· Bio-LNG is more manageable in terms of fire/explosion risk due to lower pressures and vapour dispersion controls.

3. Minimal Equipment Substitution
· Internally, the only notable changes are:

- Bio-methane compressed gas storage tank (as shown on WEW Drawing 1950-DG- 0008) replaced with bio-LNG (liquefied biomethane) storage tank, with the tank dimensions remaining the same.
- Installation of fixed arm transfer and bio-LNG-compatible isolation valves.
- Swap of high-pressure compressors with bio-LNG liquefaction and boil-off gas (BOG) recovery units.
- These changes are internal to plant buildings or fully enclosed skids — no external change to layout or aesthetic impact.

4. Seveso & LUP Compliance Maintained
· Seveso thresholds for flammable gas inventory are better aligned under bio-LNG conditions, with improved control measures.
A summary of main changes in terms of off-site transport associated with the change from the compressed biogas (CBG) to liquified biogas (LBG) / bio-LNG, are provided in Table 2.

Table 2: Amendments Summary Table

	Original Proposal	Amended Proposal	
Metric	Compressed Biogas CBG - (MEGCs)	bio LNG (Cryo-Tankers)	Change
Annual Trucks	~ 1,020	~ 857	-163 (-16%)
Daily Trucks	~ 3	~ 2.3	~ 0.7 fewer per day
Payload per Truck	~ 8.7 tonnes	~ 10 tonnes	+15% more per load
Pressure	250 bar	~ 5 bar	Safer for transport

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Project Description / Public Notices Update

As a result of the above changes from CBG to bio-LNG, as outlined above, the project description / public notices will require the following amendments (suggested ~~omissions~~ and additions).

1. An overall planning application site area of **c. 6.3 hectares** consisting of a proposed bio-renewables production facility, buffer screening, ancillary facilities and site access via the existing permitted quarry entrance.
2. The proposed bio-renewables production facility (incorporating anaerobic digestion) compound will cover an area of **c. 4 hectares**. The production facility will convert feedstocks to end of line co-products, namely bio-methane (gas), ~~compressed bio-methane (bio-CNG)~~ bio-LNG (liquefied biomethane), carbon dioxide (CO2), electricity (green), organic fertilisers (pelleted) and water, with integrated solar energy generation. The adjacent Roadstone Killough Quarry plant will utilise the electricity, bio-methane and water. Pelletised fertiliser will be available for supply to local agriculture and traders off-site. ~~CNG~~ bio-LNG and CO2 will be pressurised and stored for ongoing draw-off by tankers to points of re-use off-site. Demolition of existing quarry store building (c. **158m²**) to facilitate the proposed development.

Planning Inspection Purposes Only

Response from MLavelle: These changes were not made to the Site Notice, RFI revised Site Notice & don't apply to this Appeal.

1ST PARTY APPEAL:

1.1 Application Amendment

Between the time the application was originally submitted and the submission of the Further Information (FI) response, the applicant made the decision to amend the output detail from the facility with a switch from compressed biogas (CBG) to liquified biogas (LBG)[1].

As a result of the proposed shift from the output of CBG to LBG, the key revisions to Filling Infrastructure & Site Operation are set out below.

Response from MLavelle: The application was for compressed biogas (CBG) & not liquified biogas (LNG). LNG requires cryogenic freezing with probable liquid nitrogen down to minus 180^0Centigrade to freeze the Carbon Dioxide into a solid. This is a totally different process to the planning application. There is no mention of the method to dispose of the solid Carbon Dioxide. This appeal does not relate to the application and is invalid.

1. Shift from Compressed Biogas (CBG) to Liquified Biogas (LBG)

The Further Information submission confirmed that the gas upgrade and export will proceed via LBG / bio-LNG rather than compressed biomethane gas. This decision was driven by logistical, commercial, and storage efficiency considerations. As a result:

- The Multiple Element Gas Container (MEGC)s for CBG will no longer be used.
- LBG / bio-LNG will be stored in a cryogenic storage vessel and filled via loading arm pipework into ISO cryogenic tanks (trailers or skid units).
- This reduces high-pressure gas handling risks on site and within the surrounding area.

2. Filling Infrastructure

- The previous proposal involving armoured flexible CBG hoses is now no longer applicable.
- Instead, vacuum-jacketed bio-LNG pipework with fixed couplings and double-block isolation valves and fixed arm for loading will be used.
- Filling will occur via the dedicated loading bay, designed in accordance with EN 1473 and ISO 16924.
- No supercritical transfer will occur. Bio-LNG will remain in liquid phase at **~ -160°C and 2–6 bar(g)**.

3. Revised On-Site Staffing

In line with the above transition, a reduction in the operational manpower required for the AD facility is proposed:

- Total site staffing is now forecast at 9 full-time personnel for the AD and export facility.
- This includes operations, maintenance, logistics, and site management.

4. Implications for LUP & Risk Modelling

With regard to the Land Use Planning assessment, the following is applicable:

- Flexible CNG hose-based MEGC transfer scenarios are now excluded from the risk model.
- Bio-LNG operations will be cryogenic, low-pressure, with reduced site population and fewer active transfer events per day.

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5. Summary of Changes

A summary of the key points of positive change include:

1. No Change to External Layout or Risk Profile

- All existing building footprints, boundary limits, and access/egress points remain unchanged.
- All bio-LNG-related equipment will be housed within existing proposed structures or their immediate footprint — no new buildings or infrastructure required.

2. Improved Risk Profile vs. CNG

- Compressed Biogas (CBG) at 250 bar is now being replaced by bio-LNG at ~2–6 bar, and stored cryogenically at -160°C.
- This reduces the stored energy per volume and decreases high-pressure hazard risks.
- Bio-LNG is more manageable in terms of fire/explosion risk due to lower pressures and vapour dispersion controls.

3. Minimal Equipment Substitution

- Internally, the only notable changes are:
  - Bio-methane compressed gas storage tank (as shown on WEW Drawing 1950-DG-0008) replaced with bio-LNG (liquefied biomethane) storage tank, with the tank dimensions remaining the same.
  - Installation of fixed arm transfer and bio-LNG-compatible isolation valves.
  - Swap of high-pressure compressors with bio-LNG liquefaction and boil-off gas (BOG) recovery units.
  - These changes are internal to plant buildings or fully enclosed skids — no external change to layout or aesthetic impact.

4. Seveso & LUP Compliance Maintained

- Seveso thresholds for flammable gas inventory are better aligned under bio-LNG conditions, with improved control measures.

A summary of main changes in terms of off-site transport associated with the change from the compressed biogas (CBG) to liquified biogas (LBG) / bio-LNG, are provided in **Table 1**.

Table 1: Amendments Summary Table

	Original Proposal	Amended Proposal	
Metric	Compressed Biogas CBG - (MEGCs)	bio LNG (Cryo-Tankers)	Change
Annual Trucks	~ 1,020	~ 857	-163 (-16%)
Daily Trucks	~ 3	~ 2.3	~ 0.7 fewer per day
Payload per Truck	~ 8.7 tonnes	~ 10 tonnes	+15% more per load
Pressure	250 bar	~ 5 bar	Safer for transport

Planning Authority - Inspection Purposes

Response from MLavelle: This LNG information is not applicable to this planning appeal.

ISSUE 3:

MAPS SUBMITTED ARE NOT CONSISTENT. THE 500M CONTOUR IS FAR SMALLER IN THE COMMUNITY PUBLIC CONSULTATION REPORT

Community Public Consultation Report
Proposed Bio-Renewables Facility (including Anaerobic Digestion) at Killough Quarry, Holycross, Co. Tipperary
Roadstone Limited Fortunestown, Tallaght, Dublin 24. SLR Project No.: 501.065529.00001
Client Reference No: 00180. 10 July 2024
1.1.1 Bio-Renewables Concept

The production facility will convert feedstocks to end of line co-products, **namely bio-methane (gas), compressed bio-methane (bio-CNG), carbon dioxide (CO2),** electricity (green), organic fertilisers (pelleted) and water, with integrated solar energy generation. The adjacent Roadstone Killough Quarry plant will utilise the electricity, bio-methane and water. Pelletised fertiliser will be available for supply to local agriculture and traders off-site. CNG and CO2 will be pressurised and stored for ongoing draw-off by tankers to points of re-use off-site. All products resulting will be co-products for reuse. There will be no by-products requiring disposal.

2.7 Public Consultations

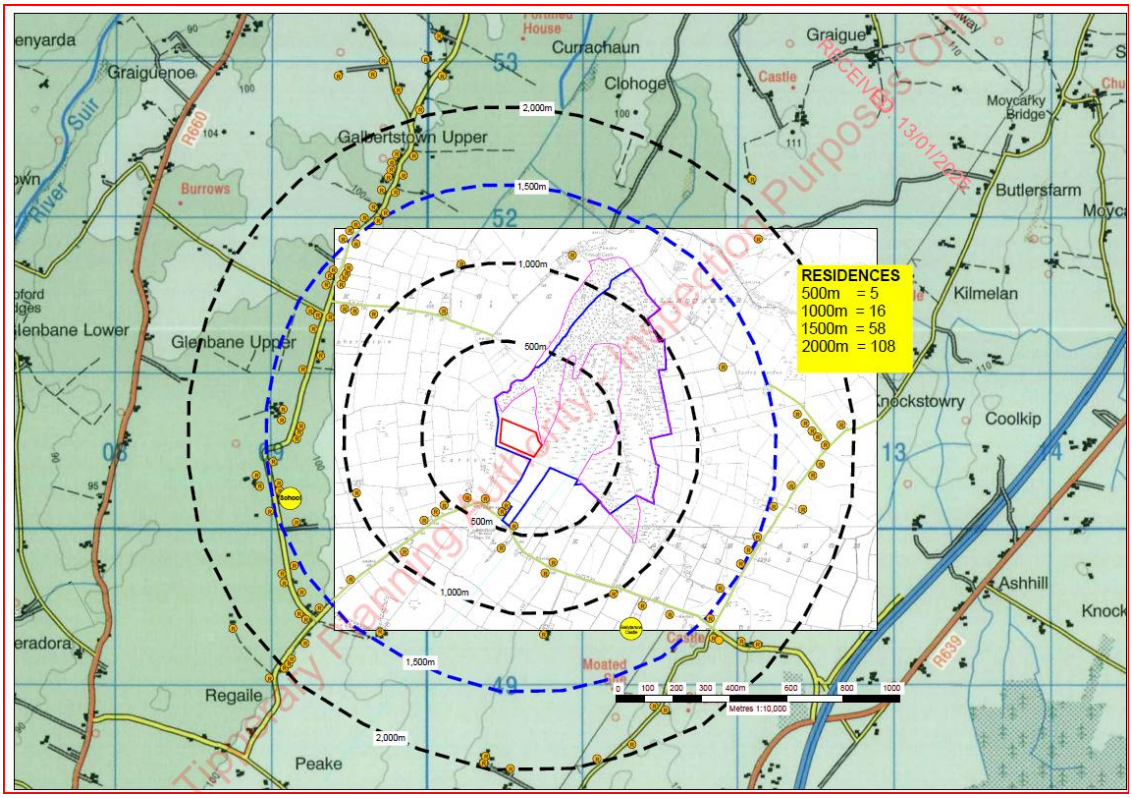
Roadstone elected to organise a public consultation event in the form of a 'Public Information Drop-In Event' at a local hotel (the Horse & Jockey), on the evening of Tuesday 25th June 2024. A local residence letter drops, and a newspaper public notice advertisement were carried out in the two-week period prior to the scheduled information drop-in event. The public were invited to submit observations and feedback either in person at the public information session or via email to info@roadstone.ie.

The event was intended to provide an opportunity for potentially impacted local residents and any interested third parties to meet with Roadstone personnel and its advisors to discuss the development and ask any relevant questions.

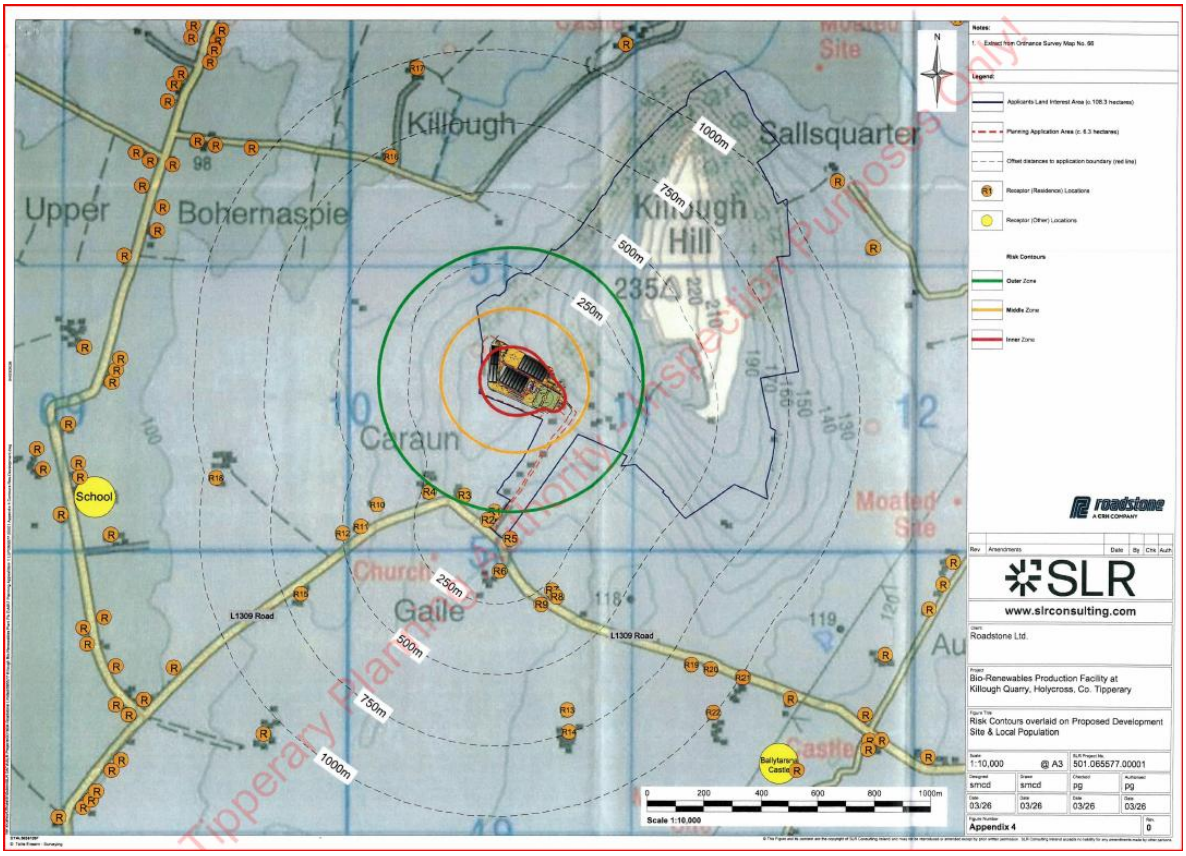
To facilitate public engagement and discussion, Roadstone set up display's information boards around the meeting room. The display boards provided some background information, proposed layout scheme, brief description of the proposed development along with some 3-D concept views.

Attendees were also invited to submit any further comments or questions to an email (info@roadstone.ie) provided by Roadstone on or before the 26th July 2024. This date was later extended to 23rd August 2024 by Roadstone Limited as requested by a local Councillor.

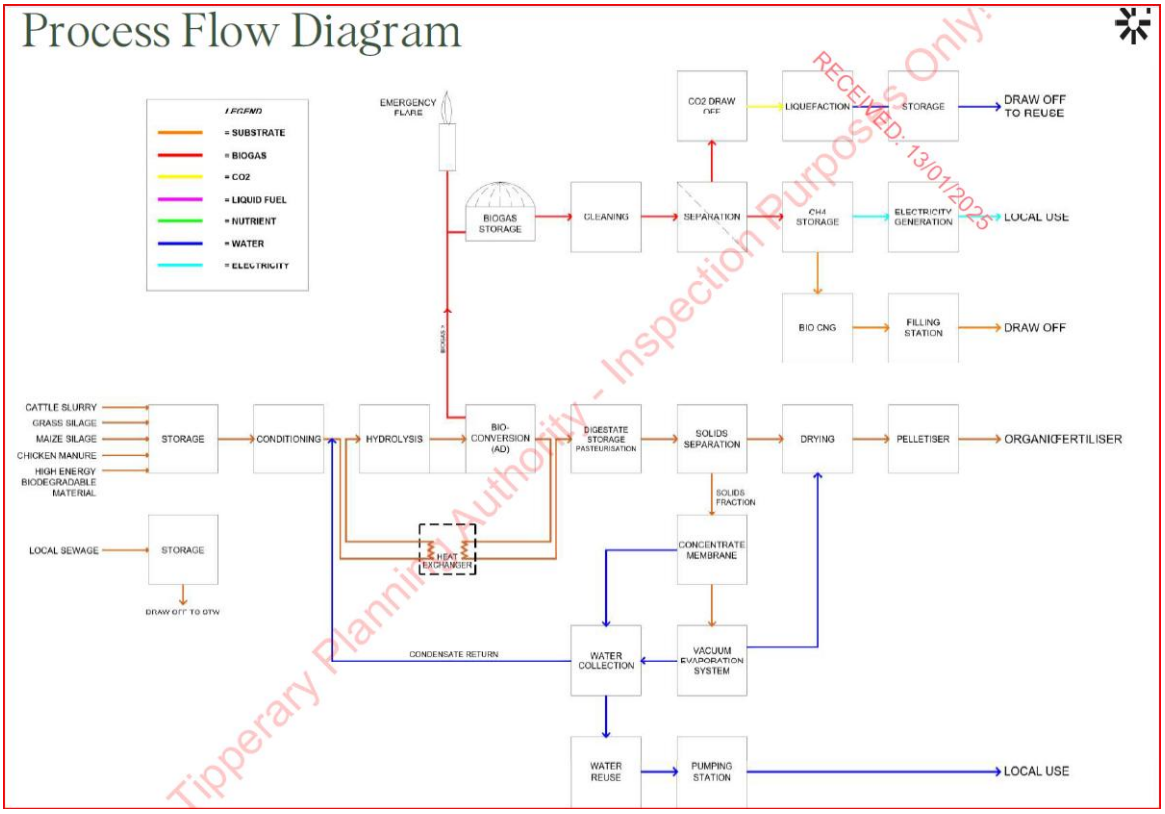
Further details on the public consultation process, attendees and the main issues raised are provided in **Appendix C**.



Introduction: Appendix A, page 55- Letter drop - Public information Pack – Note 500 metre radius



1st Party Appeal – Note totally different & far greater 500 metre radius. The local community was simply deceived.



Response from MLavelle: Introduction: Appendix D, page 68- Letter drop Public information Pack This is the process included in the planning application, but it does not reflect the process in the First Party Appeal.

Response from MLavelle: Note no mention of LNG

2 DETAILS OF DEVELOPMENT

- Feedstock importation will be c. 105,000 tonnes per annum consisting of:
  - Chicken Waste: c. 15,000 tpa
  - Cattle Slurry: c. 20,000 tpa
  - Grass Silage: c. 60,000 tpa
  - Maize Silage: c. 5,000 tpa
  - Pot ale and Spent Grain c. 5,000 tpa

Response from MLavelle: The planning application was for 90,000tonnes per annum and not 105,000 tonnes per annum and a totally different feedstock breakdown.

Table 12.11: Feedstock Intake Data

Feedstock in	Tonnes/year	Average Load (T)	Max. Loads Per Annum	Mean Deliveries/Day	Total In/Out Movements
Chicken Manure	3,000	28	107	0.4 (1 trip)	0.8 (2 trips)
Cattle Manure	6,000	28	214	0.85 (1 trip)	1.7 (2 trips)
Cattle Slurry	25,000	30	833	3.3 (4 trips)	6.6 (8 trips)
Pig Slurry	30,000	30	1000	4.0	8.0
Crops	7,000	28	250	1.0	2.0
Grass Silage	15,000	28	536	2.1 (3 trips)	4.2 (6 trips)
Belly Grass	1,000	28	36	0.1 (1 trip)	0.3 (2 trips)
Distillery Waste	1,500	30	50	0.2 (1 trip)	0.4 (2 trips)
Dairy Processing Waste	1,500	30	50	0.2 (1 trip)	0.4 (2 trips)
Subtotal	**90,000**			**12.15 (17 trips)**	**24.3 (34 trips)**

- Outputs will consist of:
  - bio-methane (gas);
  - compressed bio-methane (bio-CNG);
  - carbon dioxide (CO_2);
  - electricity (green);
  - organic fertilisers (pelleted); and
  - water.

The adjacent Roadstone Killough Quarry plant will utilise the electricity, bio-methane and water generated by the proposed development. Pelletised fertiliser will be available for supply to local agriculture and traders off-site. CNG and CO_2 will be pressurised and stored for ongoing draw-off by tankers to points of re-use off-site.

Response from MLavelle: Note no reference to LNG.

3.4 Impacts

The risk of fatality arising from a major accident hazard can be related to the consequences of the event (e.g. exposure to thermal radiation, a blast overpressure, or a toxic substance) by means of probit functions and other derived relations.

As described in the UK HSE's *Methods of approximation and determination of human vulnerability for offshore major accident hazard assessment*, probit account for the variation in tolerance to harm for an exposed population, with the fatality rate of personnel exposed to harmful agents over a given period of time calculated using a probit function of the general form:

Offshore major accident hazard assessments are not the same as onshore with existing surrounding populations. This Report deals with Thermal effects & Overpressure effects. It totally ignores the effects for asphyxiation.

Unlike the probit for thermal effects, the probit for overpressure effects is only related to the overpressure (P) expressed in pounds per square inch (psi).

In the case of overpressures, the relationship between outdoor effects and indoor effects has been examined by the Chemical Industries Association (CIA) for various types of building, and the CIA has developed correlations relating overpressures to indoor vulnerabilities[2].

4 DANGEROUS SUBSTANCES

The dangerous substances that are stored and handled at the site are set out in Table 4. This table identifies the materials at the site which have hazard properties that qualify under Schedule 1 of the COMAH Regulations, i.e. it lists the COMAH substances at the site.

Table 4: Hazardous Properties of COMAH substances

Material	COMAH Hazard Statements	Comments
LNG	H220: Extremely flammable gas H224: Extremely flammable liquid and vapour H281: Contains refrigerated gas; may cause cryogenic burns or injury	Stored in various locations. LNG storage tank, located at the biofilling station LNG trucks at filling station LNG trucks at staging area
Biogas	H220: Extremely flammable gas	This is a mixture of CO_2 and Methane. Stored at low pressure in a balloon.

In addition to the storage vessels, there are also pipelines for the distribution of LNG and biogas. The locations of the biofilling station and the staging area are shown on DWG 1905-DG-0014. The distribution pipework detail is shown in DWG 1905-DG-0024. Copies of both of these drawings are included in Appendix 1.

The total inventories of dangerous substances at the site are compared with the qualifying quantities from Schedule 1 of the Regulations in Table 5.

Table 5: COMAH inventory

Installation	Storage quantity (q)	Schedule 1	Qualifying Quantities (Q)		Σq/Q	
			Lower tier	Upper tier	Lower tier	Upper tier
LNG tank	24 tonnes	Named (18)	50	200	0.48	0.12
Biogas	7.1 tonnes	P2	10	50	0.71	0.142
IsoLNG	9.6 tonnes	Named (18)	50	200	0.192	0.048
Staging of isoLNG	28.8 tonnes	Named (18)	50	200	0.576	0.144
Totals					**1.958**	**0.454**

We have calculated the aggregated inventory of dangerous substances (Σq/Q, where q is the quantity stored and Q is the qualifying quantity under COMAH) for the site. Under normal operations, the value for Σq/Q is greater than 1 when the qualifying quantities for lower tier are

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ISSUE 5:

NOTE THE DISTANCES FOR FIRE EFFECTS & NO MENTION OF ASPHIXIATION DISTANCES

5.2 Consequence Modelling Software

The consequences from each of the hazardous events –thermal radiation and overpressures – have been determined using the GEXCON EFFECTS 13 modelling software.

Note that a different version of modelling software was identified in the Planning Application.

4.2 Consequence Modelling Software

The consequences from each of the hazardous events –thermal radiation and overpressures – have been determined using the GEXCON EFFECTS 12 modelling software.

Response from MLavelle: Is it possible to see the input parameters in this modelling software? Is it verified for use in Ireland? Where has it been used for Biogas plants in Ireland? Is Gexcon Effects 12 the up-to-date modelling software available [It's not]? Does Gexcon have an Irish office & is its modelling software covered by insurance in Ireland?

GEXCON: The 7 essential hazards in LNG facilities. Tommy Stokmo Jørstad. Consulting Manager Norway – Principal Engineer at Gexcon

As the world moves towards decarbonization, natural gas is finding its place as a cleaner-burning alternative to other fossil fuels.

For safer storage and transport, natural gas can be cooled down to its liquid form – LNG. However, facilities handling LNG, such as liquefaction plants, regasification plants, and storage facilities, are still associated with potential hazards. Understanding these hazards is essential to implementing the necessary prevention and mitigation measures.

A key risk in LNG facilities is an uncontrolled release of a cryogenic, toxic, or flammable fluid. Such releases can originate in various parts of the process system. The consequence of these releases depends on what they expose and on whether they are ignited. In short, the essential LNG facility hazards can be grouped into seven categories.

- Temperature
- Cryogenic liquid releases that cause embrittlement if they expose materials not designed to handle such releases, and freeze burns if they expose personnel.
- Hot vapour releases from turbines, boilers, and engines for power and heat generation.
- Toxic Hydrogen sulfide H2S or ammonia releases that are toxic.
- Asphyxiation: Nitrogen oxide, carbon monoxide, carbon dioxide, or sulphur dioxide releases that replace oxygen in an area and could cause asphyxiation.
- Pool fire: Liquid releases that form a pool on the ground or water and ignite, creating a potentially long-lasting pool fire.
- Jet fire: Pressurized gas or liquid releases that ignite, creating a high heat flux jet fire.
- Flammable vapour dispersion/ flash fire: Gas or liquid releases that form a flammable cloud in an open area, and ignite, causing a short and intense flash fire that is harmful to personnel.
- Vapour cloud explosion (VCE): Gas or liquid releases that form a flammable cloud in a congested or enclosed area, and ignite, causing an explosion and a pressure wave.

Tables below indicate Land Use Planning Ref: 609-25X0241 6th November 2025 with green background & LAND USE PLANNING RISK ASSESSMENT. Ref: 609-25X0241, Rev.2. 4th March 2026 with black background. The Table numbering system used by the Applicants Agent are not consistent.

Note Table 10 of 6/11/2025 versus Table 11 of 4/3/2026 & Table 11 of 6/11/2025 versus Table 12 of 4/3/2026. The same model data results in a different result with an increased factor of c5. This suggests that the model was used incorrectly or operated inconsistently. In either case it brings the model into disrepute & makes the readings invalid.

Table 6: Consequence modelling of fire scenarios following instantaneous release from LNG tank

BLEVE		Pool Fire	
Diameter	149.2 m	Diameter	98.7 m
Duration	10.5 s	Duration	21.7 s
Distance	**Flux**	**Distance**	**Flux**
95 m	25.6 kW/m²	185 m	25.6 kW/m²
202 m	12.7 kW/m²	249 m	12.7 kW/m²
277 m	8 kW/m²	300 m	8 kW/m²
320 m	6.3 kW/m²	331 m	6.3 kW/m²
413 m	4 kW/m²	400 m	4 kW/m²

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Note the 413 & 400m distances. 12 Existing houses are within this range.

Table 7: Consequence modelling of fire scenarios following instantaneous release from LNG tank

BLEVE		Pool Fire	
Diameter	149.2 m	Diameter	98.7 m
Duration	10.5 s	Duration	21.7 s
Distance	**Flux**	**Distance**	**Flux**
95 m	25.6 kW/m²	185 m	25.6 kW/m²
202 m	12.7 kW/m²	249 m	12.7 kW/m²
277 m	8 kW/m²	300 m	8 kW/m²
320 m	6.3 kW/m²	331 m	6.3 kW/m²
413 m	4 kW/m²	400 m	4 kW/m²

Inspection Purpose

Response from MLavelle: A thermal radiation flux of 4kw/m² is sufficient to cause materials in a house to catch fire (ignite) over time and it is recognised as a threshold for significant fire danger.

The following is a breakdown why this level is dangerous:

- Ignition potential: At 4kw/m², common household materials (wood, fabrics, paper) can reach their ignition temperature, especially if exposed for a prolonged period. This level of radiation can cause charring and eventually pilot ignition.
- Danger to Personnel: Thermal radiation of 4kw/m² is generally considered the maximum safe level for personnel to be exposed to for short periods (around 20-30seconds). Beyond that, it causes severe pain and second degree burns.
- Fire Spread: This level of radiation is high enough to cause a fire to spread from one building to another or from a nearby fire source to a home.

For context, in industrial safety, this level is used to determine safe distances from fire hazards, as it can cause combustible materials to ignite.

There are numerous houses (12no.) within the 500m radius and exposed to this fire hazard. These houses will not be insurable or sellable if this project is given approval. Residents are at serious risk from a nighttime event. The agricultural lands within the 500m radius will also involve animal deaths. This is not proper planning or sustainable development.

Table 7: Consequence modelling of flash fire and VCE scenarios for instantaneous release from LNG tank

Release in typical weather conditions (D5)		Release in calm weather conditions (F2)	
Max Distance to LEL	245 m	Max Distance to LEL	597 m
Width	99.2 m	Width	197 m
Flammable mass	1360 kg	Flammable mass	9750 kg
Distance	**Overpressure**	**Distance**	**Overpressure**
43 m	600 mbar	83 m	600 mbar
101 m	168 mbar	194 m	168 mbar
140 m	100 mbar	292 m	100 mbar
268 m	50 mbar	518 m	50 mbar

Table 8: Consequence modelling of flash fire and VCE scenarios for instantaneous release from LNG tank

Release in typical weather conditions (D5)		Release in calm weather conditions (F2)	
Max Distance to LEL	245 m	Max Distance to LEL	597 m
Width	99.2 m	Width	197 m
Flammable mass	1360 kg	Flammable mass	9750 kg
Distance	**Overpressure**	**Distance**	**Overpressure**
43 m	600 mbar	83 m	600 mbar
101 m	168 mbar	194 m	168 mbar
140 m	100 mbar	292 m	100 mbar
268 m	50 mbar	518 m	50 mbar

Table 8: Consequence modelling of fire scenarios following 10-minute release from LNG tank

Jet Fire – Horizontal Release		Jet Fire – Vertical Release		Pool Fire	
Duration	600 s	Duration	600 s	Duration	600 s
Distance	**Flux**	**Distance**	**Flux**	**Distance**	**Flux**
103 m	25.6 kW/m^2	17 m	25.6 kW/m^2	54 m	25.6 kW/m^2
113 m	12.7 kW/m^2	36 m	12.7 kW/m^2	70 m	12.7 kW/m^2
122 m	8 kW/m^2	47 m	8 kW/m^2	83 m	8 kW/m^2
126 m	6.3 kW/m^2	52 m	6.3 kW/m^2	91 m	6.3 kW/m^2
136 m	4 kW/m^2	63 m	4 kW/m^2	108 m	4 kW/m^2

Table 9: Consequence modelling of fire scenarios following 10-minute release from LNG tank

Jet Fire – Horizontal Release		Jet Fire – Vertical Release		Pool Fire	
Duration	600 s	Duration	600 s	Duration	600 s
Distance	**Flux**	**Distance**	**Flux**	**Distance**	**Flux**
103 m	25.6 kW/m^2	17 m	25.6 kW/m^2	54 m	25.6 kW/m^2
113 m	12.7 kW/m^2	36 m	12.7 kW/m^2	70 m	12.7 kW/m^2
122 m	8 kW/m^2	47 m	8 kW/m^2	83 m	8 kW/m^2
126 m	6.3 kW/m^2	52 m	6.3 kW/m^2	91 m	6.3 kW/m^2
136 m	4 kW/m^2	63 m	4 kW/m^2	108 m	4 kW/m^2

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Table 9: Consequence modelling of flash fire and VCE scenarios for 10-minute release from LNG tank

10-minute Horizontal (typical D5)		10-minute Horizontal (calm F2)		10-minute Vertical (typical D5)		10-minute Vertical (calm F2)	
Dist. to LEL	181 m	Dist. to LEL	321 m	Dist. to LEL	80.3 m	Dist. to LEL	149 m
Width	49.4 m	Width	148 m	Width	14.6 m	Width	119 m
Flammable mass	359 kg	Flammable mass	1400 kg	Flammable mass	0.0346 kg	Flammable mass	93.8 kg
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
28 m	600 mbar	44 m	600 mbar	-	600 mbar	18 m	600 mbar
64 m	168 mbar	102 m	168 mbar	-	168 mbar	41 m	168 mbar
97 m	100 mbar	153 m	100 mbar	-	100 mbar	62 m	100 mbar
171 m	50 mbar	270 m	50 mbar	-	50 mbar	110 m	50 mbar

Table 10: Consequence modelling of flash fire and VCE scenarios for 10-minute release from LNG tank

10-minute Horizontal (typical D5)		10-minute Horizontal (calm F2)		10-minute Vertical (typical D5)		10-minute Vertical (calm F2)	
Dist. to LEL	181 m	Dist. to LEL	321 m	Dist. to LEL	80.3 m	Dist. to LEL	149 m
Width	49.4 m	Width	148 m	Width	14.6 m	Width	119 m
Flammable mass	359 kg	Flammable mass	1400 kg	Flammable mass	0.0346 kg	Flammable mass	93.8 kg
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
28 m	600 mbar	44 m	600 mbar	-	600 mbar	18 m	600 mbar
64 m	168 mbar	102 m	168 mbar	-	168 mbar	41 m	168 mbar
97 m	100 mbar	153 m	100 mbar	-	100 mbar	62 m	100 mbar
171 m	50 mbar	270 m	50 mbar	-	50 mbar	110 m	50 mbar

Table 10: Consequence modelling of fire scenarios following 10-mm diameter release from LNG tank

Jet Fire – Horizontal Release		Jet Fire – Vertical Release		Pool Fire	
Distance	**Flux**	**Distance**	**Flux**	**Distance**	**Flux**
16.5 m	25.6 kW/m²	3 m	25.6 kW/m²	6.5 m	25.6 kW/m²
18.5 m	12.7 kW/m²	6 m	12.7 kW/m²	7.5 m	12.7 kW/m²
19.5 m	8 kW/m²	8 m	8 kW/m²	8 m	8 kW/m²
20.5 m	6.3 kW/m²	8.5 m	6.3 kW/m²	8.5 m	6.3 kW/m²
22 m	4 kW/m²	10 m	4 kW/m²	9.5 m	4 kW/m²

Table 11: Consequence modelling of fire scenarios following 10-mm diameter release from LNG tank

Jet Fire – Horizontal Release		Jet Fire – Vertical Release		Pool Fire	
Distance	**Flux**	**Distance**	**Flux**	**Distance**	**Flux**
79 m	25.6 kW/m²	10 m	25.6 kW/m²	13 m	25.6 kW/m²
87 m	12.7 kW/m²	25 m	12.7 kW/m²	16 m	12.7 kW/m²
95 m	8 kW/m²	32 m	8 kW/m²	19 m	8 kW/m²
99 m	6.3 kW/m²	36 m	6.3 kW/m²	20 m	6.3 kW/m²
108 m	4 kW/m²	42 m	4 kW/m²	23 m	4 kW/m²

