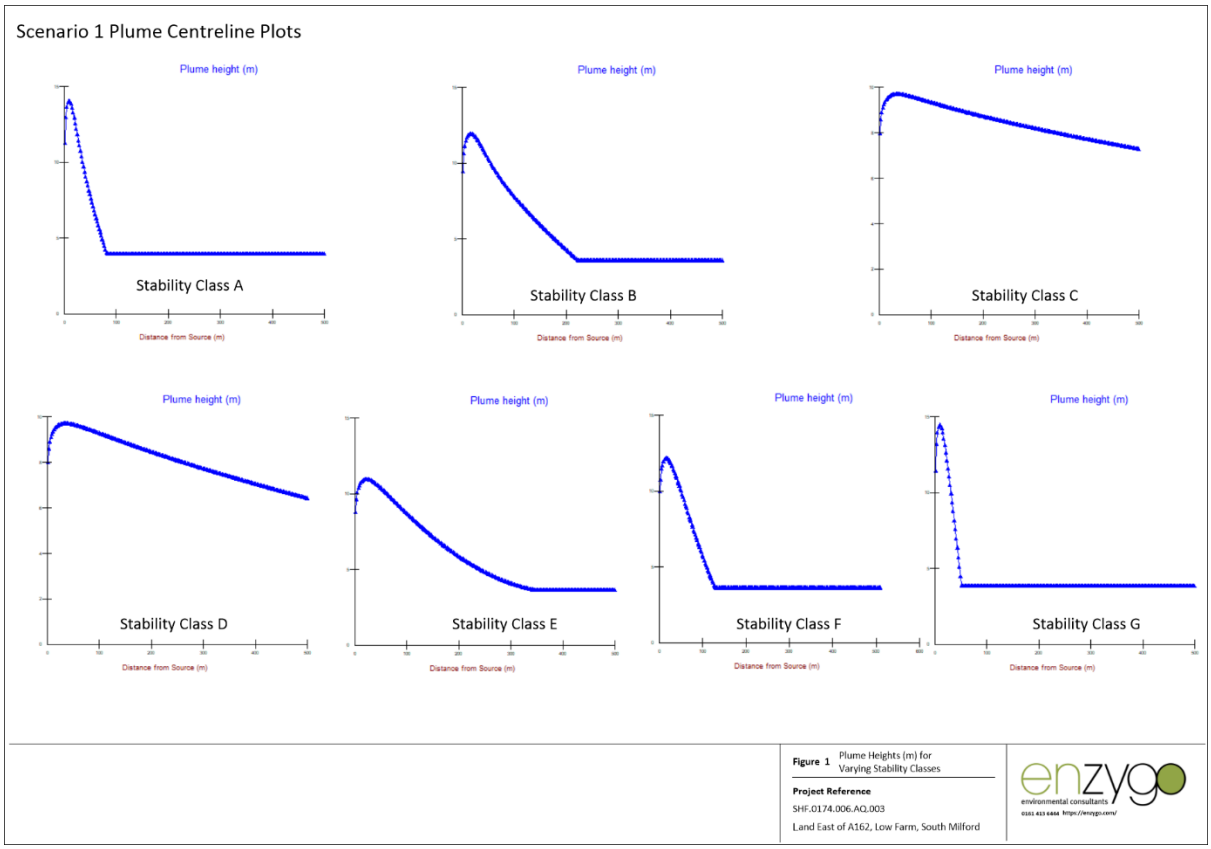
3.3.7 All predicted CO_2 impacts are **not significant** for Scenario 3.

3.4 Plume Assessment Plots and Checks

Scenario 1

3.4.1 As stated no model run errors or warnings were produced for all model scenarios. To further check the validity of the modelled predictions, the plume centrelines for each Pasquill-Gifford stability class for Scenario 1 were plotted and are shown in Figure 1 for a northerly wind direction. These were modelled without building effects to consider only plume density conditions and likelihood of grounding.

Figure 1: Scenario 1 Plume Centreline Plot



3.4.2 The plume grounding distance and density check variables for each wind direction are tabled in Appendix C for Scenario 1. This indicates that the is little variance in these metrics for differing wind directions. As such, the plots can be taken as typical for each atmospheric stability class.