Note the different distances in T10 & T11 for same event

Table 11: Consequence modelling of flash fire and VCE scenarios for 10 mm diameter release from LNG tank

10-mm Horizontal (typical D5)		10-mm Horizontal (calm F2)		10-mm Vertical (typical D5)		10-mm Vertical (calm F2)	
Dist. to LEL	13.6 m	Dist. to LEL	16.5 m	Dist. to LEL	0.285 m	Dist. to LEL	0.1 m
Width	2.4 m	Width	6.8 m	Width	1 m	Width	0.8 m
Flammable mass	0.155 kg	Flammable mass	0.367 kg	Flammable mass	0.00018 kg	Flammable mass	0.00048 kg
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
2 m	600 mbar	3 m	600 mbar	-	600 mbar	-	600 mbar
5 m	168 mbar	6.5 m	168 mbar	-	168 mbar	-	168 mbar
7 m	100 mbar	10 m	100 mbar	-	100 mbar	-	100 mbar
13 m	50 mbar	17 m	50 mbar	-	50 mbar	-	50 mbar

Table 12: Consequence modelling of flash fire and VCE scenarios for 10 mm diameter release from LNG tank

50-mm Horizontal (typical D5)		50-mm Horizontal (calm F2)		50-mm Vertical (typical D5)		50-mm Vertical (calm F2)	
Dist. to LEL	111 m	Dist. to LEL	204 m	Dist. to LEL	72 m	Dist. to LEL	103 m
Width	28 m	Width	76 m	Width	18.6 m	Width	102 m
Flammable mass	96.8 kg	Flammable mass	410 kg	Flammable mass	9.31 kg	Flammable mass	183 kg
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
18 m	600 mbar	29 m	600 mbar	8 m	600 mbar	22 m	600 mbar
42 m	168 mbar	68 m	168 mbar	19 m	168 mbar	53 m	168 mbar
63 m	100 mbar	102 m	100 mbar	29 m	100 mbar	78 m	100 mbar
111 m	50 mbar	180 m	50 mbar	51 m	50 mbar	137 m	50 mbar

Note the different distances in T11 & T12 for same event

Table 13: Consequence modelling of fireball following instantaneous release from biogas balloon

Fireball	
Diameter	111.5 m
Duration	8.65 s
Distance	**Flux**
136 m	25.6 kW/m^2
197 m	12.7 kW/m^2
249 m	8 kW/m^2
277 m	6.3 kW/m^2
347 m	4 kW/m^2

Table 14: Consequence modelling of fireball following instantaneous release from biogas balloon

Fireball	
Diameter	111.5 m
Duration	8.65 s
Distance	**Flux**
136 m	25.6 kW/m^2
197 m	12.7 kW/m^2
249 m	8 kW/m^2
277 m	6.3 kW/m^2
347 m	4 kW/m^2

Table 14: Modelling of flash fire / VCE consequences for instantaneous release from biogas balloon

	Instantaneous release of biogas from storage balloon	
Weather	D5	F2
Distance to LEL	197 m	110 m
Width to LEL	31 m	36.4 m
Explosive mass	2780 kg	2,430 kg
Distances to Endpoints		
...600 mbar	55 m	52 m
...168 mbar	127 m	122 m
...100 mbar	193 m	185 m
...50 mbar	340 m	352 m

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Table 15: Modelling of flash fire / VCE consequences for instantaneous release from biogas balloon

	Instantaneous release of biogas from storage balloon	
Weather	D5	F2
Distance to LEL	197 m	110 m
Width to LEL	31 m	36.4 m
Explosive mass	2780 kg	2,430 kg
Distances to Endpoints		
...600 mbar	55 m	52 m
...168 mbar	127 m	122 m
...100 mbar	193 m	185 m
...50 mbar	340 m	352 m

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Table 15: Modelling of Jet Fire consequences for 10-minute release from biogas balloon

Jet Fire – Horizontal Release		Jet Fire – Vertical Release	
Duration	600 s	Duration	600 s
Distance	**Flux**	**Distance**	**Flux**
72 m	25.6 kW/m^2	22 m	25.6 kW/m^2
79 m	12.7 kW/m^2	34 m	12.7 kW/m^2
85 m	8 kW/m^2	41 m	8 kW/m^2
88 m	6.3 kW/m^2	45 m	6.3 kW/m^2
96 m	4 kW/m^2	56 m	4 kW/m^2

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Table 16: Modelling of Jet Fire consequences for 10-minute release from biogas balloon

Jet Fire – Horizontal Release		Jet Fire – Vertical Release	
Duration	600 s	Duration	600 s
Distance	**Flux**	**Distance**	**Flux**
72 m	25.6 kW/m^2	22 m	25.6 kW/m^2
79 m	12.7 kW/m^2	34 m	12.7 kW/m^2
85 m	8 kW/m^2	41 m	8 kW/m^2
88 m	6.3 kW/m^2	45 m	6.3 kW/m^2
96 m	4 kW/m^2	56 m	4 kW/m^2

Table 16: Modelling of flash fire / VCE consequences for 10-minute release from biogas balloon

10-minute Horizontal (typical D5)		10-minute Horizontal (calm F2)		10-minute Vertical (typical D5)		10-minute Vertical (calm F2)	
Dist. to LEL	98.6 m	Dist. to LEL	86.8 m	Dist. to LEL	26.5 m	Dist. to LEL	12.5 m
Width	9.8 m	Width	12.2 m	Width	10 m	Width	14.4 m
Flammable mass	53.5 kg	Flammable mass	63.1 kg	Flammable mass	6.82 kg	Flammable mass	6.81 kg
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
14.5 m	600 mbar	15.5 m	600 mbar	7 m	600 mbar	7 m	600 mbar
34 m	168 mbar	36 m	168 mbar	17 m	168 mbar	17 m	168 mbar
52 m	100 mbar	55 m	100 mbar	26 m	100 mbar	26 m	100 mbar
91 m	50 mbar	96 m	50 mbar	46 m	50 mbar	46 m	50 mbar

Table 17: Modelling of flash fire / VCE consequences for 10-minute release from biogas balloon

10-minute Horizontal (typical D5)		10-minute Horizontal (calm F2)		10-minute Vertical (typical D5)		10-minute Vertical (calm F2)	
Dist. to LEL	98.6 m	Dist. to LEL	86.8 m	Dist. to LEL	26.5 m	Dist. to LEL	12.5 m
Width	9.8 m	Width	12.2 m	Width	10 m	Width	14.4 m
Flammable mass	53.5 kg	Flammable mass	63.1 kg	Flammable mass	6.82 kg	Flammable mass	6.81 kg
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
14.5 m	600 mbar	15.5 m	600 mbar	7 m	600 mbar	7 m	600 mbar
34 m	168 mbar	36 m	168 mbar	17 m	168 mbar	17 m	168 mbar
52 m	100 mbar	55 m	100 mbar	26 m	100 mbar	26 m	100 mbar
91 m	50 mbar	96 m	50 mbar	46 m	50 mbar	46 m	50 mbar

Table 18: Biogas lines at the main compound

Parameter	Value
Diameter	~4" (100 mm)
Pressure	~4–15 barg (depends on compressor stage)
Length	~40 m (within compound)
Layout	Above ground, rack-mounted or trench-level with supports

Table 19: Biogas lines at the main compound

Parameter	Value
Diameter	~4" (100 mm)
Pressure	~4–15 barg (depends on compressor stage)
Length	~40 m (within compound)
Layout	Above ground, rack-mounted or trench-level with supports

Table 19: Jet Fires following loss of containment from biogas line at compound

Guillotine failure – Horizontal		Guillotine failure – Vertical		Leak – Horizontal		Leak – Vertical	
Distance	**Flux**	**Distance**	**Flux**	**Distance**	**Flux**	**Distance**	**Flux**
51 m	25.6 kW/m²	-	25.6 kW/m²	6.5 m	25.6 kW/m²	-	25.6 kW/m²
56 m	12.7 kW/m²	17 m	12.7 kW/m²	7 m	12.7 kW/m²	2 m	12.7 kW/m²
59 m	8 kW/m²	24 m	8 kW/m²	7.5 m	8 kW/m²	3.5 m	8 kW/m²
62 m	6.3 kW/m²	27 m	6.3 kW/m²	8 m	6.3 kW/m²	4 m	6.3 kW/m²
67 m	4 kW/m²	35 m	4 kW/m²	8.5 m	4 kW/m²	4.5 m	4 kW/m²

Table 20: Jet Fires following loss of containment from biogas line at compound

Guillotine failure – Horizontal		Guillotine failure – Vertical		Leak – Horizontal		Leak – Vertical	
Distance	**Flux**	**Distance**	**Flux**	**Distance**	**Flux**	**Distance**	**Flux**
51 m	25.6 kW/m²	-	25.6 kW/m²	6.5 m	25.6 kW/m²	-	25.6 kW/m²
56 m	12.7 kW/m²	17 m	12.7 kW/m²	7 m	12.7 kW/m²	2 m	12.7 kW/m²
59 m	8 kW/m²	24 m	8 kW/m²	7.5 m	8 kW/m²	3.5 m	8 kW/m²
62 m	6.3 kW/m²	27 m	6.3 kW/m²	8 m	6.3 kW/m²	4 m	6.3 kW/m²
67 m	4 kW/m²	35 m	4 kW/m²	8.5 m	4 kW/m²	4.5 m	4 kW/m²

Table 20: Flash fires or VCEs following guillotine failure of biogas line at compound

Guillotine Horizontal (typical D5)		Guillotine Horizontal (calm F2)		Guillotine Vertical (typical D5)		Guillotine Vertical (calm F2)	
Dist. to LEL	132 m	Dist. to LEL	101 m	Dist. to LEL	11 m	Dist. to LEL	6.4 m
Width	8 m	Width	9 m	Width	9 m	Width	12 m
Flammable mass	10.5 kg	Flammable mass	10.7 kg	Flammable mass	1.87 kg	Flammable mass	2.84 kg
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
8.5 m	600 mbar	8.5 m	600 mbar	5 m	600 mbar	5.5 m	600 mbar
20 m	168 mbar	20 m	168 mbar	11 m	168 mbar	13 m	168 mbar
30 m	100 mbar	30 m	100 mbar	17 m	100 mbar	20 m	100 mbar
53 m	50 mbar	53 m	50 mbar	30 m	50 mbar	34 m	50 mbar

Table 21: Flash fires or VCEs following guillotine failure of biogas line at compound

Guillotine Horizontal (typical D5)		Guillotine Horizontal (calm F2)		Guillotine Vertical (typical D5)		Guillotine Vertical (calm F2)	
Dist. to LEL	132 m	Dist. to LEL	101 m	Dist. to LEL	11 m	Dist. to LEL	6.4 m
Width	8 m	Width	9 m	Width	9 m	Width	12 m
Flammable mass	10.5 kg	Flammable mass	10.7 kg	Flammable mass	1.87 kg	Flammable mass	2.84 kg
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
8.5 m	600 mbar	8.5 m	600 mbar	5 m	600 mbar	5.5 m	600 mbar
20 m	168 mbar	20 m	168 mbar	11 m	168 mbar	13 m	168 mbar
30 m	100 mbar	30 m	100 mbar	17 m	100 mbar	20 m	100 mbar
53 m	50 mbar	53 m	50 mbar	30 m	50 mbar	34 m	50 mbar

Table 21: Flash fires or VCEs following leak from biogas line at compound

Guillotine Horizontal (typical D5)		Guillotine Horizontal (calm F2)		Guillotine Vertical (typical D5)		Guillotine Vertical (calm F2)	
Dist. to LEL	4.4 m	Dist. to LEL	4.7 m	Dist. to LEL	0.87 m	Dist. to LEL	1 m
Width	0.65 m	Width	0.66 m	Width	1.2 m	Width	1.6 m
Flammable mass	0.0052 kg	Flammable mass	0.0053 kg	Flammable mass	0.0039 kg	Flammable mass	0.0068 kg
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
-	600 mbar	-	600 mbar	-	600 mbar	-	600 mbar
-	168 mbar	-	168 mbar	-	168 mbar	-	168 mbar
-	100 mbar	-	100 mbar	-	100 mbar	-	100 mbar
-	50 mbar	-	50 mbar	-	50 mbar	-	50 mbar

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Table 22: Flash fires or VCEs following leak from biogas line at compound

Guillotine Horizontal (typical D5)		Guillotine Horizontal (calm F2)		Guillotine Vertical (typical D5)		Guillotine Vertical (calm F2)	
Dist. to LEL	4.4 m	Dist. to LEL	4.7 m	Dist. to LEL	0.87 m	Dist. to LEL	1 m
Width	0.65 m	Width	0.66 m	Width	1.2 m	Width	1.6 m
Flammable mass	0.0052 kg	Flammable mass	0.0053 kg	Flammable mass	0.0039 kg	Flammable mass	0.0068 kg
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
-	600 mbar	-	600 mbar	-	600 mbar	-	600 mbar
-	168 mbar	-	168 mbar	-	168 mbar	-	168 mbar
-	100 mbar	-	100 mbar	-	100 mbar	-	100 mbar
-	50 mbar	-	50 mbar	-	50 mbar	-	50 mbar

Table 23: Jet Fires following loss of containment from 50 mm line to loading area

Guillotine failure – Horizontal		Guillotine failure – Vertical		Leak – Horizontal		Leak – Vertical	
Distance	**Flux**	**Distance**	**Flux**	**Distance**	**Flux**	**Distance**	**Flux**
85 m	25.6 kW/m²	37 m	25.6 kW/m²	13 m	25.6 kW/m²	5.5 m	25.6 kW/m²
95 m	12.7 kW/m²	49 m	12.7 kW/m²	14 m	12.7 kW/m²	7 m	12.7 kW/m²
103 m	8 kW/m²	59 m	8 kW/m²	15 m	8 kW/m²	8.5 m	8 kW/m²
107 m	6.3 kW/m²	65 m	6.3 kW/m²	16 m	6.3 kW/m²	9 m	6.3 kW/m²
118 m	4 kW/m²	79 m	4 kW/m²	17 m	4 kW/m²	11 m	4 kW/m²

Table 24: Jet Fires following loss of containment from 50 mm line to loading area

Guillotine failure – Horizontal		Guillotine failure – Vertical		Leak – Horizontal		Leak – Vertical	
Distance	**Flux**	**Distance**	**Flux**	**Distance**	**Flux**	**Distance**	**Flux**
85 m	25.6 kW/m²	37 m	25.6 kW/m²	13 m	25.6 kW/m²	5.5 m	25.6 kW/m²
95 m	12.7 kW/m²	49 m	12.7 kW/m²	14 m	12.7 kW/m²	7 m	12.7 kW/m²
103 m	8 kW/m²	59 m	8 kW/m²	15 m	8 kW/m²	8.5 m	8 kW/m²
107 m	6.3 kW/m²	65 m	6.3 kW/m²	16 m	6.3 kW/m²	9 m	6.3 kW/m²
118 m	4 kW/m²	79 m	4 kW/m²	17 m	4 kW/m²	11 m	4 kW/m²

Table 24: Flash fires or VCEs following guillotine failure of 50 mm line to loading area

Guillotine Horizontal (typical D5)		Guillotine Horizontal (calm F2)		Guillotine Vertical (typical D5)		Guillotine Vertical (calm F2)	
Dist. to LEL	123 m	Dist. to LEL	225 m	Dist. to LEL	73.1 m	Dist. to LEL	112 m
Width	32.2 m	Width	88.4 m	Width	17.6 m	Width	104 m
Flammable mass	129 kg	Flammable mass	541 kg	Flammable mass	1.2 kg	Flammable mass	171 kg
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
20 m	600 mbar	32 m	600 mbar	4 m	600 mbar	22 m	600 mbar
46 m	168 mbar	74 m	168 mbar	9.5 m	168 mbar	50 m	168 mbar
69 m	100 mbar	111 m	100 mbar	14.5 m	100 mbar	76 m	100 mbar
122 m	50 mbar	197 m	50 mbar	26 m	50 mbar	134 m	50 mbar

Table 25: Flash fires or VCEs following guillotine failure of 50 mm line to loading area

Guillotine Horizontal (typical D5)		Guillotine Horizontal (calm F2)		Guillotine Vertical (typical D5)		Guillotine Vertical (calm F2)	
Dist. to LEL	123 m	Dist. to LEL	225 m	Dist. to LEL	73.1 m	Dist. to LEL	112 m
Width	32.2 m	Width	88.4 m	Width	17.6 m	Width	104 m
Flammable mass	129 kg	Flammable mass	541 kg	Flammable mass	1.2 kg	Flammable mass	171 kg
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
20 m	600 mbar	32 m	600 mbar	4 m	600 mbar	22 m	600 mbar
46 m	168 mbar	74 m	168 mbar	9.5 m	168 mbar	50 m	168 mbar
69 m	100 mbar	111 m	100 mbar	14.5 m	100 mbar	76 m	100 mbar
122 m	50 mbar	197 m	50 mbar	26 m	50 mbar	134 m	50 mbar

Table 25: Flash fires or VCEs following leak from 50 mm line to loading area

Guillotine Horizontal (typical D5)		Guillotine Horizontal (calm F2)		Guillotine Vertical (typical D5)		Guillotine Vertical (calm F2)	
Dist. to LEL	16.9 m	Dist. to LEL	20.9 m	Dist. to LEL	0.1 m	Dist. to LEL	1.0 m
Width	2.6 m	Width	7.2 m	Width	0.4 m	Width	0.2 m
Flammable mass	0.273 kg	Flammable mass	0.616 kg	Flammable mass	4.8E-05 kg	Flammable mass	4.82E-05
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
2.5 m	600 mbar	3.5 m	600 mbar	-	600 mbar	-	600 mbar
6 m	168 mbar	8 m	168 mbar	-	168 mbar	-	168 mbar
9 m	100 mbar	11.5 m	100 mbar	-	100 mbar	-	100 mbar
16 m	50 mbar	21 m	50 mbar	-	50 mbar	-	50 mbar

Table 26: Flash fires or VCEs following leak from 50 mm line to loading area

Guillotine Horizontal (typical D5)		Guillotine Horizontal (calm F2)		Guillotine Vertical (typical D5)		Guillotine Vertical (calm F2)	
Dist. to LEL	16.9 m	Dist. to LEL	20.9 m	Dist. to LEL	0.1 m	Dist. to LEL	1.0 m
Width	2.6 m	Width	7.2 m	Width	0.4 m	Width	0.2 m
Flammable mass	0.273 kg	Flammable mass	0.616 kg	Flammable mass	4.8E-05 kg	Flammable mass	4.82E-05
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
2.5 m	600 mbar	3.5 m	600 mbar	-	600 mbar	-	600 mbar
6 m	168 mbar	8 m	168 mbar	-	168 mbar	-	168 mbar
9 m	100 mbar	11.5 m	100 mbar	-	100 mbar	-	100 mbar
16 m	50 mbar	21 m	50 mbar	-	50 mbar	-	50 mbar

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Table 26: Gas distribution pipelines

Pipe Section	Internal Diameter	Gas	Length	Pressure
A	50 mm	Biogas	200 m	0.1 bar
B	200 mm	Biogas	110 m	0.1 bar
C	250 mm	Biogas	296 m	0.1 bar
D	200 mm	Biogas	120 m	0.1 bar
E	50 mm	Biomethane	65 m	30 bar
F	50 mm	Bio LNG	50 m	4 bar
G	50 mm	Bio LNG	208 m	4 bar

Table 27: Gas distribution pipelines

Pipe Section	Internal Diameter	Gas	Length	Pressure
A	50 mm	Biogas	200 m	0.1 bar
B	200 mm	Biogas	110 m	0.1 bar
C	250 mm	Biogas	296 m	0.1 bar
D	200 mm	Biogas	120 m	0.1 bar
E	50 mm	Biomethane	65 m	30 bar
F	50 mm	Bio LNG	50 m	4 bar
G	50 mm	Bio LNG	208 m	4 bar

Table 27: Jet Fires following loss of containment from Pipe Section A

Guillotine failure – Horizontal		Guillotine failure – Vertical		Leak – Horizontal		Leak – Vertical	
Distance	Flux	Distance	Flux	Distance	Flux	Distance	Flux
-	25.6 kW/m²	2.5 m	25.6 kW/m²	1 m	25.6 kW/m²	0.5 m	25.6 kW/m²
6 m	12.7 kW/m²	3 m	12.7 kW/m²	1.1 m	12.7 kW/m²	0.6 m	12.7 kW/m²
6.2 m	8 kW/m²	3.5 m	8 kW/m²	1.2 m	8 kW/m²	0.7 m	8 kW/m²
6.7 m	6.3 kW/m²	4 m	6.3 kW/m²	1.3 m	6.3 kW/m²	0.8 m	6.3 kW/m²
7.2 m	4 kW/m²	4.5 m	4 kW/m²	1.5 m	4 kW/m²	1 m	4 kW/m²

Table 28: Jet Fires following loss of containment from Pipe Section A

Guillotine failure – Horizontal		Guillotine failure – Vertical		Leak – Horizontal		Leak – Vertical	
Distance	Flux	Distance	Flux	Distance	Flux	Distance	Flux
-	25.6 kW/m²	2.5 m	25.6 kW/m²	1 m	25.6 kW/m²	0.5 m	25.6 kW/m²
6 m	12.7 kW/m²	3 m	12.7 kW/m²	1.1 m	12.7 kW/m²	0.6 m	12.7 kW/m²
6.2 m	8 kW/m²	3.5 m	8 kW/m²	1.2 m	8 kW/m²	0.7 m	8 kW/m²
6.7 m	6.3 kW/m²	4 m	6.3 kW/m²	1.3 m	6.3 kW/m²	0.8 m	6.3 kW/m²
7.2 m	4 kW/m²	4.5 m	4 kW/m²	1.5 m	4 kW/m²	1 m	4 kW/m²

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Table 28: Jet Fires following loss of containment from Pipe Section B (and for Section D)

Guillotine failure – Horizontal		Guillotine failure – Vertical		Leak – Horizontal		Leak – Vertical	
Distance	Flux	Distance	Flux	Distance	Flux	Distance	Flux
28 m	25.6 kW/m²	9 m	25.6 kW/m²	3.5 m	25.6 kW/m²	1 m	25.6 kW/m²
31 m	12.7 kW/m²	14 m	12.7 kW/m²	4 m	12.7 kW/m²	1.5 m	12.7 kW/m²
33 m	8 kW/m²	16 m	8 kW/m²	4.2 m	8 kW/m²	2 m	8 kW/m²
34 m	6.3 kW/m²	18 m	6.3 kW/m²	4.5 m	6.3 kW/m²	2.5 m	6.3 kW/m²
37 m	4 kW/m²	22 m	4 kW/m²	5 m	4 kW/m²	3 m	4 kW/m²

Table 29: Jet Fires following loss of containment from Pipe Section B (and for Section D)

Guillotine failure – Horizontal		Guillotine failure – Vertical		Leak – Horizontal		Leak – Vertical	
Distance	Flux	Distance	Flux	Distance	Flux	Distance	Flux
28 m	25.6 kW/m²	9 m	25.6 kW/m²	3.5 m	25.6 kW/m²	1 m	25.6 kW/m²
31 m	12.7 kW/m²	14 m	12.7 kW/m²	4 m	12.7 kW/m²	1.5 m	12.7 kW/m²
33 m	8 kW/m²	16 m	8 kW/m²	4.2 m	8 kW/m²	2 m	8 kW/m²
34 m	6.3 kW/m²	18 m	6.3 kW/m²	4.5 m	6.3 kW/m²	2.5 m	6.3 kW/m²
37 m	4 kW/m²	22 m	4 kW/m²	5 m	4 kW/m²	3 m	4 kW/m²

Table 29: Jet Fires following loss of containment from Pipe Section C

Guillotine failure – Horizontal		Guillotine failure – Vertical		Leak – Horizontal		Leak – Vertical	
Distance	Flux	Distance	Flux	Distance	Flux	Distance	Flux
30 m	25.6 kW/m²	10 m	25.6 kW/m²	4 m	25.6 kW/m²	1 m	25.6 kW/m²
33 m	12.7 kW/m²	15 m	12.7 kW/m²	4.5 m	12.7 kW/m²	2 m	12.7 kW/m²
35 m	8 kW/m²	17 m	8 kW/m²	4.8 m	8 kW/m²	2.5 m	8 kW/m²
37 m	6.3 kW/m²	19 m	6.3 kW/m²	5 m	6.3 kW/m²	3 m	6.3 kW/m²
40 m	4 kW/m²	23 m	4 kW/m²	5.5 m	4 kW/m²	3.5 m	4 kW/m²

Table 30: Jet Fires following loss of containment from Pipe Section C

Guillotine failure – Horizontal		Guillotine failure – Vertical		Leak – Horizontal		Leak – Vertical	
Distance	Flux	Distance	Flux	Distance	Flux	Distance	Flux
30 m	25.6 kW/m²	10 m	25.6 kW/m²	4 m	25.6 kW/m²	1 m	25.6 kW/m²
33 m	12.7 kW/m²	15 m	12.7 kW/m²	4.5 m	12.7 kW/m²	2 m	12.7 kW/m²
35 m	8 kW/m²	17 m	8 kW/m²	4.8 m	8 kW/m²	2.5 m	8 kW/m²
37 m	6.3 kW/m²	19 m	6.3 kW/m²	5 m	6.3 kW/m²	3 m	6.3 kW/m²
40 m	4 kW/m²	23 m	4 kW/m²	5.5 m	4 kW/m²	3.5 m	4 kW/m²

Table 30: Jet Fires following loss of containment from Pipe Section E

Guillotine failure – Horizontal		Guillotine failure – Vertical		Leak – Horizontal		Leak – Vertical	
Distance	Flux	Distance	Flux	Distance	Flux	Distance	Flux
82 m	25.6 kW/m²	-	25.6 kW/m²	14 m	25.6 kW/m²	-	25.6 kW/m²
90 m	12.7 kW/m²	28 m	12.7 kW/m²	15 m	12.7 kW/m²	1 m	12.7 kW/m²
96 m	8 kW/m²	39 m	8 kW/m²	16 m	8 kW/m²	1.2 m	8 kW/m²
100 m	6.3 kW/m²	45 m	6.3 kW/m²	17 m	6.3 kW/m²	1.5 m	6.3 kW/m²
109 m	4 kW/m²	58 m	4 kW/m²	18 m	4 kW/m²	2 m	4 kW/m²

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Table 31: Jet Fires following loss of containment from Pipe Section E

Guillotine failure – Horizontal		Guillotine failure – Vertical		Leak – Horizontal		Leak – Vertical	
Distance	**Flux**	**Distance**	**Flux**	**Distance**	**Flux**	**Distance**	**Flux**
82 m	25.6 kW/m²	-	25.6 kW/m²	14 m	25.6 kW/m²	-	25.6 kW/m²
90 m	12.7 kW/m²	28 m	12.7 kW/m²	15 m	12.7 kW/m²	1 m	12.7 kW/m²
96 m	8 kW/m²	39 m	8 kW/m²	16 m	8 kW/m²	1.2 m	8 kW/m²
100 m	6.3 kW/m²	45 m	6.3 kW/m²	17 m	6.3 kW/m²	1.5 m	6.3 kW/m²
109 m	4 kW/m²	58 m	4 kW/m²	18 m	4 kW/m²	2 m	4 kW/m²

Table 31: Jet Fires following loss of containment from Pipe Section F (and for Section G)

Guillotine failure – Horizontal		Guillotine failure – Vertical		Leak – Horizontal		Leak – Vertical	
Distance	**Flux**	**Distance**	**Flux**	**Distance**	**Flux**	**Distance**	**Flux**
69 m	25.6 kW/m²	31 m	25.6 kW/m²	11 m	25.6 kW/m²	5 m	25.6 kW/m²
77 m	12.7 kW/m²	40 m	12.7 kW/m²	12 m	12.7 kW/m²	6.5 m	12.7 kW/m²
84 m	8 kW/m²	48 m	8 kW/m²	13 m	8 kW/m²	7.5 m	8 kW/m²
87 m	6.3 kW/m²	53 m	6.3 kW/m²	13.5 m	6.3 kW/m²	8 m	6.3 kW/m²
96 m	4 kW/m²	63 m	4 kW/m²	15 m	4 kW/m²	9.5 m	4 kW/m²

Table 32: Jet Fires following loss of containment from Pipe Section F (and for Section G)

Guillotine failure – Horizontal		Guillotine failure – Vertical		Leak – Horizontal		Leak – Vertical	
Distance	**Flux**	**Distance**	**Flux**	**Distance**	**Flux**	**Distance**	**Flux**
69 m	25.6 kW/m²	31 m	25.6 kW/m²	11 m	25.6 kW/m²	5 m	25.6 kW/m²
77 m	12.7 kW/m²	40 m	12.7 kW/m²	12 m	12.7 kW/m²	6.5 m	12.7 kW/m²
84 m	8 kW/m²	48 m	8 kW/m²	13 m	8 kW/m²	7.5 m	8 kW/m²
87 m	6.3 kW/m²	53 m	6.3 kW/m²	13.5 m	6.3 kW/m²	8 m	6.3 kW/m²
96 m	4 kW/m²	63 m	4 kW/m²	15 m	4 kW/m²	9.5 m	4 kW/m²

Table 32: Flash fires or VCEs following guillotine failure of Pipe Section A

Guillotine Horizontal (typical D5)		Guillotine Horizontal (calm F2)		Guillotine Vertical (typical D5)		Guillotine Vertical (calm F2)	
Dist. to LEL	2.7 m	Dist. to LEL	3.31 m	Dist. to LEL	0.23 m	Dist. to LEL	0.75 m
Width	0.6 m	Width	0.8 m	Width	0.6 m	Width	1 m
Flammable mass	0.012 kg	Flammable mass	0.0296 kg	Flammable mass	0.0009 kg	Flammable mass	0.0078 kg
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
-	600 mbar	-	600 mbar	-	600 mbar	-	600 mbar
-	168 mbar	-	168 mbar	-	168 mbar	-	168 mbar
-	100 mbar	-	100 mbar	-	100 mbar	-	100 mbar
-	50 mbar	-	50 mbar	-	50 mbar	-	50 mbar

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Table 33: Flash fires or VCEs following guillotine failure of Pipe Section A

Guillotine Horizontal (typical D5)		Guillotine Horizontal (calm F2)		Guillotine Vertical (typical D5)		Guillotine Vertical (calm F2)	
Dist. to LEL	2.7 m	Dist. to LEL	3.31 m	Dist. to LEL	0.23 m	Dist. to LEL	0.75 m
Width	0.6 m	Width	0.8 m	Width	0.6 m	Width	1 m
Flammable mass	0.012 kg	Flammable mass	0.0296 kg	Flammable mass	0.0009 kg	Flammable mass	0.0078 kg
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
-	600 mbar	-	600 mbar	-	600 mbar	-	600 mbar
-	168 mbar	-	168 mbar	-	168 mbar	-	168 mbar
-	100 mbar	-	100 mbar	-	100 mbar	-	100 mbar
-	50 mbar	-	50 mbar	-	50 mbar	-	50 mbar

Table 33: Flash fires or VCEs following guillotine failure of Pipe Section B or Section D

Guillotine Horizontal (typical D5)		Guillotine Horizontal (calm F2)		Guillotine Vertical (typical D5)		Guillotine Vertical (calm F2)	
Dist. to LEL	16.6 m	Dist. to LEL	14.9 m	Dist. to LEL	0.45 m	Dist. to LEL	2.41 m
Width	2.2 m	Width	3 m	Width	2.2 m	Width	3.6 m
Flammable mass	2.35 kg	Flammable mass	3.69 kg	Flammable mass	0.056 kg	Flammable mass	0.582 kg
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
5 m	600 mbar	6 m	600 mbar	1.5 m	600 mbar	3 m	600 mbar
12 m	168 mbar	14 m	168 mbar	3.5 m	168 mbar	7.5 m	168 mbar
18 m	100 mbar	21 m	100 mbar	5 m	100 mbar	11.5 m	100 mbar
32 m	50 mbar	38 m	50 mbar	9 m	50 mbar	20 m	50 mbar

Table 34: Flash fires or VCEs following guillotine failure of Pipe Section B or Section D

Guillotine Horizontal (typical D5)		Guillotine Horizontal (calm F2)		Guillotine Vertical (typical D5)		Guillotine Vertical (calm F2)	
Dist. to LEL	16.6 m	Dist. to LEL	14.9 m	Dist. to LEL	0.45 m	Dist. to LEL	2.41 m
Width	2.2 m	Width	3 m	Width	2.2 m	Width	3.6 m
Flammable mass	2.35 kg	Flammable mass	3.69 kg	Flammable mass	0.056 kg	Flammable mass	0.582 kg
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
5 m	600 mbar	6 m	600 mbar	1.5 m	600 mbar	3 m	600 mbar
12 m	168 mbar	14 m	168 mbar	3.5 m	168 mbar	7.5 m	168 mbar
18 m	100 mbar	21 m	100 mbar	5 m	100 mbar	11.5 m	100 mbar
32 m	50 mbar	38 m	50 mbar	9 m	50 mbar	20 m	50 mbar

Table 34: Flash fires or VCEs following guillotine failure of Pipe Section C

Guillotine Horizontal (typical D5)		Guillotine Horizontal (calm F2)		Guillotine Vertical (typical D5)		Guillotine Vertical (calm F2)	
Dist. to LEL	18.3 m	Dist. to LEL	15.8 m	Dist. to LEL	8.55 m	Dist. to LEL	3.16 m
Width	2.6 m	Width	3.2 m	Width	2.6 m	Width	4.2 m
Flammable mass	3.16 kg	Flammable mass	4.7 kg	Flammable mass	1.09 kg	Flammable mass	0.989 kg
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
6 m	600 mbar	6.5 m	600 mbar	4 m	600 mbar	4 m	600 mbar
13 m	168 mbar	15 m	168 mbar	9 m	168 mbar	9 m	168 mbar
20 m	100 mbar	23 m	100 mbar	14 m	100 mbar	14 m	100 mbar
36 m	50 mbar	40 m	50 mbar	25 m	50 mbar	24 m	50 mbar

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Table 35: Flash fires or VCEs following guillotine failure of Pipe Section C

Guillotine Horizontal (typical D5)		Guillotine Horizontal (calm F2)		Guillotine Vertical (typical D5)		Guillotine Vertical (calm F2)	
Dist. to LEL	18.3 m	Dist. to LEL	15.8 m	Dist. to LEL	8.55 m	Dist. to LEL	3.16 m
Width	2.6 m	Width	3.2 m	Width	2.6 m	Width	4.2 m
Flammable mass	3.16 kg	Flammable mass	4.7 kg	Flammable mass	1.09 kg	Flammable mass	0.989 kg
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
6 m	600 mbar	6.5 m	600 mbar	4 m	600 mbar	4 m	600 mbar
13 m	168 mbar	15 m	168 mbar	9 m	168 mbar	9 m	168 mbar
20 m	100 mbar	23 m	100 mbar	14 m	100 mbar	14 m	100 mbar
36 m	50 mbar	40 m	50 mbar	25 m	50 mbar	24 m	50 mbar

Table 35: Flash fires or VCEs following guillotine failure of Pipe Section E

Guillotine Horizontal (typical D5)		Guillotine Horizontal (calm F2)		Guillotine Vertical (typical D5)		Guillotine Vertical (calm F2)	
Dist. to LEL	104 m	Dist. to LEL	87.3 m	Dist. to LEL	2.4 m	Dist. to LEL	0.8 m
Width	8.2 m	Width	8.4 m	Width	8.4 m	Width	11.2 m
Flammable mass	93 kg	Flammable mass	87.7 kg	Flammable mass	2.92 kg	Flammable mass	2.12 kg
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
18 m	600 mbar	17 m	600 mbar	5.5 m	600 mbar	5 m	600 mbar
41 m	168 mbar	40 m	168 mbar	13 m	168 mbar	12 m	168 mbar
62 m	100 mbar	61 m	100 mbar	20 m	100 mbar	18 m	100 mbar
109 m	50 mbar	107 m	50 mbar	35 m	50 mbar	32 m	50 mbar

Table 36: Flash fires or VCEs following guillotine failure of Pipe Section E

Guillotine Horizontal (typical D5)		Guillotine Horizontal (calm F2)		Guillotine Vertical (typical D5)		Guillotine Vertical (calm F2)	
Dist. to LEL	104 m	Dist. to LEL	87.3 m	Dist. to LEL	2.4 m	Dist. to LEL	0.8 m
Width	8.2 m	Width	8.4 m	Width	8.4 m	Width	11.2 m
Flammable mass	93 kg	Flammable mass	87.7 kg	Flammable mass	2.92 kg	Flammable mass	2.12 kg
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
18 m	600 mbar	17 m	600 mbar	5.5 m	600 mbar	5 m	600 mbar
41 m	168 mbar	40 m	168 mbar	13 m	168 mbar	12 m	168 mbar
62 m	100 mbar	61 m	100 mbar	20 m	100 mbar	18 m	100 mbar
109 m	50 mbar	107 m	50 mbar	35 m	50 mbar	32 m	50 mbar

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Table 36: Flash fires or VCEs following leak from Pipe Section E

Leak Horizontal (typical D5)		Leak Horizontal (calm F2)		Leak Vertical (typical D5)		Leak Vertical (calm F2)	
Dist. to LEL	47.5 m	Dist. to LEL	15.3 m	Dist. to LEL	0.49 m	Dist. to LEL	0.175 m
Width	2.6 m	Width	3 m	Width	0.4m	Width	0.2 m
Flammable mass	6 kg	Flammable mass	4.35 kg	Flammable mass	0.00073 kg	Flammable mass	0.0006 kg
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
7 m	600 mbar	6 m	600 mbar	-	600 mbar	-	600 mbar
16 m	168 mbar	15 m	168 mbar	-	168 mbar	-	168 mbar
25 m	100 mbar	22 m	100 mbar	-	100 mbar	-	100 mbar
44 m	50 mbar	39 m	50 mbar	-	50 mbar	-	50 mbar

Table 37: Flash fires or VCEs following leak from Pipe Section E

Leak Horizontal (typical D5)		Leak Horizontal (calm F2)		Leak Vertical (typical D5)		Leak Vertical (calm F2)	
Dist. to LEL	47.5 m	Dist. to LEL	15.3 m	Dist. to LEL	0.49 m	Dist. to LEL	0.175 m
Width	2.6 m	Width	3 m	Width	0.4m	Width	0.2 m
Flammable mass	6 kg	Flammable mass	4.35 kg	Flammable mass	0.00073 kg	Flammable mass	0.0006 kg
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
7 m	600 mbar	6 m	600 mbar	-	600 mbar	-	600 mbar
16 m	168 mbar	15 m	168 mbar	-	168 mbar	-	168 mbar
25 m	100 mbar	22 m	100 mbar	-	100 mbar	-	100 mbar
44 m	50 mbar	39 m	50 mbar	-	50 mbar	-	50 mbar

Table 37: Flash fires or VCEs following guillotine failure of Pipe Section F or Section G

Guillotine Horizontal (typical D5)		Guillotine Horizontal (calm F2)		Guillotine Vertical (typical D5)		Guillotine Vertical (calm F2)	
Dist. to LEL	69.3 m	Dist. to LEL	115 m	Dist. to LEL	24.9 m	Dist. to LEL	65 m
Width	18 m	Width	51 m	Width	6 m	Width	45 m
Flammable mass	23.6 kg	Flammable mass	91.2 kg	Flammable mass	0.00117 kg	Flammable mass	3.07 kg
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
11 m	600 mbar	18 m	600 mbar	-	600 mbar	5.5 m	600 mbar
26 m	168 mbar	41 m	168 mbar	-	168 mbar	13 m	168 mbar
39 m	100 mbar	62 m	100 mbar	-	100 mbar	20 m	100 mbar
70 m	50 mbar	108 m	50 mbar	-	50 mbar	35 m	50 mbar

Table 38: Flash fires or VCEs following guillotine failure of Pipe Section F or Section G

Guillotine Horizontal (typical D5)		Guillotine Horizontal (calm F2)		Guillotine Vertical (typical D5)		Guillotine Vertical (calm F2)	
Dist. to LEL	69.3 m	Dist. to LEL	115 m	Dist. to LEL	24.9 m	Dist. to LEL	65 m
Width	18 m	Width	51 m	Width	6 m	Width	45 m
Flammable mass	23.6 kg	Flammable mass	91.2 kg	Flammable mass	0.00117 kg	Flammable mass	3.07 kg
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
11 m	600 mbar	18 m	600 mbar	-	600 mbar	5.5 m	600 mbar
26 m	168 mbar	41 m	168 mbar	-	168 mbar	13 m	168 mbar
39 m	100 mbar	62 m	100 mbar	-	100 mbar	20 m	100 mbar
70 m	50 mbar	108 m	50 mbar	-	50 mbar	35 m	50 mbar

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Table 38: Flash fires or VCEs following leak from Pipe Section F or Section G

Leak Horizontal (typical D5)		Leak Horizontal (calm F2)		Leak Vertical (typical D5)		Leak Vertical (calm F2)	
Dist. to LEL	14.8 m	Dist. to LEL	20.9 m	Dist. to LEL	0.1 m	Dist. to LEL	1.0
Width	2.4 m	Width	7.2 m	Width	0.2 m	Width	0.2
Flammable mass	0.188 kg	Flammable mass	0.616 kg	Flammable mass	0.02 kg	Flammable mass	4.8E-05 kg
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
2.2 m	600 mbar	3.3 m	600 mbar	-	600 mbar	-	600 mbar
5 m	168 mbar	8 m	168 mbar	-	168 mbar	-	168 mbar
8 m	100 mbar	12 m	100 mbar	-	100 mbar	-	100 mbar
14 m	50 mbar	20 m	50 mbar	-	50 mbar		50 mbar

Table 39: Flash fires or VCEs following leak from Pipe Section F or Section G

Leak Horizontal (typical D5)		Leak Horizontal (calm F2)		Leak Vertical (typical D5)		Leak Vertical (calm F2)	
Dist. to LEL	14.8 m	Dist. to LEL	20.9 m	Dist. to LEL	0.1 m	Dist. to LEL	1.0
Width	2.4 m	Width	7.2 m	Width	0.2 m	Width	0.2
Flammable mass	0.188 kg	Flammable mass	0.616 kg	Flammable mass	0.02 kg	Flammable mass	4.8E-05 kg
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
2.2 m	600 mbar	3.3 m	600 mbar	-	600 mbar	-	600 mbar
5 m	168 mbar	8 m	168 mbar	-	168 mbar	-	168 mbar
8 m	100 mbar	12 m	100 mbar	-	100 mbar	-	100 mbar
14 m	50 mbar	20 m	50 mbar	-	50 mbar	-	50 mbar

Table 39: Consequence modelling of pool fire following loss of containment from Section F or G

Guillotine failure of line		Leak from line	
Distance	**Flux**	**Distance**	**Flux**
23 m	25.6 kW/m²	6 m	25.6 kW/m²
30 m	12.7 kW/m²	6.5 m	12.7 kW/m²
34 m	8 kW/m²	7 m	8 kW/m²
37 m	6.3 kW/m²	7.5 m	6.3 kW/m²
43 m	4 kW/m²	8.5 m	4 kW/m²

Table 40: Consequence modelling of pool fire following loss of containment from Section F or G

Guillotine failure of line		Leak from line	
Distance	**Flux**	**Distance**	**Flux**
23 m	25.6 kW/m²	6 m	25.6 kW/m²
30 m	12.7 kW/m²	6.5 m	12.7 kW/m²
34 m	8 kW/m²	7 m	8 kW/m²
37 m	6.3 kW/m²	7.5 m	6.3 kW/m²
43 m	4 kW/m²	8.5 m	4 kW/m²

Table 40: Details of ISO LNG Tanks

Parameter	Value
Configuration	40-ft ISO cryogenic trailer
Tank Volume	20–24 m³ (~10 tonnes of LNG)
Dimensions	~12.2 m length × 2.5 m width × 3.9 m height
Operating Pressure	3–8 barg
Temperature	-160°C

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Table 41: VCEs inside confined buildings

VCE in bioconversion building		VCE in pretreatment building	
Distance	**Overpressure**	**Distance**	**Overpressure**
53 m	600 mbar	54 m	600 mbar
125 m	168 mbar	127 m	168 mbar
188 m	100 mbar	190 m	100 mbar
333 m	50 mbar	335 m	50 mbar

Table 41: Consequence modelling of fire scenarios following instantaneous release from ISO LNG tank

BLEVE		Pool Fire	
Diameter	117 m	Diameter	51.9 m
Duration	8.63 s	Duration	31.5 s
Distance	**Flux**	**Distance**	**Flux**
74 m	25.6 kW/m²	115 m	25.6 kW/m²
162 m	12.7 kW/m²	155 m	12.7 kW/m²
220 m	8 kW/m²	185 m	8 kW/m²
255 m	6.3 kW/m²	203 m	6.3 kW/m²
330 m	4 kW/m²	244 m	4 kW/m²

Note the effected distances

Table 43: Consequence modelling of fire scenarios following instantaneous release from ISO LNG tank

BLEVE		Pool Fire	
Diameter	117 m	Diameter	51.9 m
Duration	8.63 s	Duration	31.5 s
Distance	**Flux**	**Distance**	**Flux**
74 m	25.6 kW/m²	115 m	25.6 kW/m²
162 m	12.7 kW/m²	155 m	12.7 kW/m²
220 m	8 kW/m²	185 m	8 kW/m²
255 m	6.3 kW/m²	203 m	6.3 kW/m²
330 m	4 kW/m²	244 m	4 kW/m²

Table 42: Consequence modelling of flash fire and VCE scenarios for instantaneous release from ISO LNG tank

Release in typical weather conditions (D5)		Release in calm weather conditions (F2)	
Max Distance to LEL	181 m	Max Distance to LEL	415 m
Width	58.2 m	Width	127 m
Flammable mass	689 kg	Flammable mass	3,710 kg
Distance	**Overpressure**	**Distance**	**Overpressure**
34 m	600 mbar	60 m	600 mbar
80 m	168 mbar	141 m	168 mbar
120 m	100 mbar	212 m	100 mbar
215 m	50 mbar	375 m	50 mbar

Note the effected distances

Table 44: Consequence modelling of flash fire and VCE scenarios for instantaneous release from ISO LNG tank

Release in typical weather conditions (D5)		Release in calm weather conditions (F2)	
Max Distance to LEL	181 m	Max Distance to LEL	415 m
Width	58.2 m	Width	127 m
Flammable mass	689 kg	Flammable mass	3,710 kg
Distance	**Overpressure**	**Distance**	**Overpressure**
34 m	600 mbar	60 m	600 mbar
80 m	168 mbar	141 m	168 mbar
120 m	100 mbar	212 m	100 mbar
215 m	50 mbar	375 m	50 mbar

Table 43: Consequence modelling of fire scenarios following 10-minute release from ISO LNG tank

Jet Fire – Horizontal Release		Jet Fire – Vertical Release		Pool Fire	
Duration	600 s	Duration	600 s	Duration	600 s
Distance	**Flux**	**Distance**	**Flux**	**Distance**	**Flux**
70 m	25.6 kW/m^2	34 m	25.6 kW/m^2	54 m	25.6 kW/m^2
77 m	12.7 kW/m^2	44 m	12.7 kW/m^2	70 m	12.7 kW/m^2
82 m	8 kW/m^2	54 m	8 kW/m^2	83 m	8 kW/m^2
86 m	6.3 kW/m^2	60 m	6.3 kW/m^2	91 m	6.3 kW/m^2
92 m	4 kW/m^2	72 m	4 kW/m^2	108 m	4 kW/m^2

Table 45: Consequence modelling of fire scenarios following 10-minute release from ISO LNG tank

Jet Fire – Horizontal Release		Jet Fire – Vertical Release		Pool Fire	
Duration	600 s	Duration	600 s	Duration	600 s
Distance	**Flux**	**Distance**	**Flux**	**Distance**	**Flux**
70 m	25.6 kW/m^2	34 m	25.6 kW/m^2	54 m	25.6 kW/m^2
77 m	12.7 kW/m^2	44 m	12.7 kW/m^2	70 m	12.7 kW/m^2
82 m	8 kW/m^2	54 m	8 kW/m^2	83 m	8 kW/m^2
86 m	6.3 kW/m^2	60 m	6.3 kW/m^2	91 m	6.3 kW/m^2
92 m	4 kW/m^2	72 m	4 kW/m^2	108 m	4 kW/m^2

Table 44: Consequence modelling of flash fire and VCE scenarios for 10-minute release from ISO LNG tank

10-minute Horizontal (typical D5)		10-minute Horizontal (calm F2)		10-minute Vertical (typical D5)		10-minute Vertical (calm F2)	
Dist. to LEL	115 m	Dist. to LEL	191 m	Dist. to LEL	18.2 m	Dist. to LEL	-
Width	30.4 m	Width	88.8 m	Width	4.2 m	Width	-
Flammable mass	94.4 kg	Flammable mass	337 kg	Flammable mass	0.0589 kg	Flammable mass	-
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
18 m	600 mbar	27 m	600 mbar	1.5 m	600 mbar	-	600 mbar
41 m	168 mbar	63 m	168 mbar	3.5 m	168 mbar	-	168 mbar
62 m	100 mbar	95 m	100 mbar	5.5 m	100 mbar	-	100 mbar
110 m	50 mbar	168 m	50 mbar	9.5 m	50 mbar	-	50 mbar

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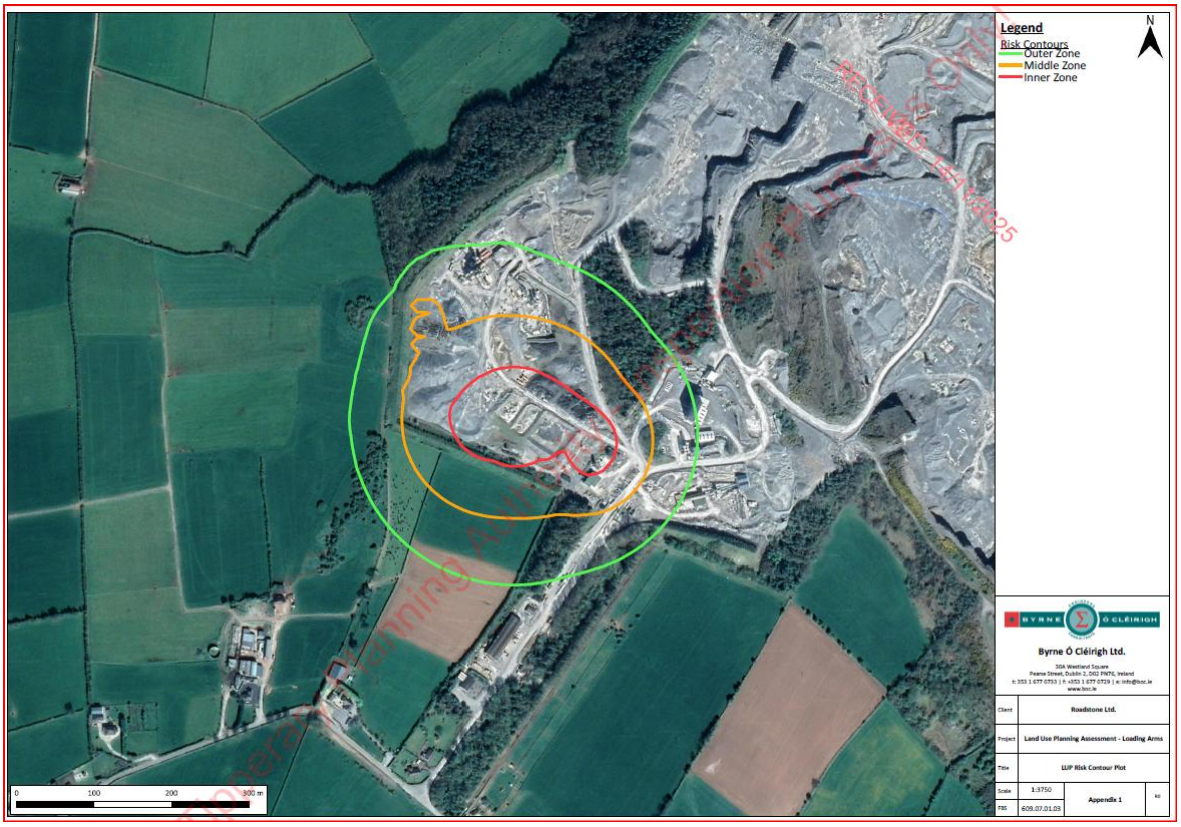
Purposes
Authority - Inspection Purposes

Table 46: Consequence modelling of flash fire and VCE scenarios for 10-minute release from ISO LNG tank

10-minute Horizontal (typical D5)		10-minute Horizontal (calm F2)		10-minute Vertical (typical D5)		10-minute Vertical (calm F2)	
Dist. to LEL	115 m	Dist. to LEL	191 m	Dist. to LEL	18.2 m	Dist. to LEL	-
Width	30.4 m	Width	88.8 m	Width	4.2 m	Width	-
Flammable mass	94.4 kg	Flammable mass	337 kg	Flammable mass	0.0589 kg	Flammable mass	-
Distance	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**	**Distance**	**Overpressure**
18 m	600 mbar	27 m	600 mbar	1.5 m	600 mbar	-	600 mbar
41 m	168 mbar	63 m	168 mbar	3.5 m	168 mbar	-	168 mbar
62 m	100 mbar	95 m	100 mbar	5.5 m	100 mbar	-	100 mbar
110 m	50 mbar	168 m	50 mbar	9.5 m	50 mbar	-	50 mbar

Response from MLavelle: These Tables indicate the unacceptable risks to people, animals & property within a 500m radius of the biogas plant.

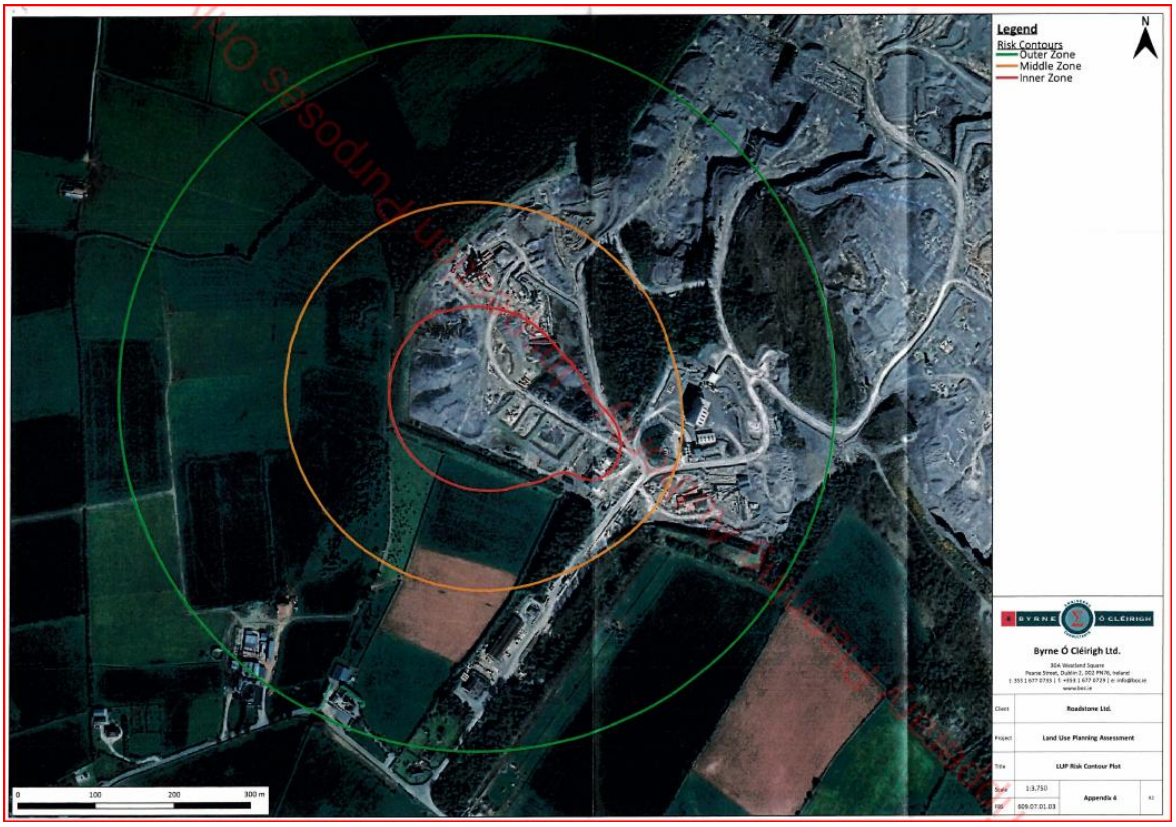
ISSUE 6: NOTE INCONSISTENCIES OF RISK ZONES ON MAPS



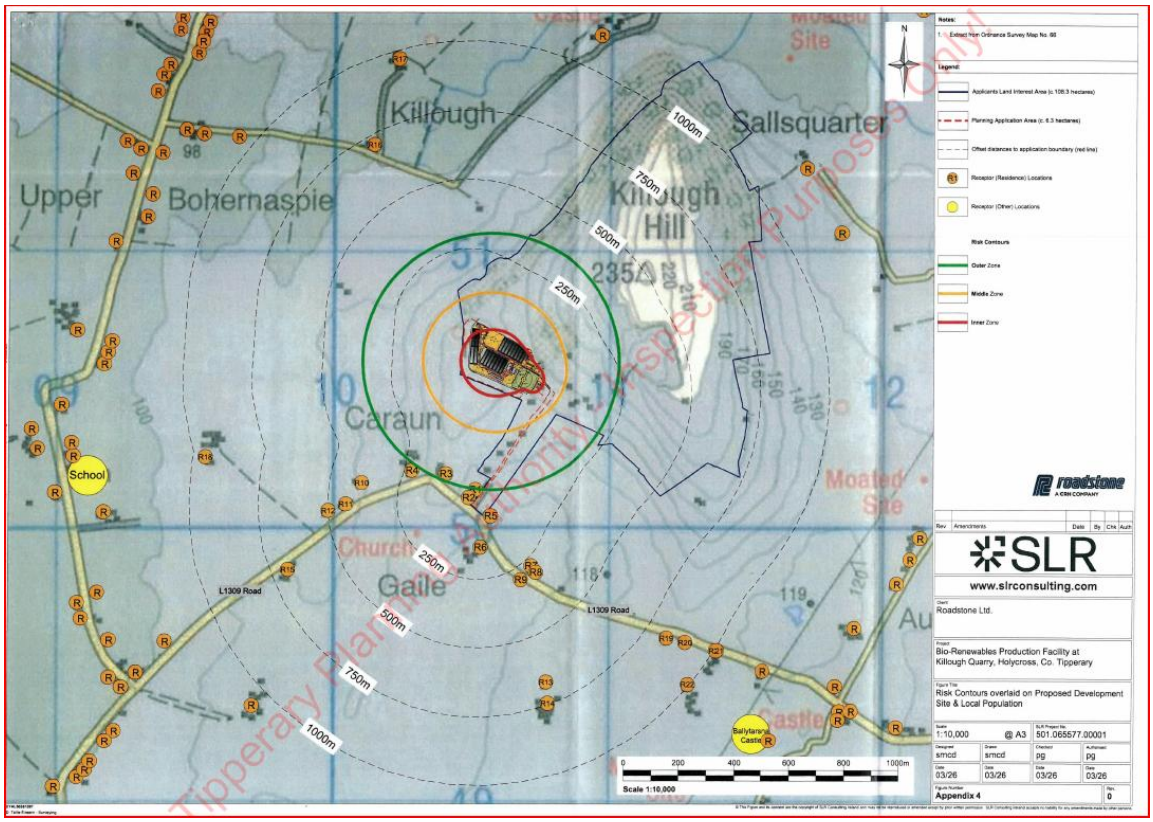
Response from MLavelle: Note Outer, Middle & Inner risk contour zone plots as coloured green, orange & red that indicated no risk to nearby houses. The Tables above show that this colour coding is totally inaccurate. The following orthophotos & maps below, show different risk contour zone plots.

Roadstone Ltd.: Response to Further Information Request (P. Ref. 25/60019) 14 November 2025 SLR Project No.: 501.065577.00001

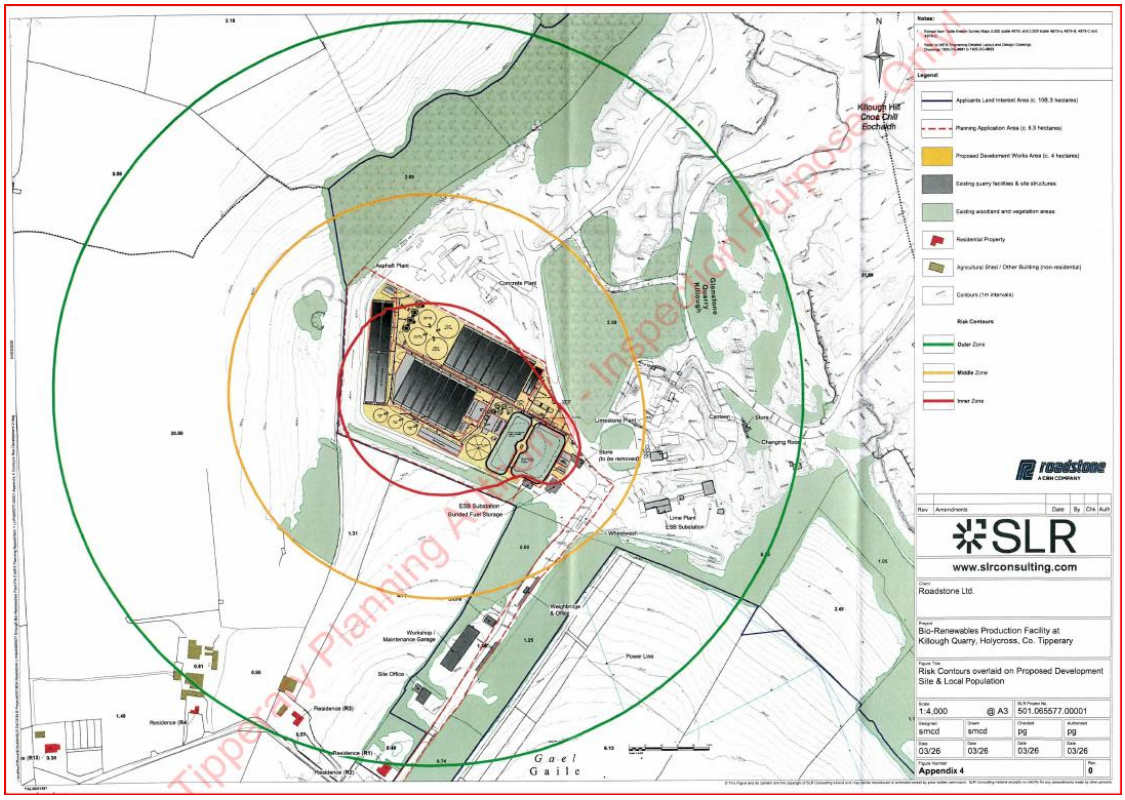
This plot shows the extents of the Inner (red line), Middle (orange line) and Outer (green line) Zones. There are no developments inside any of these contours which do not meet the sensitivity level criteria from the guidance, as set out in Table 2 of the Risk Assessment report



Response from MLavelle: Note the Outer, Middle & Inner risk contour zone plots as coloured versus the plots in previous map



Response from MLavelle: Note the Outer, Middle & Inner risk contour zone plots as coloured versus the plots in previous orthophoto images above. Note the 250 &500m radius & the 12 houses within this radius. These houses will suffer huge property losses if this development is granted. Who will purchase a property where you could be asphyxiated or burned to death? This determines the Precautionary Principle & over-riding public interest.



ISSUE 7: LNG REFERENCES: THAT INDICATE FAR GREATER RISK ZONES THAN ABOVE

Reference Number 1: Unlocking the potential of cryogenic biogas upgrading technologies integrated with bio-LNG production: A comparative assessment Ahmad Naquash, Neha Agarwal, Muhammad Nizami, Nguyen Nhu Nga, Muhammad Aziz, Moonyong Lee. Applied Energy 371 (2024) 123720. www.elsevier.com/locate/apenergy. https://doi.org/10.1016/j.apenergy.2024.123720

Liquefaction is a viable approach to increase energy density, but this approach is **energy and cost-intensive** and requires **high purity of biomethane**. **Cryogenic biogas** upgrading integrated with the biomethane liquefaction (or bio-LNG) process is an efficient technique to meet these challenges due to its dual benefits: separation with high purity/recovery and precooling of biomethane. This study evaluates different cryogenic technologies (distillation, controlled freeze zone (CFZ), and anti-sublimation) and their integration potential with the bio-LNG production process from a technical and economic perspective.

Unlike conventional natural gas, biogas transportation faces challenges due to its production at atmospheric pressure, which is lower than conventional natural gas and has lower energy density. The biogas energy density can be increased via compression or liquefaction process. **To meet natural gas quality standards before being utilised as fuel (CO2 limit below 50 ppm), biogas is upgraded to biomethane via treatment to separate the CO2 and other impurities to produce biomethane.** For long-distance transportation, the liquefaction process of biomethane to produce liquefied biomethane (LBM or bio-LNG) is preferred due to its higher energy density. The energy density of bio-LNG is about 21 MJ/L, similar to conventional LNG, and is 2.4 times higher than that of compressed biomethane (Bio-CNG)

In the cryogenic distillation process, the extraction of desired gas components depends on the boiling points of each component. This process's advantage is obtaining a high methane (CH4) purity and high CO2 recovery. In addition, the process, the output of the process has a lower temperature, with the range of- 80 to - 90 ^{0}C, which is suitable for bio-LNG production due to the requirement of cooling duty can be reduced.

The temperature and pressure of feed biogas are kept so that the CO2 solidification conditions would lie within this range with optimal energy consumption. Therefore, the optimal pressure and temperature are 4.97 bar and- 68 ^{0}C, respectively. it is assumed that CO2 is completely solidified at - 67 ^{0}C and 4.97 bar.

After upgrading, the separated CH4 is liquefied by further reducing its temperature to- 160 ^{0}C. This liquid biomethane is stored at 1.2 bar and - 160 ^{0}C.

Reference Number 2: Biogas impurities: environmental and health implications, removal technologies and future perspectives. Adhena Ayaliew Werkneh. Heliyon 8 (2022) e10929. www.cell.com/heliyon. https://doi.org/10.1016/j.heliyon.2022.e10929

Biogas is a promising bioenergy alternative to be recovered from waste/wastewater in the context of environmental sustainability and circular economy. However, raw biogas contains various secondary impurities such as carbon dioxide, hydrogen sulphide, siloxanes, nitrogen oxides (NOx), ammonia, and halogens. Depending on the emission rate of these biogas impurities, the importance of biogas is being hampered for its environmental, health and the detrimental effects possess by the impurities towards the downstream of the biogas users. **Biogas impurities can cause different public health concerns (like pulmonary paralysis, asthma, respiratory diseases and deaths) and environmental impacts (such as global warming, climate change and their indirect impacts like drought, flooding, malnutrition and other disasters).** The absence/inconsistent emission standards among countries, agencies, and other stakeholders is the other challenge that they possess during monitoring and controlling of these impurities. Different commercially available and emerging technologies are available for separating carbon dioxide (via biogas upgrading) and removing other biogas impurities. Technologies such as pressure swing adsorption, membrane separation, absorption-based techniques (water, chemical and physical organic solvents), cryogenic separation, and other emerging biotechnological platforms (like photobioreactor and biocatalysis) have been adopted in removing the impurities. This paper reviewed the main commercially available and new technologies and their performance in removing carbon dioxide (the main constituent of biogas) and other biogas impurities. Besides, the environmental and public health implications of biogas and future research perspectives are also highlighted.

Table 1. Main composition of raw biogas from different waste sources with their calorific value and corresponding effects (adapted from Kaparaju, 2013; Awe et al., 2017).

Parameter	Farm-scale AD plant	Centralized AD plant	Landfill gas	Sewage treatment	Natural gas (Holland)	Biomethane
Methane (% vol.)	55–60	60–70	30–65	60–65	81–89	>97
Carbon dioxide (% vol.)	35–40	30–40	25–45	35–40	0.67–1	<2
Hydrogen sulphide (ppm)	25–30	0–2000	30–500	<0.5–6800	0–2.9	3.5 ± 1.5*
Water vapor (% vol.)	–	1–5	1–5	–	–	–
Hydrocarbons (% vol.)	0	0	0	0	3.5–9.4	–
Hydrogen (% vol.)	0	0	0–3	0	–	<0.5
Nitrogen (% vol.)	<1–2	2–6	<1–17	<1–2	0.28–14	
Oxygen (% vol.)	<1	0.5–1.6	<1–3	<0.05–0.7	0	
Ammonia (ppm)	≈100	≈100	≈5	<1–7	0	0.25 ± 0.01*
Halogens (as Cl^- in mg/m^3)	<0.01	<0.25	0.3–225	0–2	–	
Siloxanes (mg/m^3)	<0.03–<0.2	<0.08–<0.5	<0.3–36	<1–400	–	
Wobbe index (MJ/m^3)	24–33	24–33	20–25	25–30	44–55	
Lower heating value, (MJ/Nm^3)	23	23	16	22	31–40	

Note: * – mg/m^3.

Biogas is used to generate electricity in gas turbines and is considered an environmentally friendly and clean energy source when compared to non-renewable sources (fossil fuel from coal) (Hoyer et al., 2016). However, biogas utilization is limited due to its composition, which depends on the type and origin of feedstock, treatment processes (digestion process), and the process parameters (Table 1) (Lopez et al., 2012; Kaparaju, 2013). This implies that the potential calorific value of methane in the raw biogas could be different (Mattioli et al., 2017; Wickham et al., 2018). This raw biogas mainly contains 40–75% methane and 15–60% carbon dioxide (Atelge et al., 2021; Macor and Benato, 2021; Carranza-Abaid et al., 2021; Dannesboe et al., 2021).

However, the rest are secondary impurities such as 0–15% nitrogen (N2), <0.6% carbon monoxide (CO), 0–10000 ppmv hydrogen sulphide (H2S), 0–3% oxygen (O2), 0–100 ppmv ammonia (NH3), 0–41 mg Si/m3 siloxanes, 0–200 mg/m3 hydrocarbons, 1–5% water (H2O) and other particulates.

The energy content of biogas is determined by methane composition (i.e. the higher methane concentration leads to a higher calorific energy value) (Chen et al., 2015; Kohlheb et al., 2021) (Table 1). The presence of a high content of carbon dioxide (CO2) and other trace gases reduces the economic value, its heat content and limits beneficial applications of biogas (Xu et al., 2017; Atelge et al., 2021).