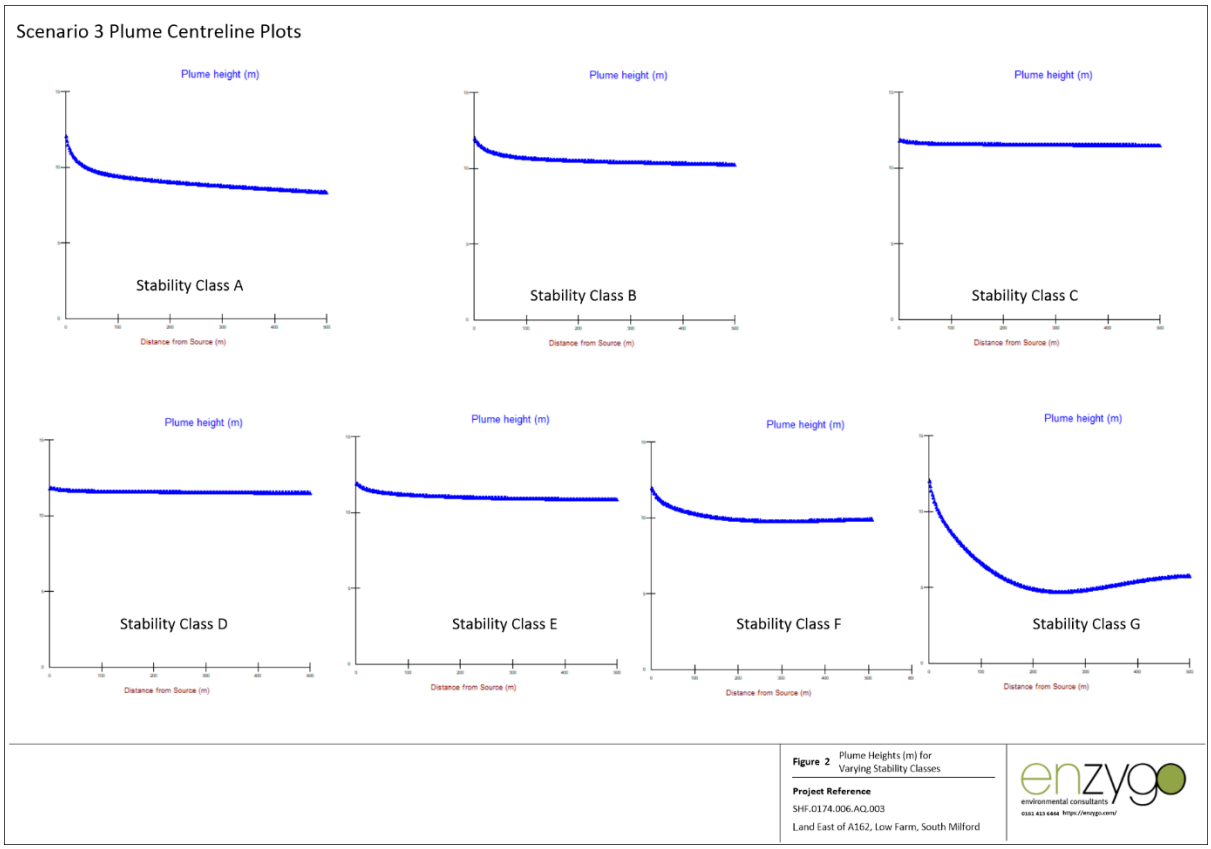
3.4.3 Figure 1 shows that the plume centreline is not predicted to ground within 250 m of the source for neutral and slightly stable/unstable conditions (stability classes C to E). The plume is predicted to ground closest to the source for extreme stable and unstable conditions (stability classes A and F) with class F being the closest at approximately 49 m from the source and as shown in the table in Appendix C for each wind direction.

3.4.4 However in these worst case conditions the maximum difference in plume and ambient density is only 0.1% and the maximum calculated Richards number is 5.1. These are below the model validation criteria given in Section 2.11.4 and provided further confirmation that the plume was not too dense at ground level for ADMS to model. This indicated that plume density was sufficiently mixed at ground level to provided valid modelled results.

Scenario 3

3.4.5 The plume centrelines for each Pasquill-Gifford stability class for Scenario 3 were plotted and are shown in Figure 2 for a northerly wind direction. These were modelled without building effects to consider only conditions and likelihood of grounding.

Figure 2: Scenario 3 Plume Centreline Plot



3.4.6 Figure 2 shows that the plume does not ground within 500 m of the vent source for all stability classes . As such it is considered that that modelled predictions for Scenario 3 are valid and can be taken as reasonable predictions at offsite sensitive receptors.

3.5 Venting Strategy Design

3.5.1 The predicted CO_2 impacts at off-site sensitive receptors were all negligible and not significant for both scenarios considered. This shows that the CO_2 vent design is sufficient to ensure adequate dispersion of vent gases and is line with best practice. Further information on the design and best practice requirements has been provided separately.

4.0 Conclusions

4.1.1 Enzygo Limited was commissioned by Halstow Energy Limited to undertake a CO_2 vent emission assessment at an AD Facility on agricultural land east of A162, Low Farm, South Milford, Sherburn in Elmet.

4.1.2 This additional technical note has been provided at the request of the Environmental Agency and considers potential CO_2 vent emission impacts from scenarios during normal and emergency operations at off-site human sensitive receptor locations. Following a review, the assessment considered scenarios pre and post the CO_2 liquefaction plant being in operation.

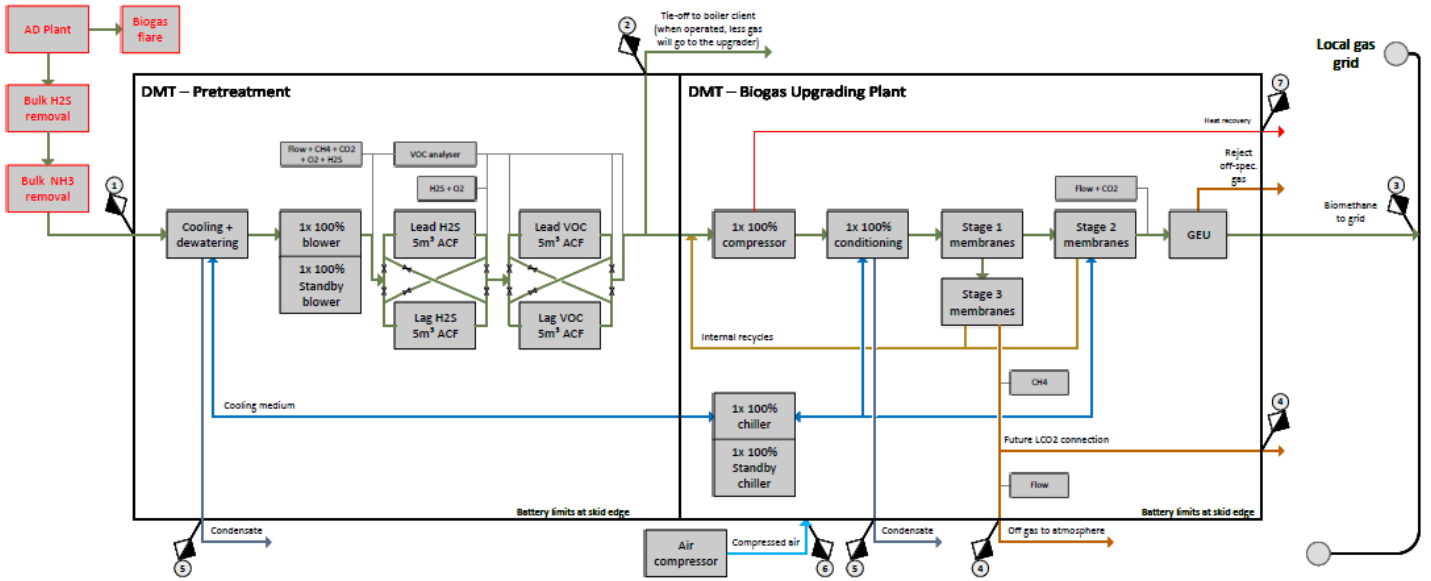
4.1.3 Modelling was based on the plant emitting concentrations constantly over 5 assessment years. The predicted concentrations showed that the CO_2 EQS was not exceeded at any human sensitive receptor and impacts were considered as negligible and not significant. This shows that the CO_2 vent design is sufficient to ensure adequate dispersion of vent gases.

4.1.4 Additional checks for plume density and grounding were provided to verify that the ADMS model was valid. This indicated that plume density would be sufficiently mixed at ground level for Scenario 1 and that the plume is not likely to be grounded for Scenario 3. As such, the modelled results are considered valid.