Accordingly, if biogas is not treated for the removal of its impurities (prior to its high value applications), the heat value of biogas will drop (due to its lower calorific value during combustion by reducing the biogas methane content) and these impurities will cause environmental impacts (Paolini et al., 2018b) and health concerns (Macor and Benato, 2020a, 2020b, 2021). Different public health concerns (like pulmonary paralysis, asthma, respiratory diseases, the spread of communicable diseases and deaths) and various environmental impacts (such as global warming, climate change and their indirect impacts like drought, flooding, malnutrition, and other disasters) have been reported (Macor

and Benato, 2020a, 2020b, 2021) (Table 2). According to the Health Impact Assessment (HIA) explained by Macor and Benato (2021), the biogas impurities, NOx, SOx, volatile organic compounds (VOC) and CO contributes to 91, 6.5, 1.4 and 0.7%, respectively to damage human health.

Biogas, which is produced through the anaerobic digestion of biodegradable waste/wastewater is typically composed of mainly methane and carbon dioxide and a variety of impurities such as H2S, water vapour, siloxanes, NH3 and VOC (Wasajja et al., 2020), where their composition differs with the source of their feedstock (Surendra et al., 2014; Saadabadi et al., 2019) and the type of biomass fed into the biogas producing digester (Wasajja et al., 2020). These biogas impurities have detrimental effect in the biogas conversion devices and possess a harmful consequence to human health and the environment as emissions when their presence are above their threshold limits (Papurello et al., 2016; Paglini et al., 2022) (Table 2).

Table 2. Effects of some common biogas impurities to human health, environment and process equipment.

Biogas impurities	Threshold limit to health and the env't.	Effects on human health and the environment	Effects to process equipment	References
Hydrogen sulphide	[1]Odor: < 0.014 mg/m^3 Few days of eye irritation and respiration irritation: < 1 ppm.[2]	[2,5,9]Hazardous to environment, forming SO_2 and SO_3 and acid rain (H_2SO_4) Bad smell[3], eye irritation and unhealthy[1,2,4] H_2S is a potent nerve poison[9]	Highly corrosive,[6,7] poisoning to the catalytic converter[8] Toxic to the PSA adsorbents[9]	[1]Drimal et al. (2010),[2]Rubright et al. (2017),[3]Axelsson et al. (2012),[4]Roth (2004), [5]Lim et al. (2016), [6]Guidotti (1994), [7]Tang et al. (2010), [8]Awe et al. (2017), Paolini et al. (2018b), [9]Atelge et al. (2021),
Siloxanes	-	No environmental effect[1], only "responsible for fouling in the post-combustion emissions control catalytic system".[2]	Formation of "glassy micro-crystalline silica" that decreases life span of equipment.[2,3]	[1]Graiver et al. (2003),[2]Soreanu et al. (2011),[3]Arnold (2009)
Ammonia	Max. emission rate: <50 ppm$_v$.[1] During combustion, NH_3 converts into NOx: <10%.[2]	Formation and emission of NOx after combusion.[3] Toxic to the anaerobic bacteria[6] Health problems, toxic and bad smell[6]	Corrosion, anti-knock properties to engines[5], NH_3 is less corrosive than H_2S.[4]	[1]Mojtahedi and Abbasian (1995), [2]Wendt and Sternling (1974), [3]Ranalli (2007), [4]Francis (1985), [5]Awe et al. (2017), [6]Atelge et al. (2021)
Nitrogen	-	No harmful environment effect.[1]	Reducing the calorific value, corrosion and anti-knock properties[2]	[1] Wasajja et al. (2020);[8]Awe et al. (2017)
Water vapour	-	Water vapour forms acids with CO_2 and H_2S.[2]	[1]Corrosion due to the reactions with NH_3	[1]Awe et al. (2017)
Particulate matter	<20 μg/m^3 for 24 h and for particle size of <2.5 μm < 2.5 μm.[1]	-	- Plugs the gas system and pores of the adsorbent.[2]	[1] Buysman (2015);[2]Williams et al. (2014)

Table 3. Comparisons between the biogas upgrading and cleaning technologies in removing carbon dioxide and other impurities (Adapted from Allegue and Hinge, 2012; Sutherland et al., 2019; Nguyen et al., 2020; Bose et al., 2020; Carranza-Abaid et al., 2021).

Methods	Opportunity	Limitations
Water scrubbers	- Its capacity is adjustable by varying the temperature and pressure - Several plants are operated worldwide (simple operation, cheap and simple method) - H_2S (>300/500 ppmv) and ammonia co-removal (tolerance for impurities) - No additional heat required - Environmental friendly and low-cost solvent - Low operating cost - Achieved 95–99% biomethane purity	- High pressure (4–10 bars), methane loss (up to 5% by vol.), and energy consumption (is up to 0.2–0.5 kWh/Nm^3 of biogas) - Pretreatment and drying of biomethane required - Clogging occurred due to the growth of bacteria - Medium content of biomethane produced, H_2S (when >300/500 ppmv) damages the equipment - Higher water consumption (even within the regeneration process) - Loading and absorbent rate is too low (water is less selective), and a possibility to cause foaming
Solvent scrubbers	- Lesser footprint exists - Higher and effective absorption rate, and "higher loading per volume of solvent"	- Methane loss is up to 4% by vol., and heat is required for effective regeneration - Energy consumption is from 0.1-0.33 kWh/Nm^3 of biogas) - Due to the environmental pollution of used solvents, additional post-treatment is required
Pressure swing adsorption	- No chemicals and no heat demand required - Cheap and compact technology, several plants are under operation, easy operation - Co-adsorption of N_2 and O_2 together with CO_2 - Achieved 95–99% biomethane purity	- Medium amount of biomethane produced with medium/higher CH_4 loss exist - "Extensive process control" and the use of valves often required - Pretreatment required for H_2S and H_2O, and attained 1–9% methane loss

Physical organic scrubbers	- Methane loss is low and coarse pretreatment step is required - Produces higher content of methane (energetic and more auspicious than water) - Co-removal of hydrogen sulphide, ammonia and other impurities - Achieved 95–99% biomethane purity	- Relatively expensive operation and investment cost - Difficulty in operation (can be reduced when the dilution of glycol with water exists) - Boiling required to avoid incomplete regeneration
Amine-based chemical absorption	- Higher efficiency of methane content - Process is carried out without pressure and no moving components required except lower - Low demand of electricity - Methane loss is very low - Dissolves more CO_2 per unit of water (when compared with water) - Achieved >99% biomethane purity	- Quite an expensive investment required - High demand of heat required for regeneration - Causes corrosion, poisoning and decomposition of amines by oxygen occurred - Salts precipitation exists and foaming possibility - Pretreatment required for hydrogen sulphide removal - Lower working pressure (1 bar) and required heat - Process handling is complex and attained 1–2% methane loss
Membrane technology	- Easy operation and construction, and low maintenance - No moving components required except blower, no demand of heat or no chemical required, higher reliability - Small footprint and low weight - Modular configuration needed even at lower volume rates, Minor gas flows as treated without proportional increment of the cost - Acquired pure CO_2 to be used in industrial applications - Gas-liquid provides cheap operation and investment cost - Achieved 95–99% biomethane purity - Low operational and moderate initial costs - Easy process handling when compared with others	- Medium methane contents produced, while multiple stages are needed to achieve higher methane purity - Medium to higher (10–15%) losses of methane (depending on membrane configuration) - Purity of methane is compromised with the amount of upgraded biogas - Requires petty operational experience for an improved membrane technology - Membrane cost is expensive, H_2S removal step is required or pretreatment should be required - It is not suitable for biogas having many unknown contaminants (like from landfill) - Unsure membrane durability and low selectivity of membrane
Cryogenic separation	- Achieved higher methane content in the upgraded biogas - Lower methane loss exists - No chemicals added, and carbon dioxide produced as a byproduct - Requires lower extra cost of energy to "reach liquid biomethane" - Achieved up to 99% biomethane recovery potential	- Expensive operation and investment cost required - Further removal step required for siloxanes, hydrogen sulphide and other impurities - Technical skill is very demanding and the process handling is complex - The technology is still emerging - Pretreatment required and needs higher working pressure (40 bar - Higher operational and initial costs. Methane loss is up to 1–2%
Photobioreactor	- Emerging Green technology (environmentally friendly), economically feasible - Applied in an integrated system with wastewater treatments (for removal of nutrients) - Sewage purification performance is too high - Higher carbon dioxide reduction and thereby increases in methane in the upgraded biogas.	- Higher methane loss because of its solubility within the microalgae culture and possess difficulty in harvesting the biomethane - Lack of tolerant microalgae species at higher carbon dioxide content; and oxygen introduction from the microalgae (photosynthesis) into the upgraded methane - Higher carbon dioxide content dissolves in water and thereby pH reduces to <6 to cause a detrimental effect to the growth of microalgae or disrupts the permeability of cell membrane and photosynthesis - Limiting solubility of carbon dioxide in the growth medium of microalgae and leads to lose up to 90% of raw biogas and this system is not yet validated at large scale operations

Reference Number 3: A Comprehensive Review of the Establishment of Safety Zones and Quantitative Risk Analysis during Ship-to-Ship LNG Bunkering. Phan Anh Duong, Bo Rim Ryu, Jinwon Jung, and Hokeun Kang. Energies 2024, 17, 512. https://doi.org/10.3390/en17020512.

2. Characteristics of LNG

2.1. General Information and Physical Properties of LNG

Natural gas is a fossil fuel, indicating its formation from organic matter that was deposited and buried in the Earth millions of years ago. LNG is a liquid mixture of various gases, primarily consisting of methane (CH4), and its mass concentration can range from 70 to 99% depending on the source of origin. LNG possesses no odour, has no colour, and is non-corrosive, non-flammable, and non-toxic. Additionally, LNG typically contains other hydrocarbon components, including ethane (C2H6), propane (C3H8), and butane(C4H10), while minor quantities of gases like nitrogen (N2) may also be present. The reserves of natural gas are substantial, with the International Energy Agency (IEA) estimating that, based on current consumption rates as of January 2011, these reserves could last for more than 250 years. When natural gas undergoes liquefaction at around −162 °C, its volume is drastically reduced to approximately 1/600th in the gaseous state. In this liquefied state, LNG is stored in tanks, and the entry of heat causes the formation of boil-off gas (BOG).

This BOG is either utilized by the engines or re-liquefied to keep the LNG tank pressure within acceptable ranges. A thorough understanding of the LNG saturation vapour curve and its impact on bunkering is essential for enhancing bunkering processes.

Table 1. Basic properties of LNG

Properties	Unit	Value
Boiling point	°C	−162 (−259 F)
Flash point	°C	<−188 (−306 F)
Evapouration rate (n-butyl acetate = 1)		>1

Flammable limit	volume % in air	5–15
Vapour pressure (at −110 F)	psia	700
Vapour density (at 14.7 psia and 60 F)	lb/ft3	0.0435–0.0481
Liquid density (at −260 F (H2O = 8.33 lbs/gallon) at 60 F) Relative density/specific gravity (at −260 F (H2O = 1)) Auto-ignition temperature Stored pressure psia atmospheric Behavior if spilled	lbs/gallon: °C psia When it evaporates, it forms visible clouds, some of which might become flammable or explosive under specific circumstances if they are confined.	3.5–4.0 537 (999 F) 0.43 atmospheric

LNG exhibits distinct characteristics in comparison to Heavy Fuel Oil, with approximately half the density and a calorific value approximately 20% higher. When all factors are considered, a ship aiming to achieve the same range using LNG must bunker approximately 1.8 times more fuel.
In its liquid state, LNG is non-flammable, unlike methane vapours, which possess flammability. When the volumetric ratio of methane to air falls within the range of 5–15%, the mixture is considered flammable. Methane itself is colourless; however, when cold LNG vapour escapes into the atmosphere, its low temperature leads to the condensation of surrounding air, creating a distinctive white cloud on the sea's surface.

Table 2. LNG incident records

Time	Place	Accident Description	Results
1965	Canvey Island, UK	While conducting an LNG transfer, an unfortunate mishap occurred, leading to the unintended release of LNG. This release subsequently ignited, resulting in severe injuries to an individual.	One reported injury involved a severe burn.
1979	Columbia Gas LNG Terminal Cove Point, Maryland	LNG seeped through the electrical penetration seal of the LNG pump, infiltrating the substation. A circuit breaker then triggered the ignition of the natural gas–air mixture, leading to a powerful explosion.	One fatality and one individual with severe injuries have been reported.
2006	Port Fortin, Trinidad, Caracas	Atlantic LNG has reported an incident at its Train 2 facility in Point Fortin, Trinidad. This unfortunate occurrence was triggered when a temporary eight-inch isolation plug succumbed to mounting pressure. The release of natural gas was successfully managed, and personnel were able to resume their duties.	A single injury has been reported.
2007	Shanghai, China	A physical explosion was caused in the testing of an LNG tank.	An explosion resulting from a tank pressure test claimed the life of 1 individual and left 16 others with injuries.
2010	Montoir de Bretagne Terminal, France	The incident transpired when liquid infiltrated the gas take-off line while the discharge operations were underway. As a consequence of this occurrence, damage extended to a portion of the ship's manifold and its associated feed lines.	
2011	Yung An LNG Terminal, Taiwan	The vessel's captain made the decision to temporarily halt the discharge process and relocate the ship away from the berth. Fortunately, the issues were subsequently resolved, allowing the vessel to return and successfully complete the discharge of its cargo.	No injuries have been recorded, but there was structural damage.
2011	Pyeongtaek LNG terminal, Korea	The vessel disengaged from the berth following the discovery of a minor LNG leak near the top of one of the emergency release couplers, shortly after the completion of a planned overhaul of the unloading arms. Subsequently, new seals and ball valves were	No injuries have been recorded, but there was structural damage.

		installed on the unloading arms, allowing the resumption of the discharge process with the two remaining arms	

In addition to the environmental advantages, it is crucial to thoroughly assess the reliability and safety of LNG utilization. In the event of an accidental release of LNG, rapid evaporation and dispersion may occur, potentially endangering the surrounding area. This could lead to risks such as asphyxiation, cryogenic burns, structural damage, fires, and the potential for a vapour cloud explosion (VCE) arising from the presence of a natural gas cloud. The presence of obstructions within processing equipment can significantly heighten the risk of a VCE. As combustible gas accumulates in substantial quantities, the gas cloud may inadvertently ignite, potentially leading to a catastrophic and devastating explosion. In the event of an accident, a chain of events can lead to simultaneous or consecutive consequences, including a gas leak, fire, VCE, and BLEVE, collectively referred to as the "domino effect". For instance, a jet fire capable of heating a pressurized liquid vessel to its boiling point can trigger a BLEVE, culminating in a catastrophic accident. A singular explosion often serves as the catalyst for the domino effect, which can lead to the occurrence of gas leaks and fires in the vicinity of the initial explosion. Blast, heat, or fragmentation has the potential to harm nearby systems, leading to equipment failures. Conducting explosion research within an LNG processing plant entails substantial expenses. Such experiments require a full-scale model and should be conducted at a safe distance from populated areas.

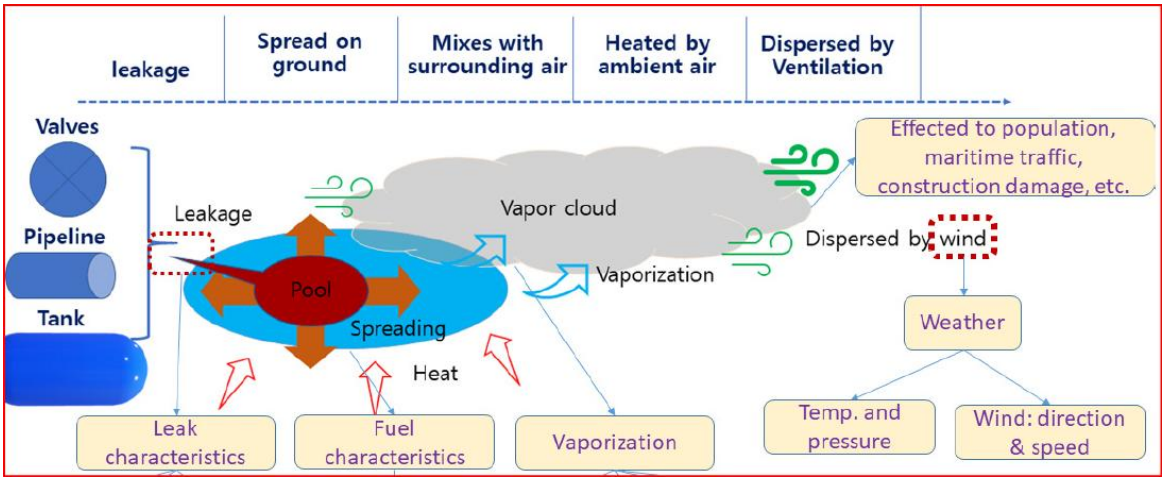
Natural gas, predominantly composed of CH4, is a non-hazardous flammable gas. The production of LNG involves cooling natural gas to a temperature lower than its boiling point, approximately −162 ◦C (−260 ◦F). The liquefaction process significantly reduces the gas's volume by a factor of 600, enhancing efficiency for storage and transportation. LNG, being a cryogenic liquid, presents distinct risks to individuals and property in the event of a release from storage or transfer equipment compared to traditional fuel oil.

(i) Primary risks involve severe injuries to individuals in close proximity who may come into contact with cryogenic liquids. LNG contact with the skin can cause effects similar to thermal burns, and exposure to sensitive areas like the eyes can result in tissue damage. Prolonged skin contact can lead to frostbite, and continued inhalation of very cold air may harm lung tissue.

(ii) Steel structures exposed to cryogenic temperatures may undergo brittle fractures. The extreme coldness of LNG can render conventional steels brittle, potentially causing surface cracking or impacting other metal equipment.

(iii) The creation of a flammable vapour cloud is a concern. For a fire or explosion to occur, the vapour cloud needs to fall within the flammable range, which, for methane, lies between 5% and 15% when mixed with air, and there could be an ignition. Various factors influence the potential consequences of an LNG release, including the surface of release, the quantity released, air and surface temperatures, wind speed and direction, atmospheric stability, proximity to nearby populations, and the location of ignition sources. Although ignited LNG vapours can generate substantial pressure in confined spaces like buildings, there is no indication to support the claim that LNG undergoes explosion upon ignition in open and unconfined areas.

LNG presents distinct hazards, including volatility and cryogenic conditions, differing from those associated with traditional fuel oil. It is imperative for potential operators to have a clear understanding of the risks associated with LNG bunkering.
Several common initial events can lead to the release of LNG, posing risks to nearby individuals, equipment, and the environment.



Reference Number 4: Systematic Review of Predictive Safety Analytics Applications in LNG Projects with ESG Implications. Oluwakemi Motunrayo Arumosoye, Oghenepawon David Obriki, Cynthia Obianuju Ozobu. Global Journal of Engineering and Technology Review Volume: 02 Issue: 02 February 2026. PP 61-73, DOI: 10.65150/EP-gjetr/V2E2/2026-05. E-ISSN: 3051-3782, P-ISSN: 3051-3774

2.6 Gaps in the Literature

Despite the growing interest in predictive safety analytics (PSA) and its application in high-hazard industries, the existing literature reveals several important gaps when examined in the context of liquefied natural gas (LNG) projects and their environmental, social, and governance (ESG) implications (Ezeh *et al.*, 2024; Adenuga *et al.*, 2025). These gaps limit the generalizability, practical relevance, and theoretical integration of current research, underscoring the need for more context-specific, longitudinal, and outcome-oriented studies.

A major gap in the literature is the limited availability of LNG-specific empirical studies. Much of the existing evidence on predictive safety analytics is derived from adjacent sectors such as oil refining, chemical processing, aviation, and manufacturing. While these industries share certain risk characteristics with LNG operations, the unique technical, organizational, and lifecycle complexities of LNG projects are insufficiently represented (Uduokhai *et al.*, 2024; Okonkwo *et al.*, 2024). LNG megaprojects involve large-scale construction, complex commissioning phases, cryogenic process hazards, and multi-contractor environments that differ markedly from steady-state industrial operations. The reliance on cross-sector extrapolation limits the ability to assess how predictive models perform under LNG-specific conditions, particularly during transient and high-risk project phases.

Another significant gap concerns the weak linkage between predictive analytics and ESG outcomes. Existing studies predominantly focus on operational safety metrics, such as incident reduction or near-miss prediction, without explicitly connecting predictive safety performance to broader ESG dimensions. Environmental benefits, social impacts beyond worker safety, and governance improvements are often discussed conceptually rather than empirically. As a result, the contribution of PSA to emissions reduction, environmental incident prevention, community risk mitigation, and governance transparency remains underexplored (Oparah *et al.*, 2024; Adenuga *et al.*, 2025). This gap is particularly problematic given the increasing importance of ESG considerations in investment decisions, regulatory oversight, and stakeholder expectations within the energy sector.

The underrepresentation of developing and emerging market LNG projects constitutes another critical limitation in the literature. Most empirical studies originate from mature LNG markets with advanced regulatory frameworks, high digital maturity, and well-resourced operators. In contrast, LNG projects in developing regions face distinct challenges, including weaker institutional capacity, fragmented data systems, high workforce turnover, and greater reliance on subcontracting (Sanni *et al.*, 2020; Ezeh *et al.*, 2023). These contextual factors can significantly influence the feasibility, effectiveness, and ethical implications of predictive safety analytics. The lack of evidence from emerging markets limits the global relevance of current findings and constrains the development of inclusive, context-sensitive PSA frameworks.

A further gap relates to the lack of longitudinal and validation studies. Many existing studies evaluate predictive models over short time horizons or during limited project phases, providing insufficient evidence of sustained performance or long-term impact. Without longitudinal analysis, it is difficult to assess whether predictive analytics delivers durable safety improvements, adapts to changing risk profiles, or maintains accuracy as operational conditions

evolve (Ogbete and Aminu-Ibrahim, 2024; Wedraogo and Sanni, 2024). Similarly, few studies report rigorous validation of predictive models using independent datasets or cross-project comparisons. This raises concerns regarding model overfitting, transferability, and reliability, particularly in complex and dynamic LNG environments.

In addition to these core gaps, the literature often underexplores the organizational and governance mechanisms that mediate the effectiveness of predictive safety analytics. While technical model performance is frequently emphasized, less attention is given to how predictive insights are interpreted, acted upon, and institutionalized within project governance structures (Seyi-Lande *et al.*, 2024; Oparah *et al.*, 2024). This omission limits understanding of why predictive systems succeed or fail in practice and constrains the development of integrative socio-technical models.

The literature on predictive safety analytics in LNG projects is characterized by limited LNG-specific empirical evidence, weak integration with ESG outcomes, insufficient representation of developing market contexts, and a lack of longitudinal and validation studies. Addressing these gaps is essential to advancing both theory and practice (Michael and Ogunsola, 2025; Sanni *et al.*, 2025). Future research should prioritize LNG-focused empirical investigations, explicitly link predictive analytics to ESG performance, incorporate diverse geographical contexts, and adopt longitudinal designs that assess sustained impact and model robustness over time.

Reference Number 5: Literature Review on LNG Supply Chain Risk Mapping , Wirayuda, M. R., Baihaqi, I. & Sugihartanto M. F. I*nternational Journal of Business and Management Technology in Society*, (2023). 1(2), 110-117. https://journal.its.ac.id/index.php/ijbmts/

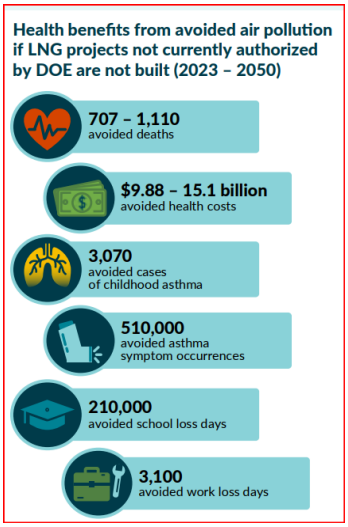
RISK MAPPING

SCOR	Risk	Reference
Plan	Investment cost risk	Resley & Reinsvold (2009); Shakhovskaya et al. (2018); Shaikh et al. (2016); Weijermars (2012a)
	Domestic regulatory risks	Chait et al. (2019); Weijmars (2012b)
	Risk policy	Weijermars (2012a); Chait et al. (2019)
Source	LNG price volatility	(Shakhovskaya et al. (2018); Chait et al. (2019); Xu & Lien (2020); Asenov (2018); Yukseltan et al. (2021)
	Single-supplier dependency	Basak et al. (2017)
	Miscalculation of natural gas consumption	Fagundes et al. (2021)
Make	Delays in upstream gas projects	Resley & Reinsvold (2009); Berle et al. (2013)
	Technology risks (technology obsolescence, *cyber-attacks*, information data breaches, and information system failures)	Stronzki et al. (2008)
	Inadequate transportation, storage, and infrastructure	Seconmadi (2010); McCreight (2019)
	Trade and operations mismanagement	Tan et al. (2020)
Deliver	Delivery delays	Stonzik et al. (2008)
	Poor delivery quality	Stonzik et al. (2008)
	Supply disruptions	Stonzik et al. (2008)
	Supplier failure: failure to meet contractual obligations and buyer expectations	Stonzik et al. (2008)
	Growth and fluctuations in electricity demand	Shakhovskaya e al. (2018)
	Power grid *collapses* due to lack of primary energy supply	Zani et al. (2010)
	Primary energy supply demand imbalance	Hibbard & Schatzki (20120
	Demand uncertainty	Weijermars (2012)

Reference Number 6: PERMIT TO KILL Potential Health and Economic Impacts from U.S. LNG Export Terminal Permitted Emissions. Authors Johanna Heureaux-Torres, Sierra Club, Andres Chang, Greenpeace USA, Tim Donaghy, Greenpeace USA. Published August 2024 by Sierra Club and Greenpeace USA

KEY FINDINGS

- Liquefied natural gas (LNG) export terminals are permitted to emit levels of air pollution that cause serious health harms for people living in the region where the terminals are built.



- Air pollution from currently operating LNG export terminals is estimated to cause 60 premature deaths and $957 million in total health costs per year. If all the planned LNG terminals and expansion projects are built, those numbers would increase to 149 premature deaths and $2.33 billion in health costs per year.

- By 2050, the same permitted air pollutants from currently operating LNG export terminals alone would yield cumulative impacts of 2,020 premature deaths and $28.7 billion in total health costs, with these figures rising to 4,470 and $62.2 billion respectively in a scenario where all planned terminals are built.

- Parishes and counties in and around Southwest Louisiana, where a cluster of LNG terminals are located, are slated to suffer the worst air pollution impacts per capita. However, several parishes and counties farther away – including Orleans Parish, Harris County, and Dallas County, which is over 250 miles from the nearest terminal – are slated to suffer high premature deaths due to large populations exposed to air pollution from terminals.

- There is a strong overlap between areas that are already environmentally overburdened and the 35 counties and parishes that would experience the worst air pollution impacts from the full LNG buildout. Of the total population within these counties and parishes, 70% live within EPA nonattainment zones. Moreover, the majority of these counties and parishes rank above the Climate Vulnerability Index's 82nd national percentile.

- At the national level, Black and Hispanic Americans would respectively experience air pollution from LNG terminals at 151–170% and 110–129% the rate of white Americans. This partly reflects that Texas and Louisiana have high average exposure rates to LNG terminal air pollution and disproportionately large Black and Hispanic American populations.

- If the Department of Energy (DOE) ceases to approve LNG export applications, it would save an estimated 707 to 1,110 lives and avoid $9.88 to $15.1 billion in health costs through 2050, by comparison to a scenario where all projects are built. A policy to phase out all LNG exports, consistent with limiting warming to 1.5^0 C, would save even more lives and health costs.

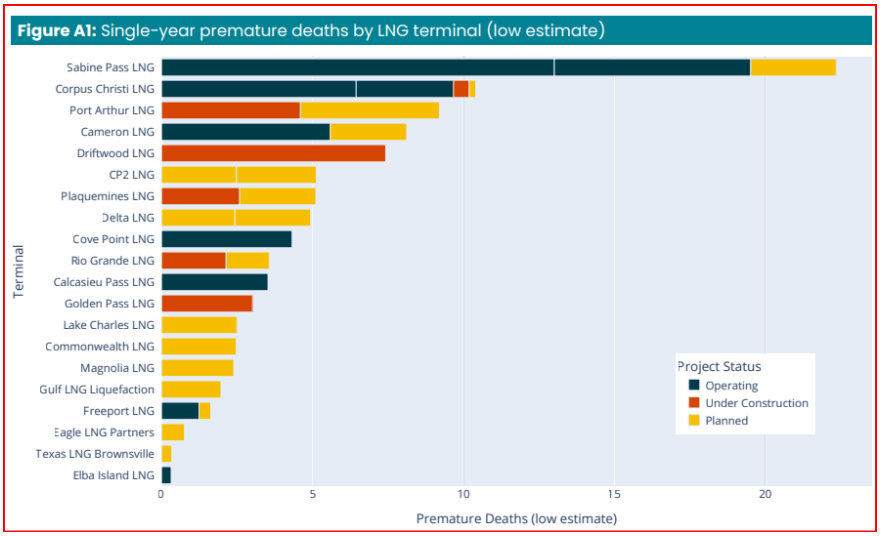
- This study does not consider the likely public health harms associated with air pollution from infrastructure upstream or downstream of LNG terminals, hazardous air pollutants such as benzene, the impacts from explosions or other emergencies, or the climate impacts of LNG's life cycle emissions.

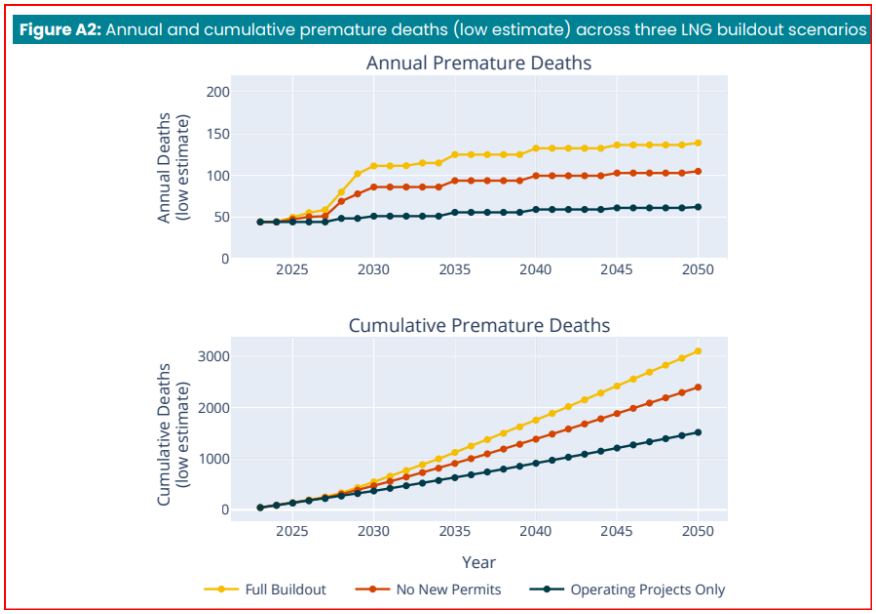
- DOE's review of the studies and analysis it uses to assess LNG exports, as well as its review of individual LNG export project applications, should make clear that any projects that exacerbate climate change or worsen local health outcomes are simply not in the public interest and must be rejected.

- DOE, Federal Energy Regulatory Commission (FERC), and other agencies should reject any approvals or permits for LNG export terminals, as well as related pipelines and compressor stations.

- DOE and FERC should assess the cumulative impacts of air pollution from existing and the slate of planned LNG terminals when evaluating the impacts of any specific project on the surrounding communities.

In May 2024, the Bullard Center for Environmental and Climate Justice published a landmark report looking at the cumulative impacts of the LNG buildout in Texas and Louisiana. Their work helps to address important research gaps in terms of assessing impacts of LNG infrastructure, as previous analyses presented only a limited review of the environmental justice implications of these facilities. The report looks at six LNG export terminals and presents data on pollution impacts, health and safety risks, and exacerbated climate risks stemming from their operations as well as pre-existing pollution burdens and health disparities tied to their siting. The report highlights that the selected LNG export facilities degrade the air quality and public health of adjacent communities through the release of various criteria pollutants (including NOx and particulate matter) as well as various hazardous air pollutants (e.g. benzene, toluene, formaldehyde) which are known to cause respiratory illness, cancer, and birth defects through prolonged exposure.





Reference Number 7: LIQUEFYING THE GULF COAST: A CUMULATIVE IMPACT ASSESSMENT OF LNG BUILDOUT IN LOUISIANA AND TEXAS Robert D. Bullard Bullard Center for Environmental and Climate Justice. Robin Saha, Ph.D. University of Montana Robert D. Bullard, Ph.D. Texas Southern University Liza T. Powers, Ph.D. Texas Southern University. May 2024

Emissions from petrochemical facilities harm reproductive health, and Texas women have the highest maternal mortality rate in the country. Moreover, Black women in the state are twice as likely to die from pregnancy-related causes as White women (Johansen et al., 2019). Overall, Black Americans and Hispanic Americans as a whole are exposed to 1.54 times and 1.20 times more particulate matter, respectively, than the U.S. general population (Mikati et

al., 2018). Studies have found a strong correlation between air pollution exposure and student health, school absences, and academic performance (e.g., Grineski et al., 2016).
Children are also particularly vulnerable to toxic air pollution from petrochemical and other industries, due to their high metabolism, stage of physiological development, and time spent outdoors. Using the interactive Air Toxics at School Tool, we found that school districts in close proximity to LNG facilities in Louisiana and Texas have higher rates of air toxics hazards than the national average. Four of the seven schools nearest to each of the LNG facilities examined have air toxics exposure levels above the 95th percentile for the nation.

In sum, communities in the vicinity of the LNG facilities we examined have disproportionately high percentages of socially and politically vulnerable populations, as well as a high prevalence of adverse health conditions. The social and health vulnerabilities that this study has revealed are an important part of the cumulative environmental burden of LNG facilities.

Environmental Impacts of LNG

Our extensive review of the environmental impacts of LNG export terminals clearly shows the serious magnitude and scope of the environmental, health and safety, and quality of life burdens of LNG development in the Gulf South. The construction and operation of LNG facilities are heavily polluting, destroy and degrade sensitive ecological areas, and harm the species and human communities that rely on them. Specifically, we found that the six LNG facilities we examined

- sacrifice nearly 8 square miles (5,120 acres) of mostly undeveloped land, including wetlands and prime agricultural lands;
- destroy 1,100 acres of wetlands and marshlands of state and national significance in Louisiana, adding to major historical losses and coastal erosion loss estimated to cost $550 million annually by 2050;
- adversely impact local fishing industries worth $367 million in Louisiana in 2021;
- pose risks to fisheries through wetland destruction, erosion, cooling water intake, and pipeline construction;
- destroy imperilled plant communities and those of special concern, including a rare coastal clay dune habitat for the endangered ocelot and northern aplomado falcon near the Rio Grande LNG; harm numerous types of wildlife, including endangered species, special status species, migratory birds, and mammals;
- disrupt wildlife breeding, nesting, foraging, sheltering, and communication behaviours.
- entail leaks and spills of hazardous substances that threaten shallow groundwater areas and wash into waterways;
- require tens of millions of gallons of fresh water, in the case of Plaquemines LNG reducing water pressure for local residents and businesses;
- involve massive amounts of dredging (19.4 million cubic yards—enough to fill over four Superdomes) that degrades water quality, damages sea and estuarine bottom ecosystems, and risks remobilizing contaminated sediments;
- require disposal of dredging spoils that degrades water quality and damages commercial, recreational, and subsistence fisheries;
- pose other risks to fisheries from cooling water intake;
- work at cross purposes to the Mid-Barataria Sediment Diversion project, which is intended to restore wetlands and mitigate land loss;
- attempt to replace some destroyed wetlands with artificial ones that have lower ecological value and are poorly monitored; and degrade air quality and threaten the public health of fenceline communities by being
  - major sources of Clean Air Act (CAA)–designated “criteria air pollutants,” including 10,382 tons of nitrogen oxides and 1,699 tons of particulate matter annually, with carrier vessels adding 10% more criteria air pollutants on top of those;
  - major sources of CAA-designated “hazardous air pollutants,” collectively emitting 264 tons per year of substances including formaldehyde, benzene, toluene, ethylbenzene, and xylene, which are known carcinogens and respiratory, neuro-, organ, and reproductive toxins that are likely to have synergistic health effects;

◦ violators of air permits, even those that already routinely exempt operators from emission standards during start-up, shutdown, and emergencies; and

◦ sources of fugitive emissions, such as venting and illegal flaring resulting from both cost-cutting measures and lax monitoring and enforcement by state regulators.