5.0 Abbreviations

AD	Anaerobic Digestion
ADM	Atmospheric Dispersion Modelling
ADMS	Atmospheric Dispersion Modelling Software
AQA	Air Quality Assessment
AQO	Air Quality Objective
CERC	Cambridge Environmental Research Consultants
CO_2	Carbon Dioxide
DEFRA	Department for Environment, Food and Rural Affairs
EA	Environment Agency
EQS	Environmental Quality Standard
IAQM	Institute of Air Quality Management
NGR	National Grid Reference
PC	Process Contribution
PEC	Predicted Environmental Concentration
ρ_a	Ambient Air Density
ρ_p	Plume Density

Appendix A: Scenario 1 Process Block Diagram



1 – Inlet biogas		2 – Pretreated biogas		3 – Outlet biomethane	
Medium:	BIOGAS+H2S	Medium:	BIOGAS+H2S	Medium:	CH4
Capacity:	1490 Nm³/h 1572 Sm³/h	Capacity:	1490 Nm³/h 1572 Sm³/h	Capacity:	843 Nm³/h 889 Sm³/h
Temp.:	45°C	Temp.:	30°C	Temp.:	5 – 20°C
Dewpoint:	45°C	Dewpoint:	9°C	Dewpoint:	≤ -70°C
Pressure:	0 mbarg	Pressure:	100 mbarg	Pressure:	8,5 – 13 barg
CH4:	55,0 vol%	CH4:	55,0 vol%	CH4:	≥ 96,6 vol%
CO2:	44,5 vol%	CO2:	44,5 vol%	CO2:	≤ 2,5 vol%
N2:	0,4 vol%	N2:	0,4 vol%	N2:	≤ 0,7 vol%
O2:	0,1 vol%	O2:	0,1 vol%	O2:	≤ 0,2 vol%
H2S:	150 ppmv	H2S:	≤ 1 ppmv	H2S:	≤ 3 ppmv
NH3:	50 ppmv	NH3:	≤ 1 ppmv	NH3:	≤ 1 ppmv
VOCs:	60 mg/Nm³	VOCs:	≤ 1 mg/Nm³	VOCs:	≤ 1 mg/Nm³
Siloxanes:	≤ 1 mg/Nm³	Siloxanes:	≤ 1 mg/Nm³	Siloxanes:	≤ 1 mg/Nm³

4 – Outlet off-gas		5 – Outlet condensate		6 – Compressed air		7 – Heat recovery		General	
Medium:	CO2 + GAS	Medium:	WATER	Medium:	AIR	Medium:	GLYCOL	Site elevation:	100m A.S.L.
Capacity:	647 Nm³/h 683 Sm³/h	Capacity:	132,0 L/h	Capacity:	10 Nm³/h	Capacity:	0,180 kWt/Nm³	Ambient T:	-18°C / +35°C
Temp.:	15 – 30°C	Temp.:	0 – 10°C	Pressure:	≥ 6 barg	Supply:	65°C	Area classification:	Non-ATEX
Dewpoint:	≤ -15°C	Pressure:	Atmospheric	Class:	ISO 8573-1 class 3.3.3 or higher	Return:	45°C	Seismic zone:	N/A
Pressure:	Atmospheric					Pressure:	2 – 3 barg	Wind load:	≤ 9 Bft.; 35 m/s
CH4:	≤ 0,7 vol%					Water:	65 – 75 vol%	Snow load:	≤ 2,4 kN/m²
CO2:	≥ 99,1 vol%					Glycol:	25 – 35 vol%		
N2:	≤ 0,1 vol%								
O2:	≤ 0,1 vol%								
H2S:	≤ 3 ppmv								
NH3:	≤ 1 ppmv								
VOCs:	≤ 1 mg/Nm³								
Siloxanes:	≤ 1 mg/Nm³								