Details about these impacts are provided in the body of this report using information from FERC's own environmental reviews supplemented by academic and gray literature. We conclude that environmental impacts on air and water quality, water resources, wildlife and aquatic species, and special status species are significant within each of those categories and in their totality. In making piecemeal licensing decisions, FERC fails to consider the cumulative impacts of LNG development as a whole, vulnerable populations, the preexisting environmental pollution burdens, and ecological damage in the Gulf South.

Finally, LNG terminals are exempt from EPA risk management planning, yet the facilities store large quantities of highly combustible and explosive pressurized methane and refrigerant gasses.

LNG facilities are prone to accidents and failures even without the added risk of extreme weather due to climate change. Accidents can result from cost-saving measures and human factors such as faulty equipment, operational errors, lack of maintenance or monitoring, and poor training. Such factors were involved in accidents at Freeport LNG in 2019 and again in 2021, resulting in a large release of fugitive emissions and a major explosion, respectively (Texas Commission on Environmental Quality, 2021; Foxhall & Buckley, 2022).

Freeport LNG reportedly had about 100 air permit violations that went unenforced, until finally the state fined the company only $9,000 (Ahmed, 2021a). When Cheniere's Corpus Christi LNG was finally found in violation of its air permit for prolonged, excessive flaring, rather than issue a fine, Texas regulators increased Cheniere's allowable emissions (Groom and Volcovici, 2022).

In addition to emitting hazardous air pollutants, **LNG production, transportation, and consumption emit substantial amounts of greenhouse gases that contribute to global climate change. Estimates show that the LNG industry is between 50% and 200% more carbon intensive than operations for gas in its natural state. This is due to the increased production and transportation that LNG adds to the process (Pickrell, 2022)**. The combined life cycle emissions of 19 proposed U.S. LNG terminals are estimated to be approximately 1 metric gigaton (1.1 U.S. gigatons) of carbon dioxide annually, which is equivalent to 250 coal plants (Rozansky, 2022, p. 7). Already, more than $500 million worth of gas is wasted by oil and gas operations annually (R. Brown, 2023).

Air pollution emitted from fossil fuels affects the populations surrounding the infrastructure, creating a major environmental justice issue. Particulate matter exposure is a particular concern.

Computer models prove that burning fossil fuels accelerates climate change and demonstrate the need for policies to reverse the course our climate is headed (Wuebbles & Jain, 2001). The latest Intergovernmental Panel on Climate Change report (IPCC, 2023) states how critical it is to reduce methane emissions in order to save our climate and provides a narrow window to do so. Replacing dirty coal with methane is a false solution (Zalik, 2008). Methane wells, pipelines, and LNG operations result in massive amounts of leaking methane, which is up to 85 times more harmful than carbon dioxide in trapping heat in the atmosphere (Rozansky, 2022; Taraska & Banks, 2014). Annually, the fossil fuel industry releases 135 million tons of methane and toxic pollutants into the atmosphere, and the release of methane has steadily increased since the mid2000s (International Energy Agency, 2022). When considering cumulative impacts, it is critical to consider the fossil fuel's life cycle, that is, the potential for emissions at each stage from extracting, processing, transporting, and eventual combustion (Donaghy & Jiang, 2021).

Health Impacts

Fossil fuels present risks to health in many forms, such as accidents, explosions, and short- and long-term exposures. The network of pipelines has only increased with unconventional oil and gas development. The watchdog group Pipeline Safety Trust used federal data to analyze pipeline failure rates and found that those constructed after 2010 have the same failure rate as those installed before the 1940s. This suggests the new demand has caused industries to cut corners in building them (2015, p. 6). A study of traffic accidents near the Eagle Ford Shale energy corridor in southern Texas reveals a significant pattern of traffic crashes near production sites of oil and gas (Majumdar & Chun, 2022).

Primarily, health concerns occur from breathing in the toxic releases. Louisiana highlights this issue. At the Cameron LNG facility, emissions levels gradually increased each year from 2018 to 2020, with carbon monoxide increasing from

20 tons to 4,153 tons. Nitrogen oxides increased from 7 tons to 1,785 tons (Jones, 2023a). Explosions also pose a public health risk for nearby workers and community members. The rush to export LNG overseas has prompted many regulators and industry officials to downplay or overlook the potential for vapour cloud explosions. Many engineers have argued since 2016 against this complacency to risk (Englund, 2021). On June 8, 2022, Freeport LNG experienced an explosion that the company has downplayed, though the explosion's force knocked a lifeguard off her chair on a beach nearby and caused injury to a toddler (Drane, 2022a). Explosion incidents have occurred from the storage of LNG—for example, at the Buncefield oil storage and transfer depot in December 2005 (Aneziris et al., 2021; Animah & Shafiee, 2020

Researchers have documented 61 hazardous air pollutants near drilling operations and 64 hazardous air pollutant emissions occurring from drilling activities, leaks, the refining process, and consumer end use (Donaghy & Jiang, 2021, p. 10). Flaring causes higher emissions of particulate matter, carbon monoxide, and nitrogen oxides, resulting in elevated hospital admission rates (Blundell & Kokoza, 2022).

Table 5.2. EJScreen Environmental Indicator Score Percentiles for Gulf Coast LNG Facilities in Comparison to State and National Scores (State/National)

Indicator	Louisiana LNG facilities			Texas LNG facilities		
	Cameron	Driftwood	Plaquemines	Corpus Christi	Freeport	Rio Grande
Particulate matter ($PM_{2.5}$)	62/73	79/79		x/78	x/62	77/86
Ground-level ozone			75/x			
Diesel PM	x/< 50	x/< 50			64/50–60	
Air toxics cancer risk	70/90–95	90/95–100	52/80–90		95/95–100	
Air toxics respiratory hazard index	x/70–80	93/95–100			99/95–100	
Traffic proximity and volume				60/x		70/66
Lead paint				57/x	82/64	52/x
Superfund proximity	54/x	62/x		71/60	89/81	
RMP proximity*	56/61	75/82		73/78	98/98	85/87
Hazardous waste proximity	54/53	59/59		75/x	97/83	
Underground and leaky storage tanks				57/58	80/73	67/64
Wastewater discharge indicator	85/78	90/85	75/68	57/55	99/96	

Note: Values less than the 50th percentile are blank or shown as "x."

* Risk Management Plan facility.

Table 5.12. Air Pollutants Associated with LNG Emissions and Example Health Hazards

Pollutant type		Example health hazards
Criteria air pollutants	Carbon monoxide	Cardiac effects; neurotoxicant
	Lead	Possible carcinogen; neurotoxicant; reproductive/ developmental toxicant; cardiac effects
	Ozone	Respiratory toxicant (including asthma)
	NO_x (nitrogen oxides)	Respiratory toxicant (including asthma); immune toxicant
	$PM_{2.5}$ (fine particulate matter)	Carcinogen; cardiac effects; respiratory toxicant (including asthma)
	PM_{10} (particulate matter)	Carcinogen; cardiac effects; respiratory toxicant (including asthma)
	Sulfur dioxide	Respiratory toxicant (including asthma)
Hazardous air pollutants (HAPs)	Acetaldehyde	Possible carcinogen; neurotoxicant; respiratory irritant; toxicant (including asthma)
	Acrolein	Respiratory irritant
	Benzene	Carcinogen; neurotoxicant; organ toxicant (blood); reproductive toxicant
	Ethylbenzene	Carcinogen; organ toxicant (liver, kidney); neurotoxicant
	Formaldehyde	Carcinogen; respiratory toxicant; respiratory irritant
	n-Hexane	Developmental toxicant; neurotoxicant
	Toluene	Developmental toxicant; immune toxicant; neurotoxicant
	Xylene	Respiratory toxicant; neurotoxicant

These emissions levels are deeply concerning given the health effects associated with criteria air pollutants. As Table 5.12 shows, many health hazards are associated with these pollutants. Several are respiratory toxicants, and particulate matter (both PM2.5 and PM10), ozone, sulphur dioxide, and NOx are also all associated with asthma (Guarnieri and Balmes, 2014). Plaquemines LNG and Driftwood LNG are being sited in areas with disproportionately high asthma rates. Also of concern is the carcinogenicity of particulate matter—a known lung carcinogen (International Agency for Research on Cancer, 2015). Emerging evidence also connects PM2.5 as well as NOx to other cancers, such as breast cancer (Amadou et al., 2023; Hvidtfeldt et al., 2023; Poulsen et al., 2023).

LNG export facilities use massive turbines that pump refrigerant gases through the methane to cool it and reduce its volume by more than 300 times. All of the turbines for the facilities studied, except for Freeport LNG, are gas fired, combusting even more methane supply gas (Freeport LNG uses electric turbines). During the operations of LNG terminals, natural gas compressor engines used for the liquefaction trains are the primary emissions source and are by far the largest contributors to emissions listed in Table 5.13. Corpus Christi's three liquefaction trains have eighteen 43,013-horsepower compressors (FERC, 2014b, p. 4-112). Although the compressors emit much less fine particulate matter than diesel compressors, they emit large amounts of ozone precursors, NOx, and VOCs. In Table 5.13, the variation in the amounts of each pollutant among the facilities may be partially a reflection of different LNG capacities and equipment. For example, the relatively low amount of emissions for Freeport LNG (52 tpy of NOx) is due to the use of electric rather than gas compressors.

Health effects from exposure to HAPs and other air pollutants depend on many factors, such as the level and duration of exposure and interactions among chemicals that are not well understood but that can magnify the health effects of individual chemicals. Such interactions can explain why low levels of exposures may have harmful health outcomes (Lagunas-Rangel et al., 2022). Recently the International Agency for Research on Cancer classified air pollution mixtures—not just individual air pollutants such as benzene or particulate matter—as being carcinogenic (International Agency for Research on Cancer, 2015). There is growing research interest in the health effects of long-term, low-level exposures to a common set of highly toxic substances produced by fossil fuel combustion—what are referred to as BTEX, or benzene, toluene, ethylbenzene, and xylene. Presently the risks of combined exposures cannot be reliably assessed, though the non-cancer effects of each of these chemicals alone are well known and include neurobehavioral health outcomes such as "poor coordination, elevated locomotor activity, measures indicative of anxiety and impulsivity, and compromised learning and memory" (Davidson et al., 2021, p. 11).

The high potential for additive and synergistic effects of LNG emissions, combined with those of other industries (see "Existing Environmental Burdens in LNG Facility Fenceline Communities" above), is illustrative of the type of cumulative impact that EJ communities, activists, and scholars have drawn attention to for decades in calling for use of the precautionary principle (Bullard et al., 2008; Myers, 2002). EJ movement leaders also point out that the current regulatory system fails to adequately address low-level, long-term, and cumulative impacts of environmental exposure to multiple toxic substances. For example, while HAP air concentration levels in fenceline communities may not exceed EPA HAP standards, EPA HAP standards have a weak connection to public health and have been criticized for being set to match the emissions reductions that current pollution control technology can achieve rather than what would protect people (Ross & Brown, 2012).

Greenhouse gas emissions are another major environmental insult of LNG operations. As Table 5.13 shows, and as FERC reports, carbon-dioxide-equivalent emissions (CO_2 e) from the six LNG facilities total 39.3 million short tons per year under normal operating conditions, which observations have shown do not consistently occur. Based on EPA estimates of annual greenhouse gas emissions from a typical passenger car (4.49 metric tons of CO_2 e), in aggregate the emissions from those six LNG facilities are the equivalent to adding 8,749,000 vehicles to the road. That amount does not include greenhouse gas emissions from LNG shipping and natural gas pipelines and wells; neither does it include the combustion at the user end. The climate change implications of LNG greenhouse gas emissions are discussed below.

Our assessment of emissions of criteria air pollutants, HAPs, and greenhouse gases indicates that LNG air pollution risks are significant and suggests that the green image that LNG facilities project of themselves is nothing but a mirage.

Climate Change Hazards, Technological Failures, Explosions, Leaks, and Spills Gulf Coast LNG facilities represent a dangerous cocktail of natural and technological hazards and are a prime example of what are referred to as natural hazards triggering technological accidents, or Natech (Cruz, 2005; Organisation for Economic Co-operation and Development, 2022). Natural hazards such as hurricanes, earthquakes, and floods can initiate events that interfere with the safe operation of facilities, especially those that lack adequate risk management plans for natural hazards (Organisation for Economic Co-operation and Development, 2022). Furthermore, hazards can create a cascade of

safety risks, such as if one tank, among multiple tanks of explosive chemicals in close proximity to each other, were to catch fire or leak. Many natural disasters—such as Hurricanes Katrina, Harvey, and Ida—have caused major damage to industrial facilities, releases of hazardous substances, fires, and explosions, resulting in environmental pollution, evacuations, toxic exposures, and economic losses (Bullard and Wright, 2009; Flores et al., 2021a; Schleifstein & Baurick, 2021). We make the case that LNG facilities are subject to failure and to natural hazards due to their location along the Gulf Coast. Importantly, these failures, threats, and risks from natural hazards are predictable and, thus, should be preventable. At the very least, there should be regulations that govern planning for the occurrence of such hazards and the aftermath.

In this section, we describe some of the types of technological failures that LNG facilities can experience and the natural hazards associated with climate change at present and in the coming decades. We also review LNG facilities' preparations for natural disasters, and, in light of their coastal locations, discuss the potential for natural hazards—sea level rise and storm surges in particular—to cause technological failures. We conclude, as have others, that Natech for Gulf Coast LNG facilities have not been adequately assessed by FERC, state, or local officials, or the industry itself, and that further evaluation is needed to understand the risks that Natech pose to fenceline communities over the lifetimes of facilities (e.g., see van Heerden, 2022).

Technological and industrial accidents can result from human factors such as faulty equipment, operational errors, lack of maintenance or monitoring, poor training, and underinvestment (United Nations Economic Commission for Europe, 2020). An explosion at the Freeport LNG on June 8, 2022, is a prime example of a technological failure. A 2020 violation case by TCEQ against Freeport LNG stated that on August 23, 2019, Freeport LNG had another technology failure that resulted in a large release of fugitive emissions (Texas Commission on Environmental Quality, 2021). The 2022 explosion, described as a "450-foot-tall wall of fire," occurred due to inadequate operating and testing procedures, human error, and personnel fatigue (Foxhall & Buckley, 2022). It created a strong shock wave experienced by nearby residents and caused a fire in the LNG terminal's liquefaction delivery system, raising concerns about what else could have gone wrong (Associated Press, 2022). See the Freeport LNG case study in Chapter 6 for further details.

High winds and hurricanes disrupt operations and result in fugitive air emissions due to facilities needing to flare to burn off materials kept under pressure that can explode if not depressurized properly. The quickest way to deal with pressure is to burn off the materials, or flare from a stack. There are also heavily polluting shutdown–and–start-up procedures. In 2020, Cameron LNG lost power for over a month after Hurricane Laura, worrying local residents, who described large flares "that looked like fireballs in the sky." Days after Cameron LNG resumed operations in October 2020, Hurricane Delta hit, forcing it offline again (Juhasz, 2021).

Although raw, and even refined, methane is not explosive, once chilled to become liquefied and form LNG, the liquid must be kept at pressure to retain the cold temperature. Any contact with ambient air forms rapidly expanding LNG vapours, which are highly combustible and explosive. According to the Philadelphia Gas Works' Safety Data Sheet for LNG (2015), a release of liquid natural gas and the resulting vapours will flow downward initially due to being heavier than air, and then will form a white vapour cloud that will dissipate into the atmosphere. In most cases, an LNG spill will not contaminate soil; however, it can contaminate water. Because LNG is stored under very high pressure and in large volumes, a liquid spill under pressure (jetting) and vapour clouds may travel "considerable distances," depending on factors such as spill amount, wind conditions, built barriers, and topography. A vapour cloud, once formed, may catch fire, flash back, or explode (Philadelphia Gas Works, 2015, p. 3). Vapour clouds can be extremely cold, and workers are especially at risk of direct of exposures that can cause eye damage, severe frostbite, and freeze burns. Inhalation of large quantities of vapours may cause central nervous system depression, nausea, headache, dizziness, vomiting, and incoordination. LNG vapours are an asphyxiant, and higher levels of exposure may cause rapid breathing, numbness in the extremities, loss of consciousness, serious injury due to lack of oxygen, or death.

Although LNG liquid is not explosive, LNG vapours are highly combustible and explosive. Vapours can explode at concentrations in the air as low as 4% by volume (Philadelphia Gas Works, 2015, p. 7). In addition to high levels of heat, fires and explosions pose added risks to nearby residents because of shock waves, flying debris, and potential secondary fires. LNG vapour "can be ignited by heat, sparks, flames, static electricity, and other sources . . . such as pilot lights, mechanical/ electrical equipment, and electronic devices that are not intrinsically safe" (Philadelphia Gas Works, 2015, p. 3). In 1944, a catastrophic series of explosions and fires resulting from an LNG leak in Cleveland, Ohio, killed 128 and injured 200 to 400 people (U.S. Bureau of Mines, 1946).

A technical report by the Pipeline and Hazardous Materials Safety Administration (PHMSA, 2017) conducted vapour emissions modelling of jetting and flashing that could result from a release from highly pressurized pipelines within LNG export facilities. The 2017 PHMSA report indicates that combustible vapours from a pipeline leak can disperse up

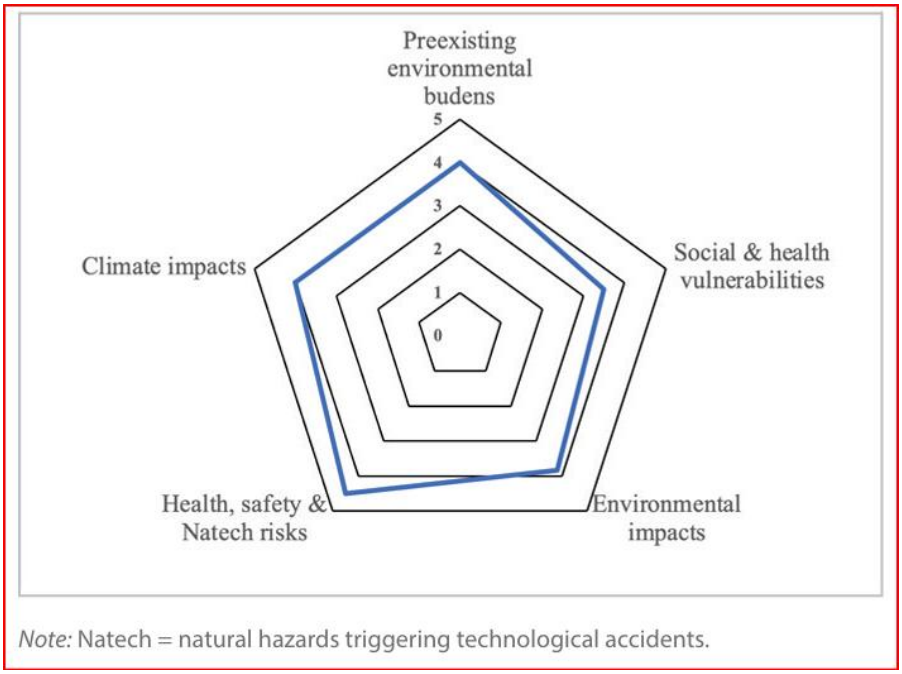
to 9,840 feet, or 1.86 miles, during light winds of 4.5 miles per hour (p. 93). The PHMSA admits that dispersal distances extend beyond the required thermal exclusion zones that LNG operators are expected to safely control. For example, FERC reports an explosion of ethylene and propane storage tanks at Cameron LNG could endanger people and property more than 4,500 feet, or 0.86 miles, from the facility property line (FERC, 2014a, p. 4-190).
Response from MLavelle: These distances indicate a large area (diameter of 1.86miles) of people at risk of death. This development does not comply with Proper Planning or Sustainable Development.

As a result of these hazards, LNG facilities may be equipped with leak detection and emergency shutoff systems, special firewater delivery systems, and high-expansion foam systems that quickly blanket liquid LNG in the event of a spill. Under 49 CFR 193, facilities should be required to install high fencing or impoundments to mitigate jetting and flashing of LNG. However, the PHMSA report does not model distances a vapour cloud could travel from a rupture from LNG storage tanks of any size or identify mitigation measures to reduce vapour cloud dispersion. LNG storage tanks and transport vessel tanks under very high pressure contain exponentially more LNG than a pipeline. It stands to reason that material could form catastrophically sized vapour clouds, if released. The PHMSA requires only modest mitigation measures to reduce vapour cloud dispersion—that is, "vapour cloud barriers," walls around 20 feet high. Such barriers would be no match for jetting from a ruptured tank, especially high off the ground, and a subsequent explosion. Large LNG storage tanks and tankers full of LNG transiting almost daily from already operating facilities potentially endanger people living many miles in every direction. That this safety issue has not been analysed and the dangers made clear to nearby communities in public NEPA documents is inexcusable. LNG export terminals, as currently regulated in the United States, are a catastrophe waiting to happen.

Climate Impacts of LNG Development

In 2022, the Environmental Integrity Project reported that if the gas industry succeeds in building all of its planned LNG facilities, their operations could emit more greenhouse gasses yearly than "20 new coal-fired power plants," or the equivalent of 18 million cars, not counting the emissions and leaks from drilling and pipeline transportation of fracked gas before exportation, transporting LNG, or the emissions from burning it at its destination (Environmental Integrity Project, 2022a). According to Climate Action Tracker's Warming Projections Global Update, the boom in LNG export capacity will compromise meeting the Paris Agreement's 1.5 degrees Celsius global warming threshold (Climate Action Tracker, 2022). The independent research consortium states, "Between 2020 and 2050, cumulative emissions from LNG could be over 40 GtCO2 [gigatons, or billion tons, of CO2] higher, equal to around 10% of the remaining carbon budget," adding "if all of the LNG capacity currently under construction or planned around the world is actually built, the oversupply of LNG by 2030 could be almost five times the amount that the European Union imported from Russia in 2021" (Climate Action Tracker, 2022). According to the International Energy Agency, to avoid the worst of climate hazards, the world needs to dramatically slash demand for natural gas, bringing it down at least 20% by 2030 and 75% by 2050 (McGhee & Canary staff, 2023). This is a sobering assessment considering that the United States recently became the world's largest exporter of natural gas (Stapczynski, 2023). Aside from the dip due to the global COVID pandemic, Figure 5.16 shows a dramatic upward trend rather than a reduction in U.S. LNG exports in recent years.

Figure 5.17. Radar Chart of Impact Ratings of Cumulative Impact Assessment Elements on a 1-to-5 Scale (extremely low to extremely high impacts)



Note: Natech = natural hazards triggering technological accidents.

Figure 5.17 indicates that each element is associated with relatively high impacts in our assessment. These findings show that LNG export facilities have a wide range of significant impacts that add to and exacerbate existing environmental and social burdens. The purpose of this assessment was not to compare the impacts of LNG facility development to their benefits. We have already made the case that the benefits accrue overwhelmingly to producers, owners, financial investors, and overseas buyers, and that LNG development magnifies existing inequalities. LNG companies fail to provide good jobs to fenceline communities, while receiving huge tax breaks and subsidies that starve local governments and school districts. With governmental blessings, they squander American resources for the short-term benefit of owners and shareholders. That is how petrocapitalism works, in this case, aided by the current geopolitical forces favouring LNG development.

Reference Number 8: Does Living Near LNG Plants Pose Health Risks? Scientists Investigate. Michelle Gamage *AMA Pediatrics,* 13 Mar 2024. UVic, Vancouver Coastal Health, the Canadian Association of Physicians for the Environment, Simon Fraser University, the University of Toronto, Texas A&M University and the non-profit My Sea to Sky.

Liquefied natural gas export facilities burn excess methane, a source of pollution called 'flaring.'

Burning methane gas, commonly referred to as natural gas, produces a number of pollutants that can affect human health. Flaring produces fine particulate matter (which is material smaller than 2.5 microns in diameter, or roughly 13 times smaller than the width of a human hair), nitrogen dioxide and volatile organic compounds like benzine and carbon monoxide.

A study in Texas found that living near flaring sites is associated with preterm birth and low birth weight. Studies in Pennsylvania, California and Alberta found that the closer someone lives to a fracking site, the more likely their baby is to be born with a low birth weight and worse health outcomes.

Low birth weight causes higher infant mortality and more chronic illness later in life and is associated with poor lung function. Babies with lower birth weight is a serious public health problem.

Exposure to these pollutants is also associated with asthma exacerbation, chronic cardiovascular disease and other illnesses like chronic obstructive pulmonary disease.

The most vulnerable people, like the very young and elderly, will be the most affected by this pollution, but anyone can be impacted by changes in air quality.

So-called natural gas is mostly made up of methane, a fossil fuel that has been found to leak during production and transportation and is 35 times more efficient as a greenhouse gas, trapping heat inside Earth's atmosphere, than carbon dioxide. That means increasing emissions, increasing temperatures, increasing extreme weather events and causing more death and destruction."

Marketing natural gas as "clean," ignores Scope 3 emissions, which happen when a fossil fuel is burned. Canada counts only Scope 1 and 2 emissions, which happen during extraction and transportation of fossil fuels — not what happens when the fuel is burned, which makes up 95 per cent of the total emissions.

Reference Number 9: ENERGY, ECONOMIC, AND ENVIRONMENTAL ASSESSMENT OF U.S. LNG EXPORTS. U.S. Department of Energy, Office of Fossil Energy and Carbon Management, Office of Resource Sustainability. December 2024.

D. Key Findings: Environmental and Community Effects

• The production and transportation of natural gas in the U.S., including natural gas for export, has energy, labor / workforce, economic, environmental, and social justice implications, among other implications.

• Communities of colour, including those with Black, Indigenous, and Hispanic populations, as well as rural and low-income communities, have historically been disproportionately exposed to the environmental risks, harms, and measurable impacts that arise from natural gas and overall fossil fuel development and production activities. These same activities also provide economic support for many communities.

• Production and Upstream Impacts

1. Increased U.S. natural gas production increases upstream environmental impacts, including impacts to water, air, and land.

2. Natural gas production and processing emits pollutants that are harmful to human health.

3. Researchers have found spatial and temporal (i.e., location and timing) correlations between seismic events precipitated by human activities and the disposal of produced water through underground injection into saltwater disposal wells (SWDs), in several states including Texas, Oklahoma, Kansas, Colourado, Arkansas, and Ohio. Various means are underway to reduce the impact, such as recycling produced water rather than disposing of it.

• Community Effects

1. Natural gas production and processing impacts upstream, midstream, and downstream communities in harmful and beneficial ways. Additional research is needed on the impact of LNG exportation on local communities. In particular, in areas with existing heavy industry, the cumulative impact of LNG exports has yet to be determined.

2. From an economic perspective, natural gas production and the development of natural gas export infrastructure tends to increase employment in regions and communities where it occurs, but some evidence indicates that jobs often go to people who either move to the area for the jobs or commute from other areas, rather than to long-term residents.

3. Oil and gas production growth brings new revenues to local governments but can also bring additional burdens such as increased emergency services and police, additional water and wastewater infrastructure, and potential damage due to increased heavy road usage.

4. Local mineral rights holders receive royalties, though such recipients are not always local residents.

5. Quality of life impacts from natural gas development include noise, light pollution, dust, increased traffic, crime, and social disruptions due to the cyclical nature of the production industry.

Outside of water withdrawal effects, there are three major water contamination concerns around natural gas development:
1) the upward migration of fluids (injected hydraulic fracturing fluids, stray hydrocarbons) into groundwater aquifers;
2) surface spills of oil and gas production fluids, including produced water; and
3) the discharge of inadequately treated produced water to surface water sources.
Wastewater spills appear to pose more of a risk than subsurface migration pathways from oil and gas development. Most leaks and spills are accidental. Intentional illegal dumping of produced water and other wastes also occurs. Dumping of produced water may cause significant changes in soil chemistry and changes in microbial community structure

Reference Number 10: Liquefied Natural Gas (LNG): Health and Climate Impacts. Environmental Health Project Aug 10, 2023 © 2026 Environmental Health Project. The Environmental Health Project (EHP) is a nonprofit public health organization that assists and supports residents of Southwestern Pennsylvania and beyond who believe their health has been, or could be, impacted by oil and gas development

Air Pollution

LNG plants emit carbon monoxide, sulphur dioxide, and volatile organic compounds (VOCs). Studies have shown that these pollutants are associated with a range of health impacts, including headaches, coughing, dizziness, and other respiratory illnesses. They can also irritate skin, eyes, nose, and lungs. Long-term exposure to these pollutants can lead to heart disease, certain types of cancer, and damage to the reproductive system and internal organs. The Louisiana Bucket Brigade issued a report in 2023 that found LNG facilities underreport pollution events. One facility, Cameron LNG, has had an average of two accidental releases due to equipment failures each month since beginning full operations in August 2020, according to the report.

Instead of requiring compliance with environmental laws, Gulf states have been increasing allowed limits for a variety of air pollutants. Texas has repeatedly raised pollution limits for the Cheniere LNG plant, the largest LNG facility in the U.S. As of 2022, the facility was permitted to release 353 tons per year of VOCs, twice the limit set out in its original permit in 2014. The state has raised limits on four other pollutants by more than 40%.

Water Pollution

The construction and operation of an LNG facility endangers groundwater and surface water in several ways. The following pathways of water contamination are reported in an environmental impact statement prepared by PNG LNG, a gas production and processing facility in Papua New Guinea. LNG facilities see potential contamination from:

- Fuels, lubrication oils, and chemicals due to the transport, storage, and handling of these materials during construction.
- Hydrocarbon products, fuels, lubricating oils, and chemicals from the transport, storage, and handling of these materials during operations.
- The operation of feed gas processing and reticulation systems for processing and transferring feed and treated gas and condensate around the LNG plant should damage occur to pipework, processing units, or transfer vessels.
- The dehydration, mercury removal, and fractionation processes, with contaminants of concern including heavier VOCs in liquid form such as benzene, xylene, and toluene, and heavy metals such as mercury.
- The operation of offsite and utility systems alongside the LNG plant, with contaminants of concern including hydrocarbon residues (from the hot oil and fuel gas systems), brine, and hazardous chemicals.

Noise

LNG plants utilize sound walls to mitigate the noise experienced in communities where they operate. Dominion Energy's Cove Point gas liquefaction facility near Lusby, Maryland, is surrounded by a 60-foot sound wall. Still, residents reported being kept awake at night by nonstop noise that sounded like a slow moving freight train during the facility's commissioning phase.

Mental Health Impacts

Living near a major pollution source increases stress, anxiety, depression, and other mental health symptoms. LNG liquefaction plants and export terminals require years of disruptive, noisy construction followed by a lifetime of uncertainty over the long-term health and safety impacts of the facility. The Agency for Toxic Substances and Disease Registry (ATSDR) provides a community stress resource center to help manage stress and build resilience in communities impacted by environmental contamination.

Reference Number 11: Recent Developments in Biogas Manufacture and Biogas Utilization: Narayanan, C. M. and Narayan, V. (2020). A Review. *European Journal of Sustainable Development Research, 4*(4), em0135. https://doi.org/10.29333/ejosdr/8366

BIOCHEMICAL DESULPHURIZATION OF BIOGAS

Hydrogen sulfide is often present in biogas. Even when present at low percentages, it could cause serious corrosion problems as it leads to the formation of SO2 gas and sulphuric acid mist, both of which are extremely harmful to the process equipment employed as well as to the environment (if exhausted to the atmosphere).

The enriched biogas is first bubbled through ferric sulfate solution in a stirred tank chemical reactor. Hydrogen sulfide present in the gas stream gets oxidized to elemental sulphur (colloidal sulphur), while ferric sulfate is reduced to ferrous sulfate.

The colloidal sulphur that gets precipitated is separated by filtration and the acidified ferrous sulfate solution (filtrate) is pumped into a microbial bioreactor that has been seeded with a culture of recombinant *Thiobacillus ferrooxidant* microbes (sulphur eating bacteria) and is sparged with sterile air from the bottom.

The product solution is fed to a sedimentation tank in which all the microbial cells settle down as sludge. A part of this microbial sludge is recycled back to the bioreactor (to maintain the optimum population of microbes in the reactor), the rest wasted. The clear ferric sulfate solution that overflows is pumped back to reactor.

MANUFACTURE OF NITROGENOUS FERTILIZERS STARTING FROM BIOMETHANE

Biomethane can also be employed as the starting material for the synthesis of nitrogenous fertilizers such as ammonium sulfate, urea, calcium ammonium nitrate (CAN or nitrolim) and ammonium phosphates (MAP, DAP). It involves three catalytic reactors (apart from the Haber reactor) such as the primary reformer, secondary reformer and the shift converter. In the primary reformer, syngas is produced by the steam – hydrocarbon reaction as discussed earlier. The process takes place in a column reactor that is composed of a packed bed of nickel – catalyst particles. Both preheated biomethane and high pressure steam are admitted from the bottom and as they move up the catalyst bed, steam – hydrocarbon (steam – methane) reaction occurs and syngas gets generated. As stated earlier, the reaction occurs at a temperature of 750 – 950^0 C (temperature of catalyst bed) and at a pressure of 10 – 15 atm. Since steam is used in excess, the product gases would contain little unreacted methane. In the secondary reformer, which is also a packed bed reactor composed of a bed of nickel catalyst, preheated mixture of biomethane and dry air (mixed in a prescribed, pre-calculated proportion) is admitted from the bottom and as the gas mixture ascends through the catalyst bed, methane gets catalytically oxidized to CO and H2. A small amount of carbon dioxide could also be formed. The reactor operates at specified temperature and pressure (T = 500 – 600℃, P = 5 – 6 atm).

The two gas streams (product gases from the primary reformer and those from the secondary reformer) are mixed (to obtain a gas mixture composed of CO, H2 , N2 and traces of CO2) and then admitted to the shift converter (the third packed bed catalytic reactor) into which excess steam is also injected from the bottom. In presence of the iron oxide – chromium oxide catalyst particles present in the shift converter, all CO present in the gas mixture is oxidized to CO2 by steam, followed by production of additional hydrogen gas. The gas mixture leaving the shift converter shall be thus composed of N2, H2 and CO2, and is sent to the absorber – desorber system to remove all the CO2 present by absorbing in aqueous MEA solution. The resulting gas mixture of nitrogen and hydrogen is called *ammonia synthesis gas*. By adjusting the amount of steam admitted to the primary reformer and the amount of air admitted to the secondary reformer, the molar ratio of N2 to H2 in this mixture could be adjusted to 1:3.

In the renowned Haber reactor, nitrogen reacts with hydrogen in presence of the iron catalyst (Haber catalyst) at high pressure (P = 10 – 15 atm), the most favorable operating temperature for Haber catalyst being 375℃.

Ammonia is the universal raw material for the manufacture of many nitrogenous fertilizers (urea, ammonium sulfate, ammonium nitrate) and nitrophosphates (monoammonium phosphate, diammonium phosphate).

MANUFACTURE OF PHOSPHATIC BIOFERTILISER (PROM) FROM ANAEROBIC DIGESTER SLUDGE (ADS)

The sludge discharged from the biogas digester, called anaerobic digester sludge (ADS), could be dewatered, dried, pulverized and then used as a low grade nitrogenous manure. **However, its N – content is only 2.5% and is thus a poor substitute to synthetic fertilizers such as urea (which contains 46% N), ammonium nitrate (33% N) and ammonium sulfate (21% N).**
Response from MLavelle: The digestate only has 2.5% nitrogen and drying to make fertiliser pellets is just a cosmetic exercise.

Reference Number 12: USEPA 456-R-20-001. AN OVERVIEW OF RENEWABLE NATURAL GAS FROM BIOGAS. July 2020

7.0 PURIFICATION PROCESSES AND GENERAL TECHNOLOGIES

Raw biogas, which is typically between 45 and 65 percent CH4 depending on the feedstock, must go through a series of steps to be converted into RNG (at 90 percent CH4 or greater, depending on the specification for the pipeline or other end use). Constituents of RNG that most often have specifications or limits to meet are CO2, O2, inert gases (including N2), total sulphur, H2S, siloxanes and VOCs. Other properties that are prescribed by pipelines or end users include heating value, temperature, pressure and moisture content.

Typical steps to convert raw biogas to RNG are reviewed below. As shown in Figure 2 and Figure 3, the treatment can be divided into:

• Primary: basic moisture and particulate removal.

• Secondary: additional moisture removal, contaminant removal and compression.

• Advanced: CO2, O2, N2 and VOC removal and further compression.

The primary and secondary treatment stages produce a medium-Btu gas, which means the heating value of the gas is less than that of fossil natural gas (typically about half). The advanced treatment stage produces RNG, with a heating value similar to fossil natural gas.

As part of advanced treatment, some CH4 is stripped out along with the CO2 and other residual constituents—especially H2S—and routed to a flare or thermal oxidizer for destruction. The amount of CH4 stripped out as "tail gas" depends on the technology used to upgrade the gas, the ultimate CH4 specification for the RNG and the cost–benefit ratio of additional CH4 capture versus the additional capital expense to achieve it.

Primary Treatment

Primary treatment consists of basic moisture and particulate removal from the raw biogas. The gas passes through a knockout pot, filter and blower to remove moisture. This treatment is all that is required for destroying the LFG in a combustion flare; in addition, some LFG energy projects have used only primary treatment when combusting LFG in medium-Btu applications such as leachate evaporators, boilers and kilns.

Secondary Treatment

Secondary treatment consists of additional moisture removal, contaminant removal and compression. The process first uses an after cooler to condense and remove additional moisture, then removes contaminants such as siloxanes and sulphur. The type of contaminants removed depends on the end use and which constituents are present in the biogas and at what levels. The gas can also be compressed further as needed. These secondary treatments are used to produce medium-Btu gas for direct thermal applications such as boilers or for electricity generation applications such as engines and turbines.

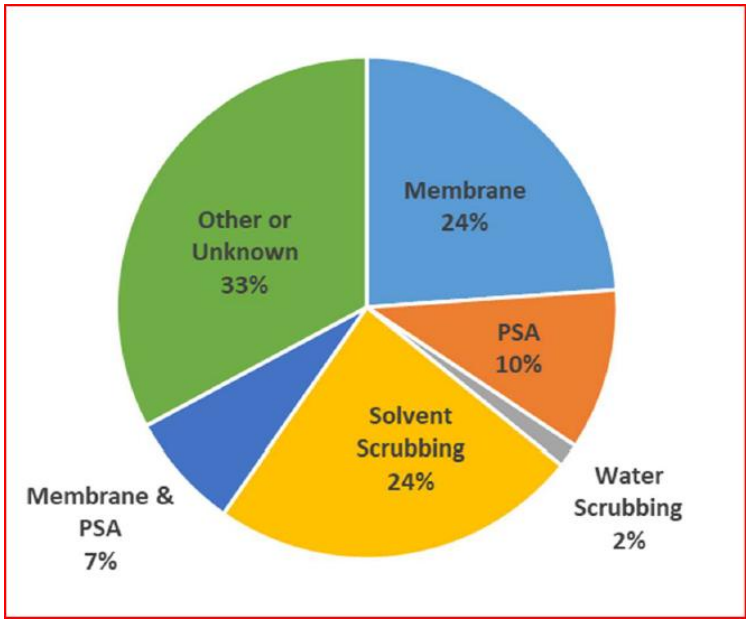
Advanced Treatment

Advanced treatment is critical to transform biogas into RNG. Advanced treatment must remove CO2, O2, N2, VOCs and siloxanes (as needed), although some projects may remove these types of contaminants in an earlier stage. The selection of the advanced treatment technology type is site-specific and project-specific, and there are advantages and disadvantages to each type. Sections 7.1 through 7.4 describe advanced treatment technologies in detail, along with their benefits and drawbacks.

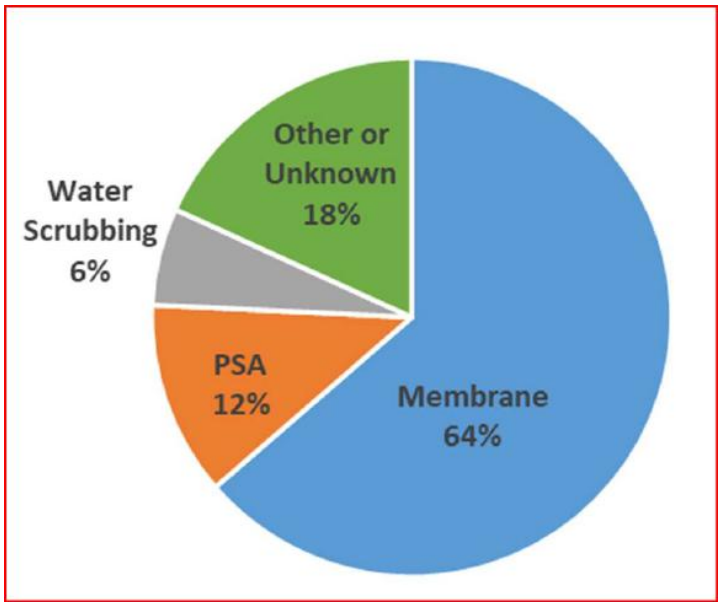
7.1 CO2 Removal Technologies

There are four common ways to remove CO2 during the advanced treatment stage: membranes, pressure swing adsorption (PSA), solvent scrubbing and water scrubbing. Each technology has strengths and weaknesses that are evaluated and balanced on a case-by-case basis for each potential RNG facility to select the technology best suited for that particular site. Each technology can achieve RNG quality standards necessary for pipeline injection or onsite vehicle use, but it is often a matter of upfront capital expense versus ongoing operating expense.

CO2 Removal Technologies for U.S. LFG-to-RNG Projects in 2018



CO2 Removal Technologies for U.S. Manure-Based Biogas-to-RNG Projects in 2018



Membrane Systems

A membrane is a type of filter that has a specific pore size rating and operates similarly to a screen or sieve, retaining particles larger than the membrane's pore size. The material that the membrane is constructed from and the method by which the large particles are captured is technology specific. Membranes are often used to remove CO2 and other unwanted constituents when upgrading raw biogas to RNG.

Single-Pass Membrane System

Onsite CNG vehicle fuel use typically does not require a heating value as high as that required by pipeline injection projects, and it also allows some minor levels of O2 and inert gases. Therefore, onsite vehicle fuel applications with smaller biogas volumes often use a single-pass membrane system that captures approximately 65 to 80 percent of the CH4. These systems either send the remaining 20 to 35 percent of the CH4 out as tail gas for economical destruction in an onsite flare or blend it with the remaining biogas for use in turbine or reciprocating engine electrical generating equipment. More efficient gas conditioning technology that would produce a gas with a higher heating value is available for small biogas flows, but historically it has not been economically feasible due to the added capital expense.

Multiple-Pass Membrane System

Larger-scale onsite vehicle fuel applications can use membrane technology similar to that of smaller-scale applications, but with more efficient processes that capture additional CH4 via multiple passes through the membranes. Many of these sites use gas conditioning technology that captures approximately 96 to 99 percent of the CH4. Tail gas from these projects must be destroyed in a flare or thermal oxidizer using supplemental fuel, since the tail gas does not

have a sufficient heating value to sustain combustion.70 The increased volume of RNG produced from conditioning larger biogas volumes can typically justify the added capital and operational expenses and the addition of a thermal oxidizer.

PSA

In PSA systems, adsorbent media are pressurized with the incoming biogas. A difference in molecular size allows CH4 to pass through into the product gas, while the media capture CO2 and, to a lesser extent, N2. Once the media have been saturated, they are depressurized, and the CO2 and N2 are released into the tail gas stream. A typical PSA system employs multiple vessels operating in different stages of pressurization, depressurization and regeneration. PSA can capture between 95 and 98 percent of the CH4; the exact percentage will vary depending on the design of the PSA, which is optimized to balance system performance and system economics.

Solvent Scrubbing

Solvent scrubbing processes use a chemical solvent such as amine or a physical solvent like Selexol to strip CO2 and H2S from the biogas stream. CO2 is adsorbed into the solvent, allowing CH4 to pass through into the RNG product stream. In an amine system, the solution is heated in a separate vessel to release the CO2 into the tail gas stream; in a Selexol process, the solvent is depressurized, which releases the CO2. CH4 capture efficiency varies between 97 and 99 percent for physical solvents but is often greater than 99 percent for amine solvents given that amine solutions are particularly selective for CO2.

Water Scrubbing

Water scrubbing (sometimes called water wash) is a simple process in which the biogas is pressurized into water. CO2 is adsorbed into the water while the CH4 passes through into the RNG product gas stream. The water is then depressurized, and the CO2 is allowed to pass through in the tail gas. CH4 capture efficiency of water scrubbing systems is typically greater than 99 percent.

Biogas Flow Rates for CO2 Removal Technologies

Each CO2 removal technology allows for a different range of biogas flow rates. Typical flow rates for the four main technologies are summarized in Table 6. Process flow diagrams of the four main types of advanced CO2 removal technologies (membrane, solvent, PSA, water scrubbing) were presented in a webinar by LMOP Industry Partner DTE Biomass Energy.

Typical Flow Rates for Advanced CO2 Removal Technologies

Technology	Inlet Biogas Flow Range (standard cfm [scfm])
Single-Pass Membrane	50 to 400
Multiple-Pass Membrane	200 to 5,000+
PSA	800 to 5,000+
Solvent Scrubbing	1,000 to 5,000+
Water Scrubbing	50 to 3,000

7.2 VOC/Siloxane Removal Technologies

For any vehicle fuel or pipeline injection project, a critical part of the LFG conditioning process is the removal of VOCs and siloxanes. Even trace amounts of siloxanes can damage engines, turbines and compressors and so must be removed. VOCs are an environmental pollutant that would be sufficiently destroyed in an engine or turbine, but they are similar in molecular structure to siloxanes. This means any medium that is designed to remove siloxanes will also capture VOCs-usually one cannot be removed without capturing the other.

The concentration of siloxanes within biogas can vary widely by source type and the specific site. A 2017 report prepared by the California Biogas Collaborative noted the following ranges by source type for siloxane concentrations in raw biogas: 0 to 400 milligrams per cubic meter (mg/m3) for WRRFs, 0 to 50 mg/m3 for landfills and 0 to 0.2 mg/m3 for livestock farms (no results available for stand-alone MSW digesters). These results indicate that siloxane contamination is a potential issue mainly with WRRF biogas and LFG, primarily because siloxanes are found in many cosmetic, health and beauty products.

7.3 N2 Removal Technologies

N2 removal (or rejection) may be required as a part of the biogas conditioning system, depending on the biogas inlet N2 levels and the required RNG specifications. Because of the potential intrusion of ambient air (which contains N2) when biogas is collected from landfills, N2 is typically more of an issue in LFG as compared to biogas from anaerobic digesters. An exception to this can be biogas collected from agricultural waste lagoons with membrane covers, as these systems can also allow air leaks into the gas stream.

N2 is difficult and expensive to remove from biogas given the similar diameters of N2 and CH4 molecules, which are approximately 3.6 angstroms and 3.8 angstroms, respectively.

Nitrogen rejection systems remove N2 gas from biogas streams via PSA or membranes. The typical RNG conditioning process initially removes trace-level contaminants and most CO2, while allowing N2 to pass through the system with the CH4. A secondary N2-specific rejection system may be required at the end of the gas conditioning system to remove N2 to acceptable end use levels. Some biogas conditioning systems remove N2 concurrently with CO2 using adsorbents that have a high kinetic selectivity toward N2 and O2.

N2 removal processing can reduce the CH4 recovery rates-the impact on CH4 recovery varies depending on the inlet N2, outlet N2 specifications and the technology used to remove the N2. In one example, the CH4 recovery drops from 90 to 81.5 percent when an N2 and O2 removal unit is added to the process.

7.4 O2 Removal Technologies

Many natural gas utilities have strict limits on O2 for RNG that is injected into a pipeline network. Excessive amounts of O2 can accelerate pipeline infrastructure corrosion, resulting in many utilities setting the upper limit of allowable O2 from 0.2 percent to as low as 2 parts per million. For RNG used directly in vehicles, SAE J1616 has no limit for O2 due to the low water vapour content requirements. CARB's specifications for commercial CNG chemical composition set a 1 percent O2 upper limit. While it is usually feasible to reduce O2 in LFG to less than 1 percent through wellfield tuning and improvements, O2 removal systems are often required for pipeline injection projects on landfills.

Stand-alone O2 removal systems remove O2 through a catalytic reactor and typically are the last step in the LFG conditioning process. Biogas is heated and passed over a catalyst bed, where the O2 reacts with some of the CH4 to create CO2 and water. The biogas exiting the reactor is saturated with moisture and must be dehydrated, typically by using a desiccant dryer or temperature swing adsorption process. Other processes involved in the conditioning of LFG, such as membrane separators and PSA, do remove some O2, which must be considered when designing and sizing a project. Some PSA systems are also effective in removing nearly all O2.

Due to the added capital and operating costs of incorporating an O2 removal system, these systems are often found to be cost-prohibitive for projects with an LFG flow rate less than 1,000 scfm. Costs to heat the biogas and remove moisture must also be considered when developing project financials. These systems may negatively impact CH4 capture efficiency and add CO2 to the product gas stream as well. The CH4 loss and CO2 addition are small, but not negligible.

Reference Number 13: Liquefied Natural Gas (LNG): Health and Climate Impacts. Environmental Health Project. Aug 10, 2023

Health and Safety Risks of LNG

Explosions

Very high temperatures are required to combust LNG, so it is typically considered nonflammable. There is even a safety video showing a lit cigarette being put out in a glass of LNG. However, when LNG is not kept at very low temperatures, it produces highly flammable and explosive vapours. Any accidents or incidents at an LNG facility can pose a significant risk to nearby communities.

On June 8, 2022, an explosion at the second-largest LNG plant in the United States, Freeport LNG, shut down production for months. In April 2023, ten months after the accident, officials from Freeport LNG attended a Brazoria County Commissioners meeting to inform the public about the cause of the accident and the company's plans to address problems that led to the explosion. "At 11:28 a.m. on June 8, the Freeport LNG facility experienced a boiling liquid expanding vapour explosion that resulted in the release of electrified natural gas, leading to the formation and ignition of a natural gas vapour cloud and subsequent fire at the facility," Freeport LNG President Sig Cornelius said. Operator fatigue was reportedly a contributing factor in the incident.

Freeport LNG maintains that there were no injuries associated with the explosion, but a local community group, Better Brazoria, learned through community outreach that a lifeguard and a small child were injured by the explosion while they were on a nearby beach. The force of the explosion shook homes in the neighbourhood.

Air Pollution

LNG plants emit carbon monoxide, sulphur dioxide, and volatile organic compounds (VOCs). Studies have shown that these pollutants are associated with a range of health impacts, including headaches, coughing, dizziness, and other respiratory illnesses. They can also irritate skin, eyes, nose, and lungs. Long-term exposure to these pollutants can lead to heart disease, certain types of cancer, and damage to the reproductive system and internal organs. The Louisiana Bucket Brigade issued a report in 2023 that found LNG facilities underreport pollution events. One facility, Cameron LNG, has had an average of two accidental releases due to equipment failures each month since beginning full operations in August 2020, according to the report.

Instead of requiring compliance with environmental laws, Gulf states have been increasing allowed limits for a variety of air pollutants. Texas has repeatedly raised pollution limits for the Cheniere LNG plant, the largest LNG facility in the U.S. As of 2022, the facility was permitted to release 353 tons per year of VOCs, twice the limit set out in its original permit in 2014. The state has raised limits on four other pollutants by more than 40%.

Water Pollution

The construction and operation of an LNG facility endangers groundwater and surface water in several ways. The following pathways of water contamination are reported in an environmental impact statement prepared by PNG LNG, a gas production and processing facility in Papua New Guinea. LNG facilities see potential contamination from:

- Fuels, lubrication oils, and chemicals due to the transport, storage, and handling of these materials during construction.
- Hydrocarbon products, fuels, lubricating oils, and chemicals from the transport, storage, and handling of these materials during operations.
- The operation of feed gas processing and reticulation systems for processing and transferring feed and treated gas and condensate around the LNG plant should damage occur to pipework, processing units, or transfer vessels.
- The dehydration, mercury removal, and fractionation processes, with contaminants of concern including heavier VOCs in liquid form such as benzene, xylene, and toluene, and heavy metals such as mercury.
- The operation of offsite and utility systems alongside the LNG plant, with contaminants of concern including hydrocarbon residues (from the hot oil and fuel gas systems), brine, and hazardous chemicals.

Noise

LNG plants utilize sound walls to mitigate the noise experienced in communities where they operate. Dominion Energy's Cove Point gas liquefaction facility near Lusby, Maryland, is surrounded by a 60-foot sound wall. Still, residents reported being kept awake at night by nonstop noise that sounded like a slow moving freight train during the facility's commissioning phase.

Mental Health Impacts

Living near a major pollution source increases stress, anxiety, depression, and other mental health symptoms. LNG liquefaction plants and export terminals require years of disruptive, noisy construction followed by a lifetime of uncertainty over the long-term health and safety impacts of the facility. The Agency for Toxic Substances and Disease Registry (ATSDR) provides a community stress resource center to help manage stress and build resilience in communities impacted by environmental contamination.

Reference Number 14: The greenhouse gas footprint of liquefied natural gas (LNG) exported from the United States. Robert W. Howarth. Energy Science & Engineering published by Society of Chemical Industry and John Wiley & Sons Ltd. 16 September 2024. DOI: 10.1002/ese3.1934

2.2 Emissions at liquefaction plants

A substantial amount of energy is required to liquefy methane into LNG, and this energy is provided by burning natural gas. That is, natural gas is both the feed source and energy source used to produce LNG. Equations (4) and (5) show the emissions of methane and carbon dioxide from the liquefaction process, in units of g CH4/kg LNG burned by the final consumer and g CO2/kg LNG burned by the final consumer. Note that emissions of both methane and carbon dioxide from the liquefaction process are larger when expressed per kg of final consumption than per kg of LNG liquefied.

$$\mathrm{CH_4} = [(0.028)*(1.028)*(1000\,\mathrm{g\ CH_4/kg})* \mathbf{LNG.\ tot}] + [\mathbf{Fuel.\ oil}*(3.9\,\mathrm{gCO_4/kg\ oil})], \quad (1)$$

$$\mathrm{CO_2} = [(612\,\mathrm{g\ CO_2/kg\ LNG})*\mathbf{LNG.\ tot}] + [\mathbf{Fuel.\ oil}*(616\,\mathrm{g\ CO_2/kg\ oil})], \quad (2)$$

$$\mathbf{LNG.\ tot} = (1\,\mathrm{kg\ /kg\ LNG}) + \mathbf{LNG.\ liq} + \mathbf{LNG.\ ship} + \mathbf{Vent.\ boil.\ off} + (0.0032\,\mathrm{kg\ /kg\ LNG}), \quad (3)$$

$$\mathrm{CH_4} = (3.5\,\mathrm{g\ CH_4/kg\ LNG})*(1\,\mathrm{kg\ /kg\ LNG} + \mathbf{LNG.\ ship} + \mathbf{Vent.\ boil.\ off} + 0.0032\,\mathrm{kg\ /kg\ LNG}); \quad (4)$$

$$\mathrm{CO_2} = (270 + 57 + 18\,\mathrm{g\ CO_2/kg\ LNG})*(1\,\mathrm{kg\ /kg\ LNG} + \mathbf{LNG.\ ship} + \mathbf{Vent.\ boil.\ off} + 0.0032\,\mathrm{kg\ /kg\ LNG}). \quad (5)$$

These two equations are simply multiplying emission factors applicable to the liquefaction process by the total amount of LNG that is transported away from the liquefaction plant in tankers, including LNG burned by the final consumer, LNG burned or emitted by tankers, and methane emissions from pipelines in the destination country that carry gas to the final consumer. As noted in Equation (3), the value of 1 kg/kg LNG represents the LNG burned by the final consumer, and the value of 0.0032 kg/kg LNG is the methane emitted during pipeline transportation from the LNG terminal to the electric plant where the gas is finally consumed. In Equation (4), 3.5 g CH4/kg LNG is the total rate of release of unburned methane during liquefaction and for regasification based on the mean from the review by Balcombe et al. Note that a recent paper reported a lower value, which may represent a best case of what is possible, since they required the cooperation from owners of the LNG facilities. The higher value from Balcombe et al. seems likely to be more representative of standard industry performance. For Equation (5), the values 270, 57, and 18 g CO2/kg LNG are, respectively, the quantities of carbon dioxide emitted from burning gas to power liquefaction, from the CO2 that was in the natural gas before processing, and from carbon dioxide produced from flaring. Carbon-dioxide emissions from the combustion of the gas powering the plants have been measured at many facilities in Australia, Alaska, Brunei, Malaysia, Indonesia, Oman, and Qatar, with emissions varying from 230 to 410 g CO2/kg LNG liquefied. Here, I use the mean estimate of 270 g CO2/kg LNG liquefied, which is equivalent to 9.8% of the natural gas being liquefied This is comparable to the value used by Balcombe et al. in their lifecycle assessment and is at the very low end of emission estimates provided by Pace Global for guidance for new plants built in the United States: 260–370 g CO2/kg LNG liquefied. My estimate is, therefore, conservative. In addition, carbon dioxide present in unprocessed natural gas, which sometimes contains significant quantities of carbon dioxide, is emitted to the atmosphere as the methane in natural gas is liquefied. These emissions are estimated as 23 to 90 g CO2/kg LNG liquefied. Here, I use a mean estimate of **57 g CO2/kg**. In addition, some natural gas is flared at liquefaction plants to maintain gas pressures for safety, with a range of measured carbon-dioxide emissions from zero up to 50 g CO2/kg LNG, and a mean estimate of 18 g CO2/kg.15,1

Reference Number 15: LNG Hazards & their Assessment

LNG Hazards
and
Their Assessment

Presented by
Ertugrul Alp, PhD, PEng, MCIC

56th Canadian Chemical Engineering Conference
Process Safety and Loss Management Symposium

October 18, 2006
Sherbrooke, Quebec

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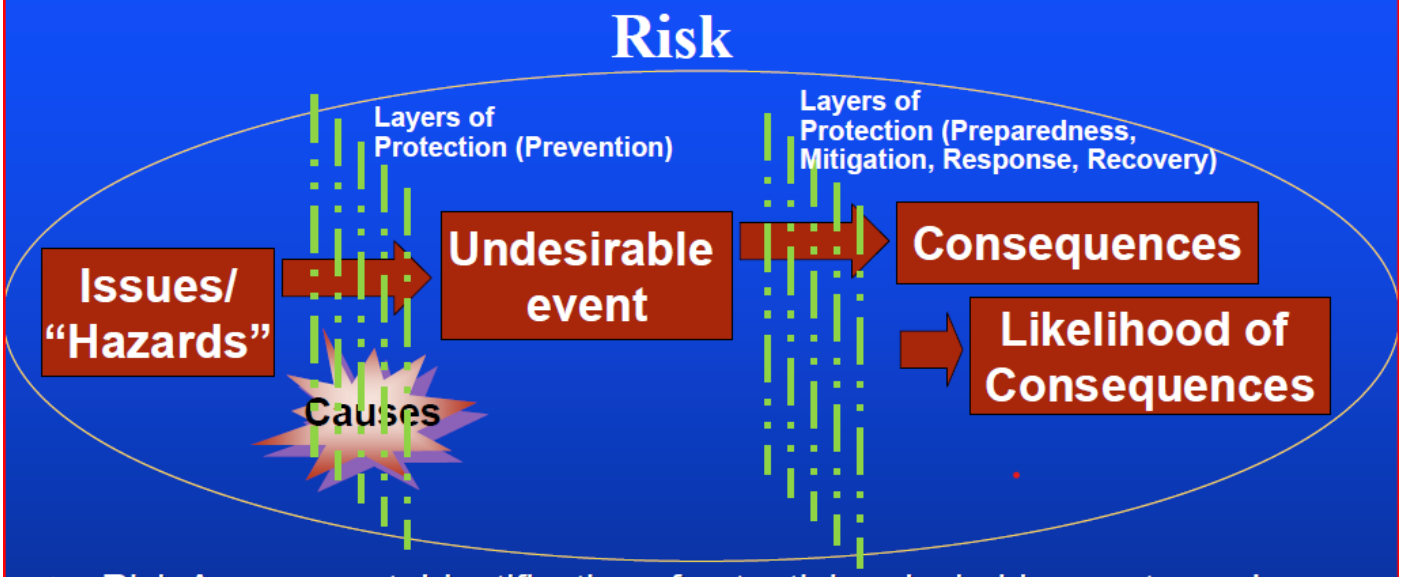
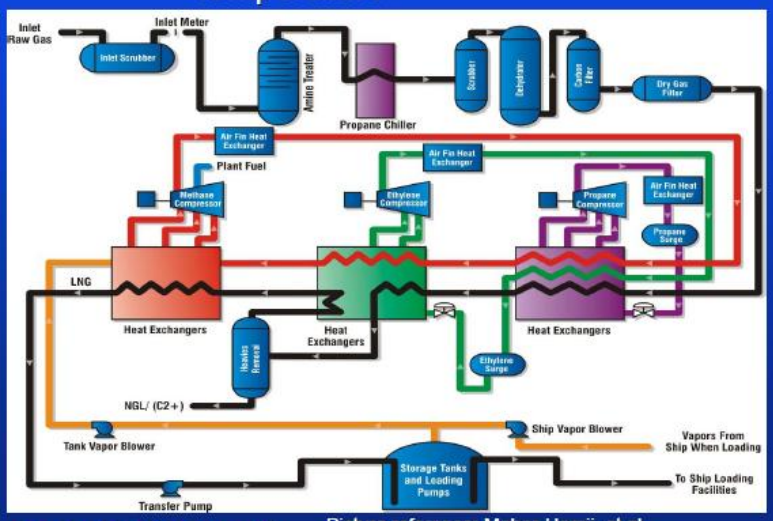
Hazard, Risk, Hazard Assessment and Risk Assessment



- Risk Assessment: Identification of potential undesirable events, and developing an understanding of their importance to us considering their potential consequences and likelihood, for the purpose of deciding whether we should reduce their risk or continue living with that potential
- Hazard Assessment: Concerns itself with only the consequence aspects of risk

Major Processes in the Supply Chain (2)

- Liquefaction of NG from field processing (LNG "cascade" process)
  - Refrigeration to -162 °C is required
  - Typical refrigerants include ethylene, propane and butane
  - Refrigerant quantities stored are on the order of 5-30 tonnes
  - Ethylene is stored near its boiling point (-73 °C)
  - The others are stored under pressure-liquefied conditions at ambient temperature



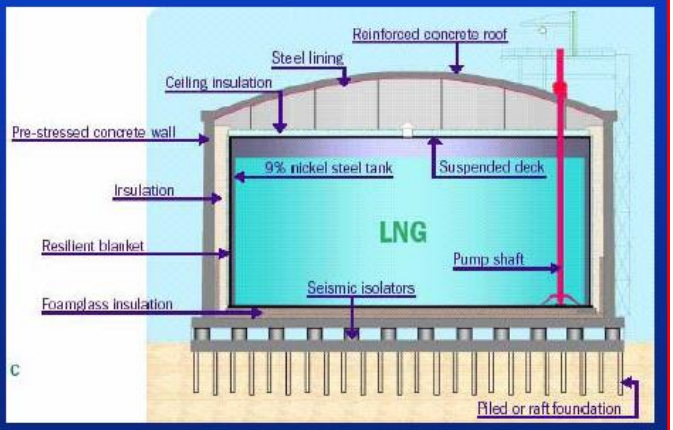
CoP LNG Process℠

Picture reference: Meher-Homji, et al., AIChE/CSChE LNG Conferenece, 2005; Eaton, et al., AIChE Spring Mtg, 2004

Picture reference: CEE, Introduction to LNG, 2003

Major Processes in the Supply Chain (3)

- LNG Storage
  - Quantities stored in above-ground or in-ground double-walled cylindrical tanks with capacity ranging from 7,000 m^3 to 200,000 m^3
  - Stored at pressures slightly above atmospheric at boiling point (-162 °C)
  - Inner wall requires to be for "cryogenic service": 9% nickel steel, aluminum or pre-stressed concrete
  - Outer wall: carbon steel or pre-stressed concrete
  - Heavily insulated between the two walls
  - The outer wall is sometimes built only to support the insulation and the roof
    - The trend is to construct the outer wall such that it can also withstand the LNG temperatures and contain it in case the inner wall fails.



Picture reference: CEE, LNG Safety & Security, 2003

LNG Properties and Associated Hazards

- Example Composition of Natural Gas

Component in Natural Gas	Higher Limit (mole %)	Lower Limit (mole %)
methane	95.3	93.9
ethane	3.5	2.25
propane	0.48	0.077
iso-butane	0.057	0.003
n-butane	0.07	0.002
iso-pentane	0.017	0.0000
n-pentane	0.013	0.0000
C6+	0.0120	0.0000
nitrogen	1.8	1.7
carbon dioxide	0.76	0.66

- Boiling Point = -162 °C at 1.7 kPag (typical LNG storage temperature and pressure)
  - Cryogenic
    - Freeze burns
    - Brittle fracture of metals if not specifically prepared for LNG service
- Its main component methane is considered to be a simple asphyxiant
- Flammable range in air : ~5% (LFL) to ~15% (UFL)
  - Jet fires
  - Flash fires
  - Pool fires
  - Building explosions
  - Vapour cloud explosions

LNG Properties and Associated Hazards (2)

- Methane (CH_4) molecular weight: 16 (air: 29)
  - NG is lighter than air at equal temperatures
    - specific gravity (air = 1): 0.55 at 21 °C and atmospheric pressure
  - When LNG at -162 °C is spilled, the vapour is heavier than air until it warms up to approximately -110 °C
    - *This results in a heavier-than-air flammable gas cloud, that can travel relatively large distances before it disperses to below LFL*
    - *The flammable range of the cloud is generally visible due to condensation of humidity in the air*
- Liquid density (1.013 bar at boiling point) : 422.62 kg/m^3
  - Floats on water
- Liquid/gas expansion : ~600 times
- Critical temperature : -82.7 °C; Critical pressure : 45.96 bar
  - Unlike, for example, propane and butane, NG cannot be kept as a liquid at normal ambient temperatures
- Auto-ignition temperature : 595 °C (for LPG: 450 to 500 °C)

Hazard Modelling (Focus: large spills)

- Spills may occur
  - on land or on water,
  - from piping, loading/unloading arms, breach of storage tanks, and breach of marine vessels

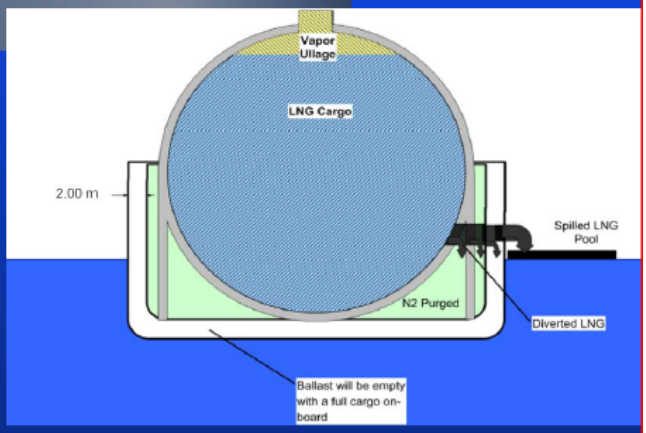
Picture reference: Kytomaa, et al.; 2005, Vancouver)

- Source term
  - Calculating the mass release rate from containment is based on the classical hole discharge equation

$$\dot{m}_l = \rho_l \, v \, A_0$$
$$v = C_d \sqrt{g h_l}$$

  - The height h_l of the liquid inside the vessel above the hole can be calculated using the time-dependent differential equation for conservation of mass

$$\frac{dm_l}{dt} = -\rho_l \, v \, A_0$$
$$m_l = \rho_l A_{\text{tank}} h_l$$

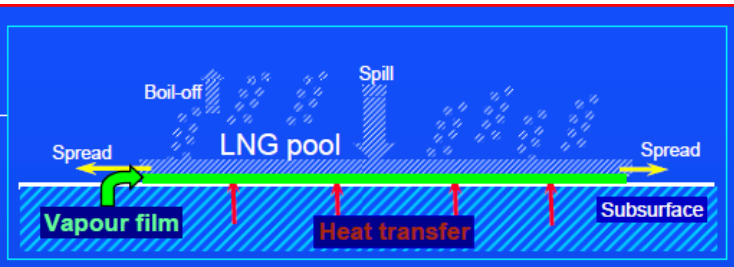


Picture reference: Sandia Report SAND2004-6258, 2004

Modelling of Liquid Pool Spread

- Spread of liquid takes place under the influence of gravity.
  - The size of the pool as a function of time can be calculated using
    - the mass conservation differential equation, balancing the incoming spill rate with the outgoing boil-off, and
    - Newton's equation of motion, balancing the gravity head of the liquid pool height and its acceleration in the direction of spread.
  - In a spread and boil-off model, it is usually assumed that the pool will spread until a minimal layer thickness is reached, if unconfined.
  - The spread is very fast, as a layer of vapour builds between the spreading liquid and the subsurface.
    - It is usually assumed that the pool spreads to this minimum thickness very quickly
  - *Complication: For spills on large bodies of water, the effect of wave action could significantly reduce pool size (Quest, see Sandia Report, 2004)*
    - *However, this approach has been later criticized (Havens, LNG Summit, 2004)*
  - *Complication: For spills on land, the effect of topography and surface roughness on spread can significantly change pool shape and limit pool size*
    - *These effects are generally not taken into account in hazard studies*

Modelling Boil-off (1)



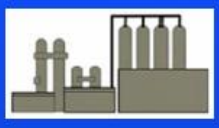
- Boil-off takes place primarily as a result of the heat flow from the subsurface (land or water) and any solar radiation.
  - Solar radiation is generally negligible compared with the heat from the subsurface.
- For spills on land, this holds true until boiling stops due to cooling of the ground to the boiling point of the liquid. Evaporation and evaporative cooling may then take over.
- For spills on unconfined water, there is sufficient water circulation in the vertical that the heat flux to the LNG can be assumed constant over time.
- For spills on confined water, the water surface freezes over, decreasing the heat transfer into the LNG with time.
- The rate of boil-off also depends on the kind of subsurface (e.g., concrete, soil types).