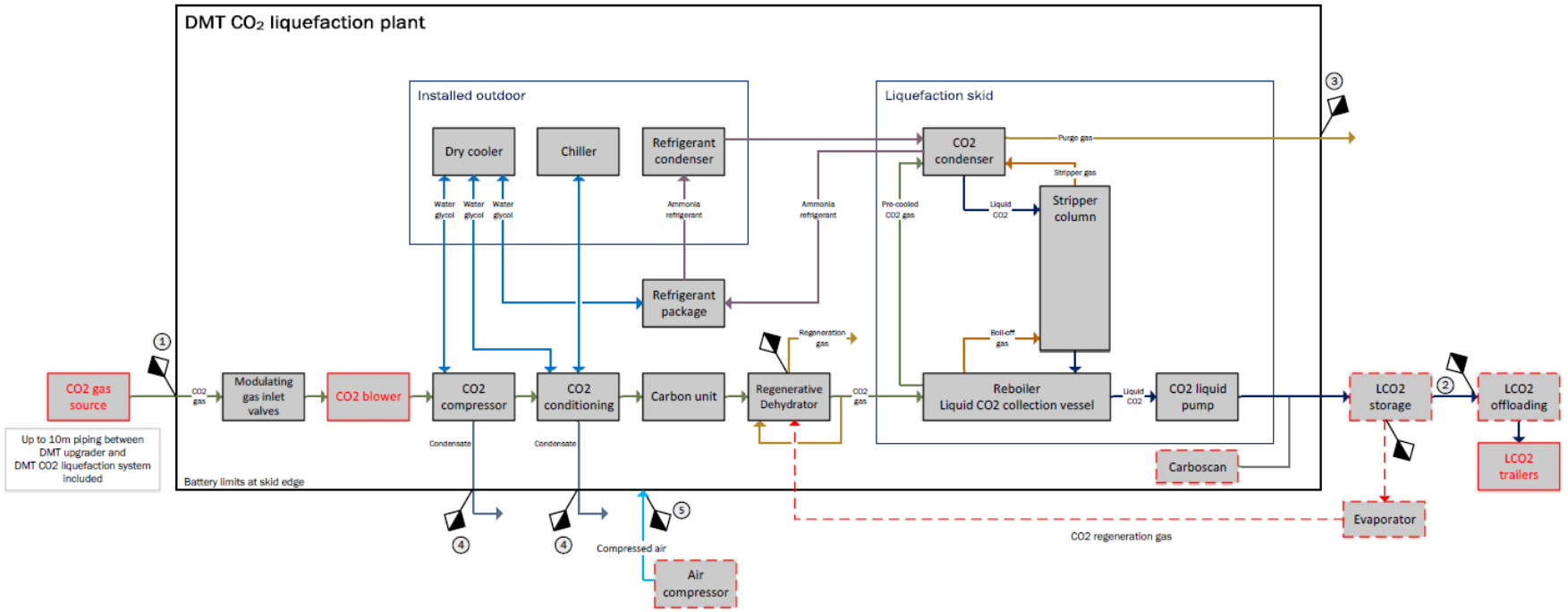
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TITLE:	Block Diagram	PROJECT NO:	250090 v2
CLIENT:	ENGIE	STATUS:	FOR INFORMATION ONLY
PROJECT:	Home Farm Biogas upgrading project	DATE:	12/11/2025

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Appendix B: Scenario 3 Process Block Diagram



1 – Inlet CO2-rich gas	
Medium:	CO2 GAS
Capacity:	647 Nm³/h
Capacity CO2:	1265 kg/h
Temperature:	15 – 30°C
Dew point:	≤ -15,0
Pressure:	50-200mbarg
CH4:	≤ 0,63 vol%
CO2:	≥ 99,13 vol%
N2:	≤ 0,01 vol%
O2:	≤ 0,09 vol%
H2S:	≤ 1 ppmv

2 – Outlet liquid CO2	
Medium:	LCO2
Capacity:	1145 kg/h
Temperature:	≤ -22°C
Dewpoint:	≤ 20 ppmv
Pressure:	≤ 18,5 barg
CH4:	≤ 50 ppmv
CO2:	≥ 99,9 vol%
N2:	≤ 0,00
O2:	≤ 30 ppmv
H2S:	≤ 0,1 ppmv

3 – Outlet purge gas	
Medium:	GAS
Capacity:	5 – 10%
Temperature:	≤ -22°C
Dewpoint:	≤ -60°C
Pressure:	≤ 18,5 barg
CH4:	± 22,0 vol%
CO2:	± 74,6 vol%
N2:	± 0,4 vol%
O2:	± 3,0 vol%
H2S:	≤ 0,1 ppmv