Modelling Boil-off (2)

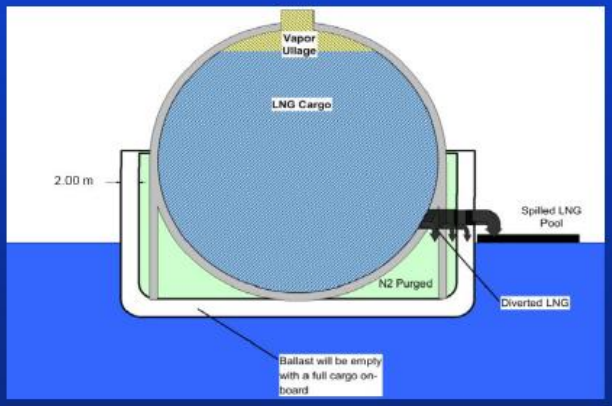
- Because of the vapour layer between the subsurface and the liquid pool, the heat transfer is limited.
  - It has been shown that the boil-off rate for LNG on water could be up to twice as much as that for pure methane, possibly due to patchy breakdown of this film for LNG (Sandia, 2004).
- If the LNG vapour above the liquid pool is burning, the additional heat from the flames need to be taken into account in modelling boil-off.
- Boil-off flux estimates vary (Sandia, 2004)
  - 0.02 to 0.2 kg/m^2-s for un-ignited pools (experimental),
  - 0.1 to 0.5 kg/m^2-s if the pool is also burning

Other Hazards (1)

- In an LNG liquefaction facility hazard assessment, the relatively large amounts of hydrocarbon refrigerants should be taken into account.

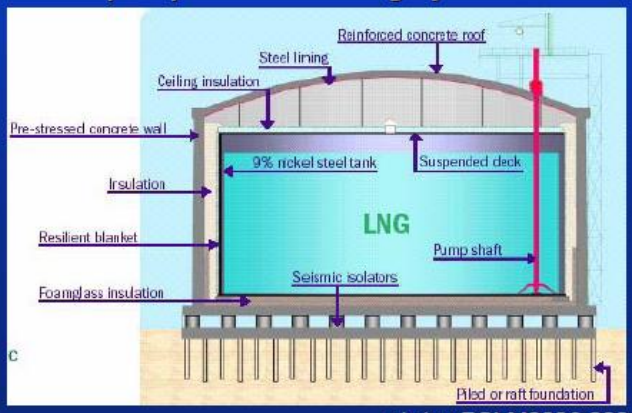


- In case of a large spill of LNG from a marine tanker, *could the cryogenic temperatures of the LNG lapping the hull of the tanker result in loss of structural integrity of the hull?*



Other Hazards (3)

- Rollover
  - When LNG supplies of multiple densities are loaded into a tank one at a time, they do not mix at first; they layer themselves.
  - As the lower LNG layer is heated by normal heat leak, it changes density until it finally becomes lighter than the upper layer.
  - At that point, a liquid rollover would occur with a sudden vaporization of LNG that may be too large to be released through the normal tank pressure release valves.
  - At some point, the excess pressure can result in cracks or other structural failures in the tank.
  - To prevent stratification, operators unloading an LNG ship measure the density of the cargo and, if necessary, adjust their unloading procedures accordingly.
  - LNG tanks have rollover protection systems, which include distributed temperature sensors and pump-around mixing systems.



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Reference Number16: Unlocking the potential of cryogenic biogas upgrading technologies integrated with bio-LNG production: A comparative assessment. Ahmad Naquash, Neha Agarwal, Muhammad Nizami, Nguyen Nhu Nga, Muhammad Aziz , Moonyong Lee . Applied Energy Volume 371, 1 October 2024, 123720

Biogas has gained increasing consideration as a competitive, environmentally benign, and sustainable alternative to fossil fuels. These benefits of biogas necessitate the need for intercontinental transportation, which is challenging because of its low energy density. Liquefaction is a viable approach to increase energy density, but this approach is energy and cost-intensive and requires high purity of biomethane. Cryogenic biogas upgrading integrated with the biomethane liquefaction (or bio-LNG) process is an efficient technique to meet these challenges due to its dual benefits: separation with high purity/recovery and precooling of biomethane. **This study evaluates different cryogenic technologies (distillation, controlled freeze zone (CFZ), and anti-sublimation) and their integration potential with the bio-LNG production process from a technical and economic perspective. This type of comparative assessment is not found in the open literature. In addition, the CFZ process has not been investigated previously for biogas upgrading.** The processes are designed and simulated in Aspen Hysys v14. Among all these processes, the CFZ performs better due to its single-column operation, which reduces cost and energy requirements. The results reveal that the CFZ process is an efficient and economical integrated process, boasting high exergy efficiency (40%), competitive energy consumption (0.30 kWh/kg), and a low production cost (6.3 $/MMBtu). This study can help process engineers design an improved biogas supply chain in terms of cost and energy.

Introduction

The consumption of fossil fuels continues to constitute 80% of the global energy demand. Fossil fuel combustion significantly contributes to carbon dioxide (CO_2) emissions. During the industrial revolution, the CO_2 concentration in the atmosphere increased from 280 to 390 ppm in 2010. It is estimated to reach around 570 ppm by 2100. There are many programs to achieve energy transition toward sustainable, clean, low-carbon energy resources, with the goal of carbon neutrality, such as “Horizon Europe,” Tokyo Protocols,” “Paris Agreement,” and “Net-Zero Target” . One type of clean energy that can play an essential role in energy transformation is biogas. It can be produced via anaerobic digestion of organic fractions of municipal solid waste, energy crops, agricultural residues, or anaerobic fermentation

in landfill gas. Biogas can be utilised as a natural gas substitute for domestic and industrial purposes by being injected into the natural gas grid, generating electricity, and producing heat. According to the World Biogas Association, using biogas as a natural gas substitute can reduce greenhouse gas emissions by about 20%.

Unlike conventional natural gas, biogas transportation faces challenges due to its production at atmospheric pressure, which is lower than conventional natural gas and has lower energy density. The biogas energy density can be increased via compression or liquefaction process. To meet natural gas quality standards before being utilised as fuel (CO_2 limit below 50 ppm), biogas is upgraded to biomethane via treatment to separate the CO_2 and other impurities to produce biomethane. For long-distance transportation, the liquefaction process of biomethane to produce liquefied biomethane (LBM or bio-LNG) is preferred due to its higher energy density. The energy density of bio-LNG is about 21 MJ/L, similar to conventional LNG, and is 2.4 times higher than that of compressed biomethane (Bio-CNG).
Biogas upgrading is the essential step in the bio-LNG value chain. There are several ways of upgrading: water scrubbing, chemical scrubbing, membrane separation, pressure swing adsorption, and cryogenic processes that produce high-purity biomethane.
The cryogenic process for upgrading biogas has attracted much attention due to its high-purity biomethane production and its integration potential with the bio-LNG production process. The cryogenic separation is performed via cryogenic distillation, anti-sublimation, and controlled-freeze zone (CFZ) processes. In the cryogenic distillation process, the extraction of desired gas components depends on the boiling points of each component. This process's advantage is obtaining a high methane (CH_4) purity and high CO_2 recovery. In addition, the process, the output of the process has a lower temperature, with the range of −80 to −90 °C, which is suitable for bio-LNG production due to the requirement of cooling duty can be reduced. In the anti-sublimation process, the CO_2 is separated from the CH_4 via the solidification process on the heat exchanger surfaces or a designed cold box that yields the high purity of the product. In a controlled freeze process, single cryogenic distillation is employed by separating the CO_2 from the natural gas via freezing and melting in a design chamber located in the middle distillation column, which consists of three subsections: spray nozzles, freeze zone, and melting trays.
Many researchers have performed and investigated the biogas upgrading via a low-temperature cryogenic separation process that influences the economic performance of the bio-LNG value chain. In the cryogenic distillation process, Yousef et al. investigated the upgrading process of a biogas mixture of 60 mol% CH_4 and 40 mol% CO_2 through one distillation column that produces biomethane with a purity of 94.5% and CO_2 recovery of 99.7% with a specific energy consumption (SEC) of 0.26 kWh/Nm^3. The energy efficiency process results up to 95.52%, higher than that of other processes, such as membrane (90.2%), chemical absorption (93.1%), and water scrubbing with generation (94.4%). Yousef et al. also proposed the biogas upgrading at the same composition as the previous study via two-column distillation columns integrated with the heat recovery system. The energy consumption can be reduced to 0.25 kWh/Nm^3, with the purity of biomethane and CO_2 recovery increasing to 97.1% and 99.9%, respectively. However, these two studies only investigated biogas upgrading. Pellegrini et al. studied the comparison of biogas upgrading via cryogenic process (distillation and anti-sublimation) and monoethanolamine (MEA) scrubbing process, integrated biomethane liquefaction. The study shows that in the MEA scrubbing case, the liquefaction process requires 34.82% of the total energy to obtain the bio-LNG. It differs from the anti-sublimation and distillation processes, which require 25.85% and 29.88% of the total energy, respectively. Baccioli et al. proposed biogas upgrading using a cryogenic process through CO_2 solidification with small-size biomethane liquefaction. The study demonstrates that liquefaction with liquid nitrogen is the choice and the energy consumption of 1.45 kWh/kg of bio-LNG production. Ghorbani et al. proposed the thermo-economic analysis of an integrated biogas upgrading process using cryogenic separation with biomethane liquefaction using a mixed fluid cascade cycle. The study shows that the thermal energy efficiency, exergy efficiency, and specific power consumption are 73.11%, 72.58%, and 0.4761 kWh/kg bio-LNG, respectively. In addition, the economic analysis demonstrates that the production cost of bio-LNG is 0.2399 $/kg bio-LNG with a payback period of 2.122 years. In the CFZ process, no study specifies biogas upgrading to separate CO_2 from methane.
Nevertheless, Nizami et al. compared the performance of CFZ and membrane separation of CO_2 from CO_2-rich natural gas integrated with LNG, dimethyl ether (DME) and multi-chemicals (methanol, dimethyl ether, acetic acid, and formic acid) production. The study shows that the CFZ process performs better than the membrane process in terms of CO_2 capture (99.47%) and hydrocarbon recovery (95.40%). Moreover, biogas upgrading through CO_2 anti-sublimation has also been investigated by a few authors. Spitoni et al. proposed integrated biogas upgrading through an anti-sublimation process and integrated biomethane liquefaction to bio-LNG through an optimisation process using an evolutionary strategy algorithm. The result shows that the SEC of 1.093 kWh/kg of bio-LNG produced in the optimised case. Naquash et al. performed the optimisation process using a modified coordinate descent (MCD) algorithm in biogas upgrading via an anti-sublimation process integrated with single mixed-refrigerant liquefaction to produce bio-LNG, with energy and exergy analysis, coupled with economic analysis. The optimal case of this study delivers overall

energy and exergy savings of 68.6% and 44.62%, respectively, compared to the base case. In addition, the study also performed an economic analysis with a total annual cost (TAC) reduction of 37.2% in optimal design.

Several authors have studied standalone cryogenic biogas upgrading and its integration with bioLNG production. They concluded that these cryogenic processes are challenging in terms of high purity requirement for biomethane, CO_2 freezing, and high energy requirement by compressors in the refrigeration cycle. The literature review further suggests that cryogenic biogas upgrading process becomes energy efficient when integrated with bio-LNG production mainly because of two reasons: production of high purity biomethane and precooling due to low temperature operation. This claim needs further investigation as different types of cryogenic technologies exist based on the phase (solid and liquid) separation of CO_2. Some authors have investigated CO_2 separation in solid or liquid form; however, no author has developed a comparative evaluation of these separation technologies to conclude which cryogenic technology works best with bio-LNG production. To fill this research gap, three cases have been developed and discussed in this study:

- 1. Cryogenic distillation process (Case-I)
- 2. CFZ process (Case-II)
- 3. Anti-sublimation process (Case-III)

In addition to the above contribution, this study also presents a novel contribution in evaluating CFZ technology for biogas upgrading. The CFZ technology has been investigated before for natural gas purification; however, **no study has been published yet for biogas upgrading**. Therefore, this study presents the comparison of the CFZ process along with the cryogenic distillation and anti-sublimation processes for biogas upgrading integrated with bio-LNG production. These integrated processes are further analysed with respect to energy, exergy, and economic perspectives.
Response from MLavelle: It is obvious that this cryogenic biogas upgrading is only at conceptual stage. This paper from October 2024 reinforces this point. No details are presented in this application indicating the process to be used for coolants & subsequent products.

ISSUE 8: LEAKS

Having regard to the lack of information with regards to satisfactory measures in the event of an incident, the potential for spillage of slurry feedstock, Freezing compounds, solid CO_2 and servicing and maintenance details, An Commission Pleanala cannot be satisfied that the likely significant effects of the proposed development on European sites (River/underground aquifer from karstic under the site), on human population can be screened out.

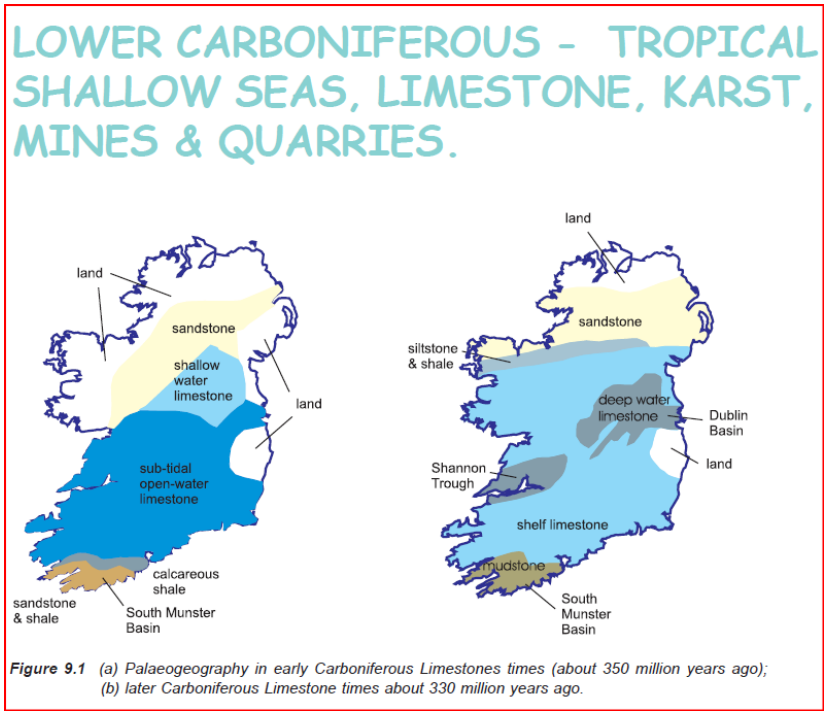


Figure 9.1 *(a) Palaeogeography in early Carboniferous Limestones times (about 350 million years ago); (b) later Carboniferous Limestone times about 330 million years ago.*

Therefore, if permitted as proposed, the planning authority cannot be satisfied that the proposal will not adversely affect the integrity of European sites in view of their conservation objectives of protected European sites for aquatic species & flora and fauna plus nearby houses & wells and would materially contravene numerous Policy Objectives of the Tipperary County Development Plan and would be contrary to the proper planning and sustainable development of the area. In the event of a spill or fire vast quantities of polluted water will access the adjoining underground aquifer through the geological fault under the quarry & Designated European sites. Additionally, it will pollute the future source of the Uisce Eireann Shannon to Dublin drinking water project.

The EIAR has submitted numerous conflicting site maps & boundaries as above. ACP must reject the appeal.
It is considered that the EIAR submitted has not presented a sufficient level of information and correct information for assessment in relation to impacts on the Environment and Roads and Transportation, and the interaction between the above, for the competent authority to make an EIA determination in accordance with Section 172 of the Planning and Development Act 2000 (as amended) that there is a likelihood of environmental effects of a magnitude which would have a significant effect on sensitive environmental receptors as a result of the proposed development. Therefore, if permitted as proposed for the development would be contrary to the proper planning and sustainable development of the area.

Having regard to the location of the application site insofar consideration of the traffic movements scenario that entails regularisation of large rigid body articulated vehicles (4- 6 axles) along substandard roads in width, alignment, surface of narrow local roads, uncertainty in road composition in conjunction with the existing road pattern of overgrown nature of rural boundary landscape with the lack of width for two articulated vehicles to safely pass one another, the potential of creating variability in road edge (swerve /pinch point) and void of any detail road design. Whilst such undefined road alterations can inevitably increase approach exit speeds from junctions to the development junction traffic movements interalia with development junctions restricted sight distances whereby it is considered that the proposed development would endanger public safety by reason of a traffic hazard and would be contrary to the proper planning and sustainable development of the area.

ISSUE 9: TRAFFIC & TRANSPORT [ISSUES WERE DEALT WITH IN PREVIOUS SUBMISSION TO TCC].

Traffic and Transport Assessment of the P25109-PMCE-XX-XX-RP-TR-3_0003 (2.0) 7 Bio-Renewables Plant at Killough Hill, Holycross, Co. Tipperary

2.3 Traffic Volumes

Classified 12-hour Junction Turning Counts (JTCs) were carried out on Tuesday 28th May 2024, by Traffinomics Ltd, at the following locations:

- L1309 / Killough Quarry Site Access
- L1309/ R639 T-Junction
- L1309 / Aughnagamun Road T-Junction

The traffic counts were carried out between 7am and 7pm.
It is submitted that the plant will operate on a 24/7 basis. The automatic traffic count should have been continuous over a 24hr period for 14 days.

In addition, Automatic Traffic Counts (ATCs) were carried out over a 7-day period in the vicinity of the proposed site access, between Friday 23rd May 2025 and Thursday 29th May 2025 on the L1309 at two locations (east and west) in the vicinity of the proposed site access.

Vehicle Speed Survey were also undertaken between Friday 23rd May 2025 and Thursday 29th May 2025, on both approaches to the site access. The results of the speed survey indicate that the 85th percentile speed on the L1309 in the vicinity of the site is currently below 80kph (recorded speed was approximately 59-64kph). The results of the speed survey that the reduction of the speed limit did not reflect to a decrease by the full amount of the speed limit reduction, but speed limits did decrease approximately to the new speed limit of 60kph.
A separate independent traffic count & 85% speed assessment was included in my previous submission which indicated 85% speed at 77.4kph. [160/85x77.4 = 145.69m Y-distance]. The X-distance of 4.5m is not available and not shown on SDT Maps and neither is the Y-distance of 145.69m

The automated Traffic Count below was conducted by Councillor Seamus Walshe, BE, from the 28th October 2025 to the 9th November 2025 on behalf of the local community.
The following results were obtained.

MetroCount Traffic Executive
Speed Statistics

SpeedStat-244 -- English (ENI)

Datasets:

Site:	**[Killough, Community Assoc.] Gaile, Thurles, Co. Tipperary.**
Attribute:	[+0.000000 +0.000000]
Direction:	7 - North bound A>B, South bound B>A. **Lane:** 0
Survey Duration:	09:47 Tuesday 28 October 2025 => 11:15 Sunday 9 November 2025,
Zone:	
File:	Killough, Community Assoc. 0 2025-11-09 1116.EC0 (Plus.)
Identifier:	WX3273VB MC5900-X13 (c)MetroCount 09Nov16
Algorithm:	Factory default axle (v5.08)
Data type:	Axle sensors - Paired (Class/Speed/Count)

Profile:

Filter time:	**00:00 Wednesday 29 October 2025 => 00:00 Thursday 30 October 2025 (1)**
Included classes:	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15
Speed range:	10 - 160 km/h.
Direction:	North, East, South, West (bound), P = North, Lane = 0-16
Separation:	Headway > 0 sec, Span 0 - 100 metre
Name:	Default Profile
Scheme:	Vehicle classification (VRX)
Units:	Metric (metre, kilometre, m/s, km/h, kg, tonne)
In profile:	Vehicles = 479 / 4374 (10.95%)

Speed Statistics

SpeedStat-244	
Site:	Killough, Community Assoc..0.1NS
Description:	**Gaile, Thurles, Co. Tipperary.**
Filter time:	**00:00 Wednesday 29 October 2025 => 00:00 Thursday 30 October 2025**
Scheme:	Vehicle classification (VRX)
Filter:	Cls(1-12, 14-15) Dir(NESW) Sp(10,160) Headway(>0) Span(0 - 100) Lane(0-16)

Vehicles = 479
Posted speed limit = 60 km/h, Exceeding = 253 (52.82%), Mean Exceeding = 72.84 km/h
Maximum = 139.8 km/h, **Minimum** = 18.2 km/h, **Mean** = 61.5 km/h
85% Speed = 77.40 km/h, **15% Speed** = 88.02 km/h, **Median** = 60.66 km/h
20 km/h Pace = 51 - 71, **Number in Pace** = 253 (52.82%)
Variance = 256.50, **Standard Deviation** = 16.02 km/h

MetroCount Traffic Executive
Individual Report

Individual-252 -- English (ENI)

Datasets:

Site:	**[Killough, Community Assoc.] Gaile, Thurles, Co. Tipperary.**
Attribute:	[+0.000000 +0.000000]
Direction:	7 - North bound A>B, South bound B>A. **Lane:** 0
Survey Duration:	09:47 Tuesday 28 October 2025 => 11:15 Sunday 9 November 2025,
Zone:	
File:	Killough, Community Assoc. 0 2025-11-09 1116.EC0 (Plus.)
Identifier:	WX3273VB MC5900-X13 (c)MetroCount 09Nov16
Algorithm:	Factory default axle (v5.08)
Data type:	Axle sensors - Paired (Class/Speed/Count)

Profile:

Filter time:	**00:00 Thursday 30 October 2025 => 00:00 Friday 31 October 2025 (1)**
Included classes:	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15
Speed range:	10 - 160 km/h.
Direction:	North, East, South, West (bound), P = North, Lane = 0-16
Separation:	Headway > 0 sec, Span 0 - 100 metre
Name:	Default Profile
Scheme:	Vehicle classification (VRX)
Units:	Metric (metre, kilometre, m/s, km/h, kg, tonne)

Speed Statistics

SpeedStat-245
Site: Killough, Community Assoc..0.1NS
Description: **Gaile, Thurles, Co. Tipperary.**
Filter time: **00:00 Thursday 30 October 2025 => 00:00 Friday 31 October 2025**
Scheme: Vehicle classification (VRX)
Filter: Cls(1-12, 14-15) Dir(NESW) Sp(10,160) Headway(>0) Span(0 - 100) Lane(0-16)

Vehicles = 395
Posted speed limit = 60 km/h, Exceeding = 191 (48.35%), Mean Exceeding = 71.41 km/h
Maximum = 112.0 km/h, **Minimum** = 10.2 km/h, **Mean** = 58.9 km/h
85% Speed = 73.80 km/h, **15% Speed** = 83.05 km/h, **Median** = 59.22 km/h
20 Km/h Pace = 48 - 68, **Number in Pace** = 211 (53.42%)
Variance = 247.94, **Standard Deviation** = 15.75 km/h

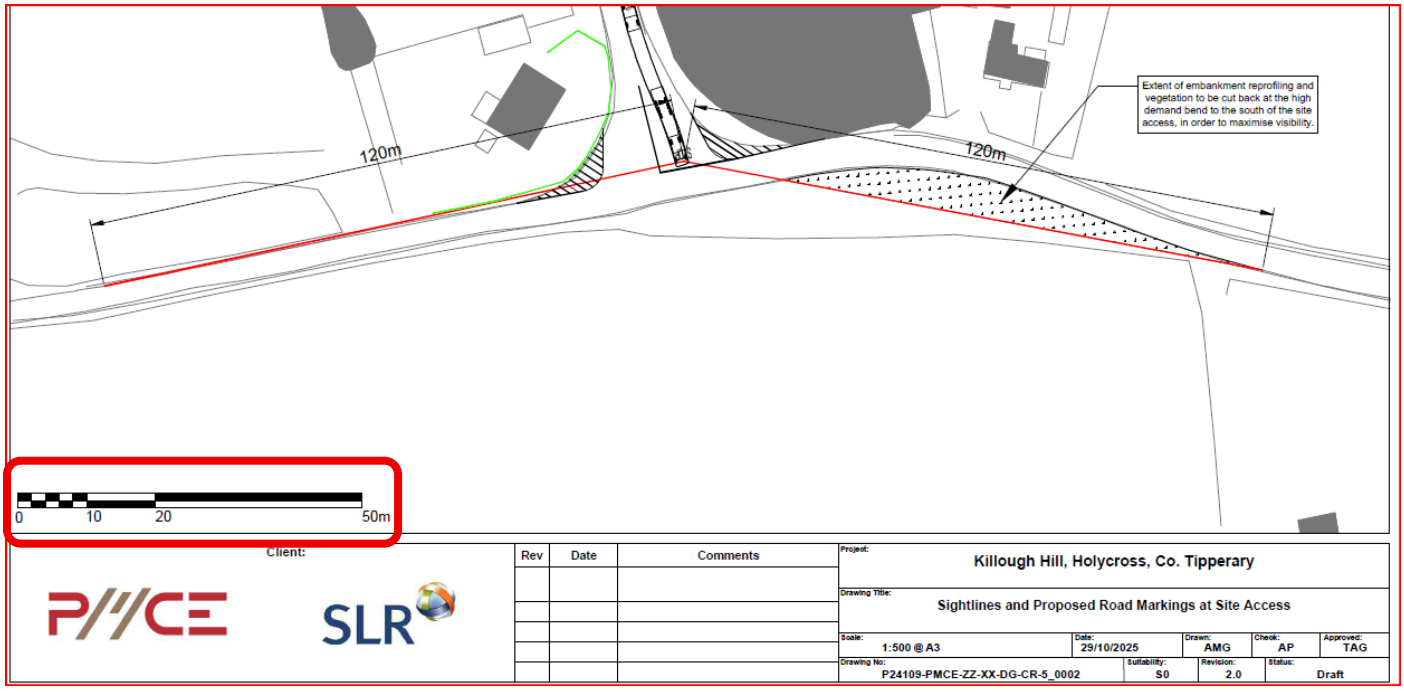
The predicted traffic generated by the Proposed Development was not based on comparative biogas plants but **based on a guestimate of the expected number of truck movements** resulting from their operations.' An estimation of traffic movements does not have any real meaning in determining the potential traffic generation from the development. The Appellant should have provided verified independent traffic counts from comparable developments.

Traffic and Transport Assessment of the 2 P25109-PMCE-XX-XX-RP-TR-3_0003 (2.0) Bio-Renewables Plant at Killough Hill, Holycross, Co. Tipperary

Executive Summary

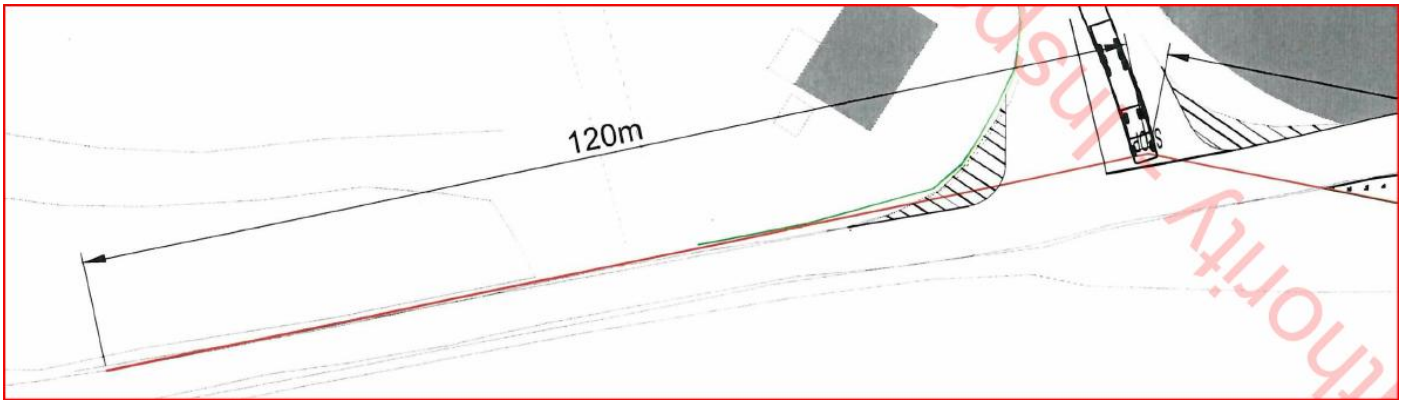
Sightlines have been assessed against Section 6.1 and Tables 6.1 and 6.2 of Volume 3, Appendix 6 of the Tipperary County Development Plan 2022-2028, which requires 120m of unobstructed visibility (for a design speed of 60kph on the L1309 in accordance with the Road Traffic Act 2024) at a point 4.5m back from the edge of the carriageway.

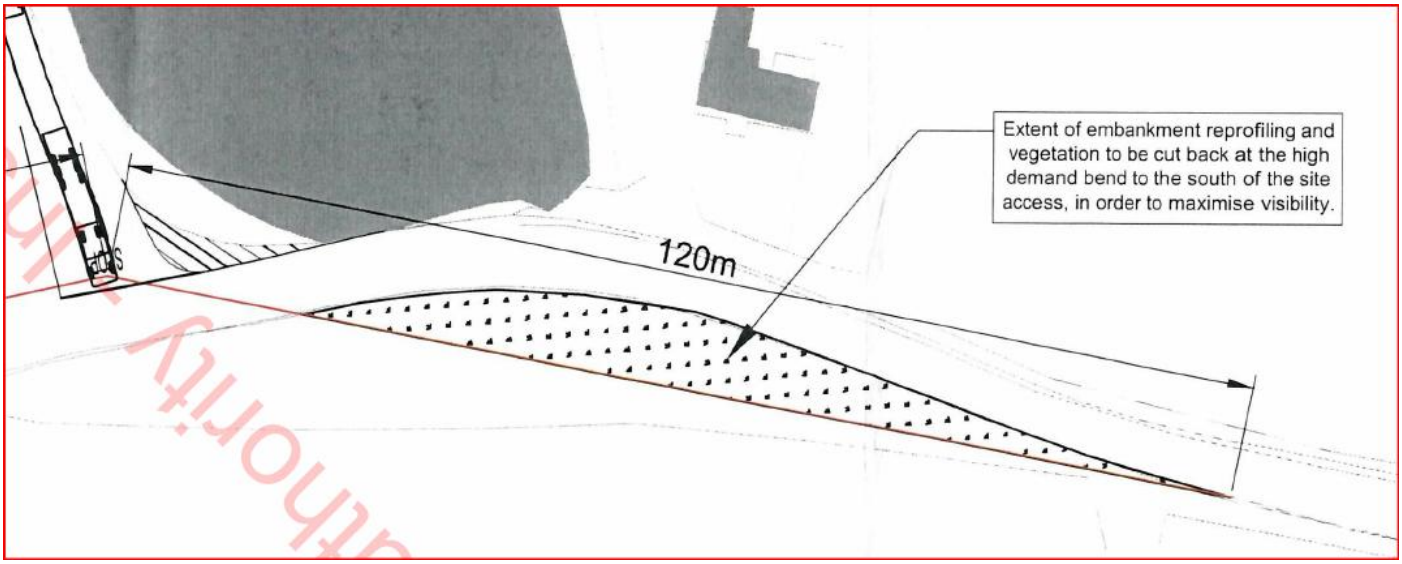
Visibility splays looking south are currently restricted due to the embankment, overgrown trees and vegetation at the high demand bend to the south of the site. The vegetation will be trimmed/removed, and maintained regularly, and the embankment will be reprofiled in order to ensure that the sightlines at the access are kept clear at all times.



Response from MLavelle: The x-distance setback in this map is not 4.5m as stated by the applicant. Using the scale outlined in red, it can be seen that it is less than 2m.

Table 6.1: X-Distance Requirements		
Major Road Use	**Minor Road use/Direct Access**	**X-Distance**
National Roads	Simple Junctions, Stop control	2.4m
Regional & Local Roads	All junctions and accesses, Stop control	2.4m
Regional & Local Roads	All junctions and accesses, Yield control	3.0m
National Roads, Regional & Local Roads	Multiple residential, Commercial, Agricultural or other	4.5m





Response from MLavelle: The applicant has no authority or consent to reprofile or cut back vegetation. Dromada Windfarm Ltd. Versus Denis Cremins refers.

3.2.2 Miscellaneous Trips

Feedstock intake trucks during the operational period normally will be not associated with tractors. Tractors will only operate for 17 days over a 5-month period to haul silage with a maximum of 15 loads per day. Therefore, a total of 30 trips **has been assumed to occur daily** in the most conservative approach to cater for possible miscellaneous trips associated with the site. These miscellaneous trips also allow for operations meetings, site inspections, maintenance operations for plant and machinery, etc.

Response from MLavelle: These assumptions are just that. They are not verified through comparable traffic counts at similar plants.

The 12hour period/6-day period over which the May automated traffic count was conducted on the 28th May 2025/23rd-29th May does not seem a sufficient duration of time to determine a reliable weekday road traffic average according to PE-PDV-02045 where it states: *'It is essential that the developer or promoter should provide a full and detailed assessment of how the trips to and from the development might affect the transport network'.* Additionally, TII PAG Unit 16.0 (PE-PAG-02038) guideline states that *'AADT is best calculated by using a long sample set of data'* (Section 2) and suggests an alternative method of estimating AADT (Section 3) using the Localised Period Count Method which stating a minimum of 14 days during a neutral period.

3.2 Trip Generation [Operations]

The proposed development operations would include the following:

- Feedstock intake, including fresh grass, slurry and potale, which is estimated to be c. 45,000 tonnes per annum. The majority of feedstocks will be supplied locally (c. 81%), and consideration will be given to supply within a radius of less than 20kms approximately.
- Total production, includes fertiliser, biomethane and CO2. The adjacent Roadstone Killough Quarry plant will utilise the electricity, bio-methane and water generated by the proposed development. Pelletised fertiliser will be available for supply to local agriculture and traders off-site. LNG and CO2 will be pressurised and stored for ongoing draw-off by tankers to points of re-use off-site.
- Same trucks leave the site with fertiliser that brought silage feedstock to the site.
- A percentage of bio-methane will be used on site.

Response from MLavelle: They feedstock is stated to be 45,000 tonnes per annum versus previous 90,000 tonnes per annum & 105 tonnes per annum. Which one are they basing the guestimates of traffic count on?

Tipperary County Development Plan 2022 – 2028

12 – 6 (a) Facilitate a limited level of new accesses, or the intensified use of existing accesses to the national road network, on the approaches to, or exit from urban centres that are subject to a speed limit zone between 50kmph and 60kmph, otherwise known as the transition zone noting the provisions of TII Publication Standard DN-GEO-03084 'The Treatment of Transition Zones to Towns and Villages on National Roads.

(b) Such accesses will be considered where they facilitate orderly urban development and would not result in a proliferation of such entrances, leading to a diminution in the role of these transitional zones.

(c) A Road Safety Audit, prepared in accordance with the Design Manual for Roads and Bridges (TII, 2010), shall be submitted, where appropriate.

Response from MLavelle: Stage 1/2 Road Safety Audit was not provided as part of Application

TIPPERARY COUNTY DEVELOPMENT PLAN 2022 – 2028 VOLUME 3

6.2 Traffic and Transport Assessments

The Council in accordance with the Traffic and Transport Assessment Guidelines (TII, 2014) and any amendment thereof, will require the submission of a Traffic and Transport Impact Assessment (TTIA) for large scale developments or developments that may impact on the carrying capacity or public safety of the road network. The following are the minimum thresholds of developments which will require a TTIA:

• Residential Development over 200 dwellings

• Retail and Leisure Developments over 1000 sqm.