4 – Outlet condensate	
Medium:	WATER
Capacity:	< 0,1 m³/h
Temperature:	0 – 15°C
Pressure:	Atmospheric

5 – Inlet compressed air	
Medium:	AIR
Capacity:	10 Nm³/h
Pressure:	≥ 6 barg
Class:	ISO 8573-1 class 3.3.3 or higher

General	
Site elevation:	22m A.S.L.
Ambient T:	-18°C/+35°C
Area classification:	Non-ATEX
Seismic zone:	None
Wind load:	≤ 35 m/s
Snow load:	≤ 2,4 kN/m²

Included scope | Optional scope | Excluded scope | Client | DMT

DOCUMENT INDICATIVE ONLY AND SUBJECT TO DETAILED ENGINEERING

TITLE:	Block diagram	PROJECT NO:	250090 v1
CLIENT:	ENGIE	STATUS:	FOR INFORMATION ONLY
PROJECT:	Home Farm CO2 liquefaction	DATE:	23/06/2025

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Appendix C: Scenario 1 Plume Density Calculations

Wind Direction	Stability Class	Plume Grounding Distance (m)	Plume Density (kg/m³) ρ_p	Ambient Air Density (kg/m³), ρ_a	% Difference of Plume ρ to Ambient ρ	Richards Number
N	A	81	1.23	1.23	0.0%	0.03
	B	221	1.23	1.23	0.0%	0.02
	C	-	-	-	-	-
	D	-	-	-	-	-
	E	343	1.22	1.22	0.0%	-0.12
	F	128	1.22	1.22	0.0%	0.00
	G	49	1.22	1.23	0.1%	5.12
N	A	81	1.23	1.23	0.0%	0.03
	B	221	1.23	1.23	0.0%	0.02
	C	-	-	-	-	-
	D	-	-	-	-	-
	E	343	1.22	1.22	0.0%	-0.12
	F	129	1.22	1.22	0.0%	-0.01
	G	49	1.22	1.23	0.1%	5.11
E	A	81	1.23	1.23	0.0%	0.03
	B	221	1.23	1.23	0.0%	0.02
	C	-	-	-	-	-
	D	-	-	-	-	-
	E	343	1.22	1.22	0.0%	-0.12
	F	128	1.22	1.22	0.0%	0.00
	G	49	1.22	1.23	0.1%	5.10
SE	A	81	1.23	1.23	0.0%	0.03
	B	222	1.23	1.23	0.0%	0.02
	C	-	-	-	-	-
	D	-	-	-	-	-
	E	343	1.22	1.22	0.0%	-0.12
	F	128	1.22	1.22	0.0%	0.01
	G	49	1.22	1.23	0.1%	5.11
S	A	81	1.23	1.23	0.0%	0.03
	B	221	1.23	1.23	0.0%	0.02
	C	-	-	-	-	-
	D	-	-	-	-	-
	E	343	1.22	1.22	0.0%	-0.12
	F	128	1.22	1.22	0.0%	0.01
	G	49	1.22	1.23	0.1%	5.11
SW	A	81	1.23	1.23	0.0%	0.03
	B	222	1.23	1.23	0.0%	0.02
	C	-	-	-	-	-
	D	-	-	-	-	-
	E	343	1.22	1.22	0.0%	-0.12

Wind Direction	Stability Class	Plume Grounding Distance (m)	Plume Density (kg/m³) ρ_p	Ambient Air Density (kg/m³), ρ_a	% Difference of Plume ρ to Ambient ρ	Richards Number
	F	129	1.22	1.22	0.0%	-0.01
	G	49	1.22	1.23	0.1%	5.12
W	A	81	1.23	1.23	0.0%	0.03
	B	221	1.23	1.23	0.0%	0.02
	C	-	-	-	-	-
	D	-	-	-	-	-
	E	343	1.22	1.22	0.0%	-0.12
	F	127	1.22	1.22	0.0%	0.02
	G	49	1.22	1.23	0.1%	5.11
NW	A	81	1.23	1.23	0.0%	0.03
	B	221	1.23	1.23	0.0%	0.02
	C	-	-	-	-	-
	D	-	-	-	-	-
	E	343	1.22	1.22	0.0%	-0.12
	F	129	1.22	1.22	0.0%	-0.01
	G	49	1.22	1.23	0.1%	5.11

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