• Industrial Developments over 5000 sqm.

• Office, Hospitals and Educational Developments over 2500sqm.

• Distribution and Warehousing Developments over 10000 sqm. TTIAs will also be required where there is a 10% increase in traffic (or a 5% increase in congested areas). Where the Council considers that a development may have an impact on the carrying capacity of the surrounding network, a TTIA may also be required for sub threshold

development. Such a decision will be based on an evaluation of the proposal against Table 2.2 and 2.3 of the Traffic and Transport Assessment Guidelines (TII, 2014), and any amendment thereof.

6.3 Road Safety Audits

A Road Safety Audit is an evaluation of the road's element of a development proposal from preliminary design to post-construction stage with a view to promoting the highest standard of safety for all road users, but especially vulnerable road users such as pedestrians, cyclists and children, to identify potential road safety issues, and to suggest measures to eliminate or mitigate concerns. **The Council will require a Road Safety Audit where a development is likely to have a significant impact on road safety and where it is necessary to ensure that housing proposals comply with the Guidelines on Sustainable Residential Development in Urban Areas and the Design Manual for Urban Roads and Streets (DEHLG, 2009) (DMURS).** Road Safety Audits shall be carried out independently by assessors approved by TII in accordance with their guidance publication, Road Safety Audit, March 2017 (as may be amended) and in the case of new residential development (of 20 units or more) with the DMURS

3.1 Collision History

Due to ongoing review of road traffic collision data by the Road Safety Authority website, no traffic collision data could be obtained for the vicinity of the proposed development site.

No Road Safety Audit was submitted and the collision data could have been sought as was done by a community for a nearby Biogas Plant in Galway.

The local community requested FoI from the Road Safety Authority and were provided with the following:

I refer to your request, received by this office on 1 December 2025, which you have made under the Freedom of Information Act 2014 for records held by Road Safety Authority (RSA).

" I, Velma Burns have now made a final decision to grant your request on 30 December 2025.
The purpose of this letter is to explain that decision. This explanation has the following parts:
1. an explanation of the relevant findings, and
2. a statement of how you can appeal this decision should you wish to do so.
This letter addresses each of these two parts in turn.

1. Findings
Between 1 January 2020 and 28 January 2025, there have been 10 road traffic collisions (fatal, serious injury, or minor injury) reported to An Garda Síochána and recorded by An Garda Síochána having occurred on the R355 from Ballinasloe Town (approximate coordinates 53.31463537563086, -8.244126916437608) to Portumna (approximate coordinates 53.09785740238358, -8.225737608412963)
Of these 10 collisions, 3 were serious injury collisions and 7 were minor injury collisions.
Of these 10 collisions:
• 6 of the collisions were multiple vehicle collisions meaning there was more than one vehicle involved. Of these 6 collisions, 3 were head on collisions and the remaining 3 were either rear end collisions or angle collisions.
• 4 of the collisions were single vehicle collisions meaning there was no more than one vehicle involved. These single vehicle collisions involved the vehicle colliding with a road edge ditch or with a wall.
The above information is provisional and subject to change.

Please note, the collision data does not contain information on cause or contributory factors of the collision i.e. drink driving.
For list of definitions, please see below:
***Serious injury collisions:** Where there are no deaths but a person or persons are seriously injured.*

Serious injury: *A "serious injury" is an injury for which the person is detained in hospital as an 'in-patient', or any of the following injuries whether or not detained in hospital: fractures, concussion, internal injuries, crushings, severe cuts and lacerations, or severe general shock requiring medical treatment.*
Minor Injury Collision: *Where there are no deaths or serious injuries, but a person or persons are minorly injured.*
Minor Injury: *An injury of a minor character such as a sprain or bruise*

2. Rights of appeal
In the event that you are unhappy with this decision you may appeal it. In the event that you need to make such an appeal, you can do so by writing to the Freedom of Information Officer, Road Safety Authority, Moy Valley Business Park, Primrose Hill, Ballina, Co. Mayo, F26 V6E4 or by e-mail to foi@rsa.ie. Please note that a fee applies for such a review. The level of this has been set at €30 and payment can be made as set out in the enclosed information note. You should submit this within 4 weeks from the date of this notification, where a day is defined as a working day excluding the weekend and public holidays. However, the making of a late appeal may be permitted in appropriate circumstances. The appeal will involve a complete reconsideration of the matter by a more senior member of staff of this body and the decision will be communicated to you within 3 weeks.
Should you have any questions or concerns regarding the above, please contact me at vburns@rsa.ie.
Yours sincerely,
Velma Burns
Research Manager

There is no excuse for the applicant not accessing this information & including it as part of the application in an unlimited application period.

Ist Party Appeal :

1.4 Methodology

The methodology adopted for this appraisal and report involved, in brief:-

- Site Visit: Site visits on Tuesday 16th July 2024 and on Friday 24th October 2025, the weather was dry, and the ground surface was dry.

2.3 Traffic Volumes

- Classified 12-hour Junction Turning Counts (JTCs) were carried out on Tuesday 28th May 2024, by Traffinomics Ltd, at the following locations:

The traffic counts were carried out between 7am and 7pm. This time period also includes the peak hours on the adjacent road network.

In addition, Automatic Traffic Counts (ATCs) were carried out over a 7-day period in the vicinity of the proposed site access, between Friday 23rd May 2025 and Thursday 29th May 2025 on the L1309 at two locations (east and west) in the vicinity of the proposed site access.

Response from MLavelle: Automatic speed counts were conducted over a 7-day period according to above & not automatic traffic counts.

Vehicle Speed Survey were also undertaken between Friday 23rd May 2025 and Thursday 29th May 2025, on both approaches to the site access. The results of the speed survey indicate that the 85th percentile speed on the L1309 in the vicinity of the site is currently below 80kph (recorded speed was approximately 59-64kph). The results of the speed survey that the reduction of the speed limit did not

4 Trip Distribution & Assignment
4.1 Trip Distribution & Composition
Appendix A includes extracts from the TRICS database, which provides forecast data for arrivals and departures at similar sites.

Appendix A – TRICS Output 7.10.4

TRIP RATE CALCULATION SELECTION PARAMETERS:
Land Use : 02- EMPLOYMENT
Category : H- QUARRY TOTAL VEHICLES

- DC-02-H-02 STONE QUARRY DORSET
- DH-02-H-01 LIMESTONE QUARRY DURHAM
- GM-02-H-01 STONE QUARRY GREATER MANCHESTER
- HP-02-H-01 QUARRY HARTLEPOOL
- NN-02-H-01 GRAVEL QUARRY NORTH NORTHAMPTONSHIRE

Response from MLavelle: This TRICS assessment does not relate to a Biogas Plant.

The proposed development would give rise to the intensification of use of access onto/from National/Regional/Local Roads at points where the maximum 80kph speed limit applies or the 85% speed applies, where the roads have curving horizontal radii and sub optimum vertical alignment which significantly results in substandard sightlines for vehicles accessing, egressing and in particular whereby the potential arises to generate haphazardous right hand turning movements from the Local Roads, the primary haulage routes to the proposed site. It is considered the required visibility splays lie outside the control of the applicant in conjunction with the intensification of development traffic would endanger public safety by reason of a traffic hazard and would give rise to additional potential conflict to arise between traffic arising from these junction and other road users of these routes. The proposed development would be contrary to Policy Objectives of the Tipperary County Development Plan, which seeks to protect and safeguarding the capacity and safety of Restricted Regional & local Roads of the Tipperary County Road network. If permitted as proposed, the development as proposed would interfere with the safety and free flow of traffic on the public road and would endanger public safety by reason of traffic hazard, obstruction of road users, or otherwise, and therefore would be contrary to the proper planning and sustainable development of the area.

The Agent states that the developer provided the traffic estimation. This is not acceptable. Proper referenced traffic volumes with automatic counts from similar plants should have been provided. Basically, the traffic estimation is just a guess.

ISSUE 10:

The issues raised in relation to Roads & Transportation & compliance with the Tipperary County Development Plan 2022-2028 have not been complied with:

Tipperary County Development Plan – Chapter 6 : Transport and Movement

There is incomplete information provided with the application regarding Traffic and Transport Impacts for the following reasons;

- The set back distance for sightlines does not comply with the requirements of the Tipperary County Development Plan 2022- 2028 & TII Standards, which require a 4.5m sightline set-backs for a development of this nature.
- The sightlines as indicated are not achievable owing to the absence of landowner consent and should be 145.69m & not 120m.
- The Traffic and Transport Assessment (TTA) states that traffic volumes generated by the proposal will be low. This assertion requires evidence based support.
- Turning lanes at the entrance should have been considered to minimise potential traffic impacts & at dusk/dawn, especially relating to:
  - HGV deliveries entering the site,
  - Slow-moving vehicles exiting the site,
  - Associated road safety risks on the road network.
- The Road Safety Audit was not provided.
- No pavement impact assessment has been carried out for the existing road network.
- Feed materials are described as originating from local sources, but:
  - No assessment of external haul routes has been provided, or safe farmyard accesses,

- No pavement or structural impact assessment has been completed for the local road network serving these routes.

3.1 Neutral Periods

In order to ensure an unbiased sample, all data collection should be carried out during a "neutral" or representative month, avoiding national and local holiday periods, local school holidays, mid-terms and any other abnormal periods. Where a study area is impacted upon by a third level institution, surveys should also avoid exam periods (which can occur in late January and during May and June) as well as the longer holiday periods throughout the year.

Other periods to avoid include local festivals or unusual events, which may influence vehicle traffic and public transport usage at a local level; where an unusual event (including severe weather) occurs during traffic or passenger surveys it may be necessary to undertake the surveys again at a neutral time.

For the purposes of data collection, with reference to guidance supplied in UK DfT WebTAG Unit M1.2 and the TII *PAG Unit 16.1 - Expansion Factors for Short Period Traffic Counts*, neutral periods have been defined as Monday to Thursdays during the following periods:

- Late March and April – excluding the period surrounding St. Patrick's Day and Easter
- May – excluding the Thursday before and all of the week of the Bank Holiday
- September – excluding school holidays and the return to school weeks
- October – excluding the Thursday before and all of the week of the Bank Holiday
- All of November

Bank Holidays (and the days before and after it) should be avoided. Neutral periods should be used unless alternatives are agreed in advance with TII.

TII Publications *PE-PAG-02016*
Project Appraisal Guidelines Unit 5.2 - Data Collection *December 2023*

4.1 Traffic Volume Data - Link Counts

A link count survey which is commonly referred to as an Automatic Traffic Count (ATC) records each vehicle passing a fixed location by direction and according to a specified vehicle classification and speed. The classification of vehicles can vary but in general the classification should allow for the aggregation of vehicle data into the seven classifications recorded by the TII Traffic Monitoring Units:

1. Motorbikes
2. Cars
3. Light Goods Vehicles (LGV)
4. Bus
5. Other Goods Vehicles 1 (OGV1)
6. Other Goods Vehicles 2 (OGV2)
7. Caravans

An ATC can be temporarily installed for a specified period or permanently installed as per the network of TII TMUs which allow for the long term monitoring of traffic growth. Either type of ATC can provide useful supplementary information to a turning count or roadside interview data (which are usually undertaken on one day only) as they can indicate whether that survey day was typical or not.

ATCs may also be used to count the number of pedal cyclists but there are known problems with accuracy under this approach. For example, pneumatic tube counters deployed over multiple lanes of carriageway may not generate a big enough pulse to reach the counter. This problem is partly overcome by the use of a second (more sensitive) tube. Inductive loops are the most common method of counting traffic over a long period. However, the accurate detection of cycle flows under this approach is difficult. As well as pneumatic tubes, camera detection methods can also be used for ATCs and later analysed through Artificial Intelligence (A.I.) powered engines for tracking and classification of vehicles.

It is normal practice for ATCs to be conducted for at least two full weeks. ATCs carried out for two weeks or longer will capture day to day variability. Furthermore, it is essential to place ATCs in favourable positions along links so as to avoid or minimise the likelihood of queues forming over the counters as this leads to less accurate counts. In general, link counts should be undertaken on links that are liable to experience changes in traffic flow related to a scheme proposal.

At the most basic level, ATCs may be required for the development of simple junction models, microsimulation models as well as assignment and variable demand models. ATCs can be used to monitor traffic flows and to provide information about the relationship between survey day traffic and longer term flow levels. ATCs can also be used to provide information about local 12 hour, 16 hour, 18 hour and 24-hour flow ratios, and daily and seasonal traffic variations, all of which are required to estimate average daily traffic flows from shorter period data. In addition, good quality counts are required for both validation and calibration of link traffic flows in transport models.

Table 6.2: Link-Based Growth Rates: County Annual Growth Rates (excluding Metropolitan Area)

County	Low Sensitivity Growth Rates						Central Growth Rates						High Sensitivity Growth Rates					
	2016-2030		2030-2040		2040-2050		2016-2030		2030-2040		2040-2050		2016-2030		2030-2040		2040-2050	
	LV	HV	LV	HV	LV	HV	LV	HV	LV	HV	LV	HV	LV	HV	LV	HV	LV	HV
Dublin	1.0163	1.0303	1.0046	1.0123	1.0036	1.0143	1.0180	1.0317	1.0062	1.0139	1.0050	1.0158	1.0211	1.0348	1.0100	1.0170	1.0099	1.0250
Kildare	1.0180	1.0363	1.0044	1.0135	1.0035	1.0169	1.0197	1.0378	1.0062	1.0155	1.0053	1.0187	1.0229	1.0413	1.0098	1.0191	1.0107	1.0283
Laois	1.0130	1.0265	1.003	1.0105	1.0018	1.0136	1.0147	1.0280	1.0047	1.0125	1.0036	1.0155	1.0179	1.0314	1.0082	1.0160	1.0090	1.0248
Longford	1.0119	1.0298	1.0019	1.0104	1.0000	1.0138	1.0134	1.0313	1.0038	1.0124	1.0027	1.0157	1.0167	1.0347	1.0072	1.0161	1.0073	1.0256
Louth	1.0134	1.0347	1.0054	1.0153	1.0048	1.0180	1.0148	1.0363	1.0070	1.0174	1.0063	1.0198	1.0177	1.0397	1.0100	1.0211	1.0103	1.0295
Meath	1.0156	1.0349	1.0052	1.0164	1.0043	1.0189	1.0173	1.0365	1.0070	1.0186	1.0059	1.0207	1.0205	1.0400	1.0108	1.0226	1.0116	1.0304
Offlay	1.0103	1.0307	1.0021	1.0119	1.0014	1.0158	1.0118	1.0323	1.0042	1.0139	1.0033	1.0176	1.0152	1.0357	1.0081	1.0176	1.0100	1.0272
Westmeath	1.0145	1.0300	1.0042	1.0126	1.0033	1.0156	1.0161	1.0316	1.0062	1.0147	1.0053	1.0176	1.0194	1.0352	1.0101	1.0185	1.0100	1.0279
Wicklow	1.0140	1.0361	1.0033	1.0153	1.0029	1.0185	1.0157	1.0377	1.0051	1.0173	1.0047	1.0204	1.0189	1.0412	1.0091	1.0211	1.0110	1.0305
Cavan	1.0098	1.0295	1.0024	1.0108	1.0010	1.0140	1.0112	1.0311	1.0041	1.0127	1.0028	1.0158	1.0141	1.0345	1.0076	1.0164	1.0084	1.0256
Donegal	1.0097	1.0270	1.0024	1.0123	1.0017	1.0142	1.0111	1.0286	1.0039	1.0141	1.0035	1.0161	1.0139	1.0320	1.0072	1.0178	1.0094	1.0258
Galway	1.0243	1.0430	1.0087	1.0177	1.0088	1.0218	1.0259	1.0446	1.0109	1.0198	1.0105	1.0236	1.0294	1.0480	1.0148	1.0236	1.0181	1.0336

S.I. No. 600/2001 - Planning and Development Regulations, 2001

(g) where the applicant is not the legal owner of the land or structure concerned –

(i) the written consent of the owner to make the application, or

(ii) in the case of a proposed development, or part of a proposed development, that is in, on, over or under a public road, written confirmation that the proposed development concerned is to be undertaken by a statutory undertaker having a right or interest to provide services in connection with the proposed development.

Private Wires Policy Statement: From: Department of Climate, Energy and the Environment 15 July 2025

3.2 Private Wires Guiding Principles

The statement set out that any expansion of the right of private developers to build Private Wires will be guided by the following policy considerations:

- Private Wires will have to be developed with the consent of local communities and landowners. Private Wire developers will not have wayleave or other powers to use land.

4.1 Private Lines from a Generator to a Customer

The developers of Private Wires will not enjoy any statutory powers to acquire or use lands. Private Wire projects will have to be built based on the agreement of any landowners affected.

Note that Dromada Windfarm (ROI) V Denis Cremins, HC. (2023)IEHC 417 determined that the grass verge is private property and consent is required to use it.

ISSUE 11:

The Applicant indicates a supply system covering a 20km radius. This supply system involves traffic intensification. The existing Local Roads do not have widths greater than 4metres, which cannot accommodate HGV passing movements. Additionally, no structural assessment of these roads was provided. The significant additional heavy vehicle traffic movements that will be necessary to both feed into the AD Plant and remove product in itself increases the risk to road users in a very rural environment and already well used category of road. A twoway-sweptpath analysis for HGV's should have been included with farmyard accesses and excluding setdown areas in front of existing houses. It should also be noted that the grass verge is not part of the public road as per Dromada Windfarm (ROI) V Denis Cremins, HC. (2023)IEHC 417. Similarly ACP have to comply with the adopted policies adopted by the Galway CDP in relation to Road Safety Policies as outlined in DM 27 & 28. Crofton Buildings Management CLG & Anor v An Bord Pleanála and Fitzwilliam DL Limited, High Court [2022] IEHC 704.
The 20km radius is largely beef cattle farms. The use of digestate from a biogas unit will be continuous over the 12-month period. This will involve a change from grass to tillage with annual crop rotation. This change will remove the carbon sequestration of the grass & totally change the Carbon savings submitted in association with the collection & delivery of biogas & its digestate plus increased tillage farming mechanical plant. The surrounding lands are in grassland and it is likely that crop rotation is not practised and that land is in permanent pasture.

ISSUE 12:

Table 12.11: Feedstock Intake Data

Feedstock in	Tonnes/year	Average Load (T)	Max. Loads Per Annum	Mean Deliveries/Day	Total In/Out Movements
Chicken Manure	3,000	28	107	0.4 (1 trip)	0.8 (2 trips)
Cattle Manure	6,000	28	214	0.85 (1 trip)	1.7 (2 trips)
Cattle Slurry	25,000	30	833	3.3 (4 trips)	6.6 (8 trips)
Pig Slurry	30,000	30	1000	4.0	8.0
Crops	7,000	28	250	1.0	2.0
Grass Silage	15,000	28	536	2.1 (3 trips)	4.2 (6 trips)
Belly Grass	1,000	28	36	0.1 (1 trip)	0.3 (2 trips)
Distillery Waste	1,500	30	50	0.2 (1 trip)	0.4 (2 trips)
Dairy Processing Waste	1,500	30	50	0.2 (1 trip)	0.4 (2 trips)
Subtotal	**90,000**			**12.15 (17 trips)**	**24.3 (34 trips)**

3.2 Trip Generation [Operations]

The proposed development operations would include the following:

- Feedstock intake, including fresh grass, slurry and potale, which is estimated to be c. 45,000 tonnes per annum. The majority of feedstocks will be supplied locally (c. 81%), and consideration will be given to supply within a radius of less than 20kms approximately.

Response from MLavelle: Table 12.11 indicates 90,000tonnes/annum for these products. Where is 45,000tonnes coming from? Where is the other 45,000tonnes/annum? Were the traffic assumptions based on this 45,000tonnes/annum?

Table 12.12: Biobased Fertiliser Transport Data

Product	Tonnes per annum	Average Load (T)	Loads per annum	HGV/Trailer/day	Total in/out Movements
Digestate Liquid	53,500	30	1,783	6	12
Digestate Fibre	24,500	28	875	3	6
Subtotal	**78,000**			**9**	**18**

Table 12.13: CO_2 Export

Product	Loads per annum	Loads/day (vehicles/day)	Total in/out Movements
CO_2	120	0.4 (1 trip)	**2**

Table 12.14: Staff Traffic Generation

	AM	PM
Arrivals	5	0
Departure	0	5
Total staff movements	**5**	**5**

Table 12.15: Total Movements In and Out of the Site on National Roads

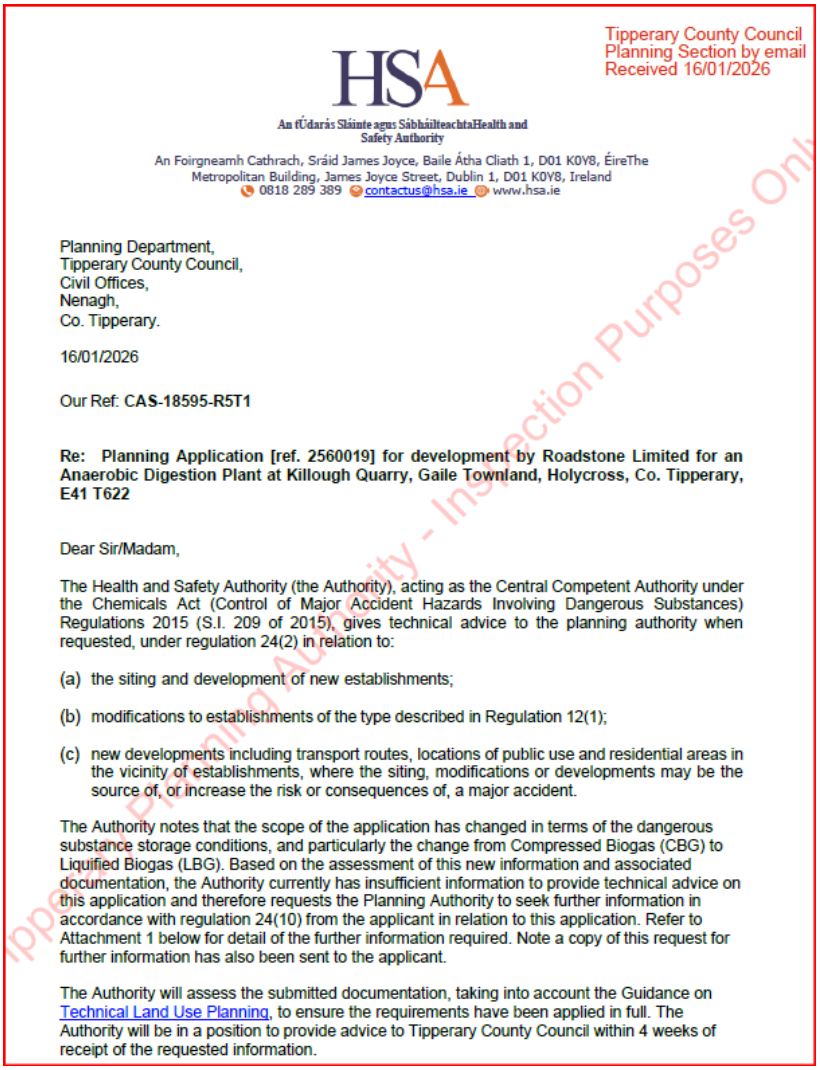
	HGV/Walking Floor/Tankers/day for intake	HGV/Walking Floor/Tankers/day for export	Staff (in/out)	Total in/out Movements
Total Movements	17 (34)	10 (20)	5 (10)	64

Table 12.16: Expected AM and PM Traffic Flows

	Arrivals (Vehicles/PCUs)	Departures (Vehicles/PCUs)	Total (Vehicles/PCUs)
AM	19/33	13/26	32/59
PM	13/26	19/33	32/59
Average movements			**64/118**

ISSUE 13 :

This proposed project involves the processing of dangerous substances in a rural area with nearby houses & farms. The determination by the HSA(below) indicates that there is no conclusion yet on the issue of a COMAH site. The biogas process of methane generation does not end as soon as the digestate is removed into storage & that creates an explosive risk for the community.



Tipperary County Council
Planning Section by email
Received 16/01/2026

HSA
An tÚdarás Sláinte agus SábháilteachtaHealth and Safety Authority
An Foirgneamh Cathrach, Sráid James Joyce, Baile Átha Cliath 1, D01 K0Y8, ÉireThe Metropolitan Building, James Joyce Street, Dublin 1, D01 K0Y8, Ireland
0818 289 389 contactus@hsa.ie www.hsa.ie

Planning Department,
Tipperary County Council,
Civil Offices,
Nenagh,
Co. Tipperary.

16/01/2026

Our Ref: **CAS-18595-R5T1**

Re: Planning Application [ref. 2560019] for development by Roadstone Limited for an Anaerobic Digestion Plant at Killough Quarry, Gaile Townland, Holycross, Co. Tipperary, E41 T622

Dear Sir/Madam,

The Health and Safety Authority (the Authority), acting as the Central Competent Authority under the Chemicals Act (Control of Major Accident Hazards Involving Dangerous Substances) Regulations 2015 (S.I. 209 of 2015), gives technical advice to the planning authority when requested, under regulation 24(2) in relation to:

(a) the siting and development of new establishments;

(b) modifications to establishments of the type described in Regulation 12(1);

(c) new developments including transport routes, locations of public use and residential areas in the vicinity of establishments, where the siting, modifications or developments may be the source of, or increase the risk or consequences of, a major accident.

The Authority notes that the scope of the application has changed in terms of the dangerous substance storage conditions, and particularly the change from Compressed Biogas (CBG) to Liquified Biogas (LBG). Based on the assessment of this new information and associated documentation, the Authority currently has insufficient information to provide technical advice on this application and therefore requests the Planning Authority to seek further information in accordance with regulation 24(10) from the applicant in relation to this application. Refer to Attachment 1 below for detail of the further information required. Note a copy of this request for further information has also been sent to the applicant.

The Authority will assess the submitted documentation, taking into account the Guidance on Technical Land Use Planning, to ensure the requirements have been applied in full. The Authority will be in a position to provide advice to Tipperary County Council within 4 weeks of receipt of the requested information.

Tipperary County Council
Planning Section by email
Received 16/01/2026

Yours sincerely

Dermot O'Callaghan

Dermot O'Callaghan
Inspector,
COMAH, Chemical Production & Storage (CCPS)

cc: Shane McDermott- SLR Environmental Consulting (IRE) Ltd

2.3.3 SEVESO III Directive / Control of Major Accident Hazards (COMAH) Regulations

The Chemicals Act (Control of Major Accident Hazards Involving Dangerous Substances) Regulations 2015 (S.I. No. 209 of 2015) transpose Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, which amended and subsequently repealed Council Directive 96/82/EC ("the Seveso III Directive").

The purpose of the COMAH Regulations is to establish rules for the prevention of major accidents involving dangerous substances and to limit, as far as possible, the consequences of such accidents for human health and the environment, with the overall objective of providing a high level of protection in a consistent and effective manner.

Under the COMAH Regulations, operators of establishments that store, handle or process dangerous substances above defined threshold quantities are required to take all necessary measures to prevent major accidents and to limit their consequences for human health and the environment. An establishment may be classified as an upper-tier or lower-tier site depending on the inventory of dangerous substances present; sites that store, handle or process dangerous substances only below the relevant lower-tier thresholds do not qualify as establishments for the purposes of the Regulations.

SEVESO/COMAH Assessment of the Proposed Development

Methane, the primary combustible component of biogas, is classified as a P2 flammable gas under Regulation (EC) No. 1272/2008 on the classification, labelling and packaging of substances and mixtures. Of the flammable substances considered for the Proposed Development—biomethane, propane and diesel—all are classified as "named dangerous substances" under Part 2 of the Seveso III Directive / COMAH Regulations, with the exception of biogas (i.e. untreated biomethane), which is not a named substance but is captured under the generic P2 flammable gas category.

According to Note 19 in Annex I of the Seveso III Directive, upgraded biogas (biomethane) is treated in the same way as natural gas. It therefore has qualifying quantities of 50 tonnes for lower-tier and 200 tonnes for upper-tier classification. Propane (LPG) shares the same qualifying quantities, whereas diesel has significantly higher qualifying quantities of 2,500 tonnes for lower-tier and 25,000 tonnes for upper-tier classification.

Biogas falls under Part 1 of Annex I to the Directive, within the "categories of dangerous substances" as a P2 flammable gas. Under the COMAH Regulations, P2 flammable gases have a threshold quantity of 10 tonnes for lower-tier classification. For the Proposed Development, the maximum quantity of biogas has been calculated as 7.98 tonnes, taking into account gas membranes, digester tank freeboards and associated pipework.

Applying the aggregate calculation method set out in Annex I of the Seveso III / COMAH regime, the proposed facility, when operating at full capacity, remains below the lower-tier threshold at which the COMAH Regulations would apply. The aggregated fraction for all relevant dangerous substances is calculated to be 0.81, i.e. less than 1, and therefore the site does not constitute a Seveso / COMAH establishment.

Reference Number 17: Australian Meat Processor Corporation Ltd (AMPC). -- Appendix 2: Hazard and Risk Assessment - Biogas Systems

Response MLavelle: Distances for Explosion at 200m & H_2S/CO Risks up to 500m are provided in this Appendix. The author of this Response could not find a similar Appendix that gave distances. There are numerous houses & farms within this 500m radius.

3 Hazard identification and qualitative risk estimation

3.1 Hazards

The principal events having potential impact both on-site and off-site are primarily related to the hazardous properties of the biogas and the release locations. Bio-gas is flammable and consists primarily of methane and carbon dioxide with traces of other compounds such as hydrogen sulphide. It is therefore flammable and potentially explosive. These types of events within the biogas system need control, using both installed safety systems as well as physical separation of plant from vulnerable resources.

A bio-gas system is often composed of:
1. Influent feed system
2. Covered anaerobic lagoons (CALs)
3. Bio-gas transfer systems (BGT)
4. Flare systems
5. Bio-gas utility systems (UTIL).

A hazard identification (HAZID) exercise was carried out using a combination of loss of containment (LoC), Failure Modes and Effects Analysis (FMEA) and Hazard and Operability (HAZOP) study techniques. The outcomes are shown in Tables 2 to 5.

1. Typical severity scales are:

(i) People (PE):
1 = Slight injury (no medical treatment needed)
2 = Minor injury (medically treated injury)
3 = Major injury (potentially permanent effects, hospitalization)
4 = Fatality
5 = Multiple fatalities

(ii) Environment (EN):

1 = Low pollution (no observable effects)
2 = Minor pollution (minor effects on plant and animals; contained impacts, cleanup)
3 = Moderate pollution (moderate effects on plants and animals, extensive cleanup, report to authorities)
4 = Major release (major effects on plants and animals, possible prosecution, substantial cleanup)
5 = Extreme event (permanent environmental effects, possible loss of licence to operate, possible company and director prosecutions)

(iii) Assets (AS):
1 = Negligible impact (no equipment damage, no loss of production)
2 = Minor (minor/superficial damage to equipment/facility, minor impact on production)
3 = Moderate (moderate damage and significant loss of production)
4 = Major (requires significant preventative/corrective actions, serious loss of production)
5 = Extreme impacts (future operation seriously affected, urgent corrective action, major loss of production)

2. Typical frequency ranges would be:
A = less than 1 in 1000 years (frequency, f < 0.001 per annum.)
B = between 1 in 100 to 1000 years (f range is 0.001 – 0.01 p.a.)
C = between 1 in 10 to 100 years (f range is 0.01 – 0.1 p.a.)
D = between 1 in 1 to 10 years (f range is 0.1 – 1 p.a.)
E = greater than 1 per annum. (f > 1 p.a.)

The above severity and frequency scales were used to estimate qualitative risks that are presented in Tables 2 to 5 for each of the sub-systems of a typical bio-gas facility.

The risks related to people on-site considered a probability of exposure PE to the hazardous event, as well as a probability of gas ignition PI1 when flammable gas releases were involved. Again this was classed as:

High (H) = almost certainly in the event area (PE > 0.9),
Medium (M) = occasionally in the area (PE ~ 0.5), or
Low (L) = rarely in the area (PE < 0.1)

In the case of environmental and asset impacts, the exposure probability of the risk receptor was assumed to be 1. The residual risk estimates (R) are shown in Tables 2 to 5.

In making the risk rankings for identified events, a semi-quantitative approach was taken that used some generic failure rates for certain equipment types. These frequencies2 included:

1. Major and total failure of DN 200-350 steel pipelines: 6 x 10-7 /yr/m
2. Major failure of valves: 1 x 10-3 /yr
3. Flange or connection failures: 1 x 10-2 /yr
4. Reciprocating compressor failure: major 1 x 10-4 /yr; minor 1 x 10-2 /yr.
5. Ventilation electric motor failure: 1 x 10-1 /yr

Little information is available on failure rates and reliability of equipment operating in the bio-gas industry and as such the generic oil and gas data were used. For pipelines a segment length of 10m was used as a basis for frequency estimates.

Off-site individual risks would normally assume constant exposure to any risks generated from bio-gas operations. However, given the general location of bio-gas facilities and the use of separation distances between bio-gas facilities and sensitive land uses, the risks to the general public are likely to be low.

For specific plant locations and surrounding sensitive land uses, quantified risk assessment would be required to assess the imposed risks and adequacy of the proposed design and operations.

Table 2. Influent feed system

ITEM	HAZARD OR EVENT	POSSIBLE CAUSES	POSSIBLE CONSEQUENCES	DETECTION/PROTECTION MEASURES	RESIDUAL RISKS (*S X F = R*)		
					PE*	EN	AS
INF1	Loss of containment of raw influent	• Cover anchor trench failure • Blockage in feed line/trench • Inspection/cleaning failures • Blockage in CAL outlet	• Spill to environment • Contamination of land and/or water courses • Business interruption • Legal action by authorities or affected parties • Erosion of CAL walls	• Best practice for the industry • Regular inspections of feed systems • Preventative maintenance measures • Upstream pre-treatment to minimize downstream blockages • Access points for cleaning purposes • Gravity flow to CALs reduces system pressure	1 x A = L (P_E = L)	3 x C = M	2 x C = L
INF2	Excess bio-gas production	• CAL under-design • Strong organic stream spills upstream of CAL	• Bio-gas production exceeds flare capacity • Overpressure of CAL and controlled gas release • Overpressure of CAL, failure of pressure relief and uncontrolled gas release with jet fire or flash fire • Odour release through overpressure release devices	• Appropriate feed stream characterization • Appropriate design factors used in CAL design & flare sizing • Upstream pre-treatment to minimize shock loads	1 x C = L (P_E = L, P_I = L)	1 x D = M	2 x C = M

Table 3. Covered anaerobic lagoons (CALs)

ITEM	HAZARD OR EVENT	POSSIBLE CAUSES	POSSIBLE CONSEQUENCES	DETECTION/PROTECTION MEASURES	RESIDUAL RISKS (*S X F = R*)		
					PE*	EN	AS
CAL1	Release of liquid contents from CAL	• Breach of lagoon containment wall and lining • Breach of lining and seepage to ground • Failure of tank wall (concrete systems) • Human failure on sludge recirculation system	• Release of effluent to environmentally sensitive areas • Major business interruption • Legal action by authorities or affected parties • Odour release	• Construction best practice standards for CALs • Inspection and leakage detection especially trench below liner pipe. • Isolation of spill • Spill control and recovery procedures • Emergency response procedures • Separation distances to vulnerable resources • Low probability of people in area, site layout planning • Strict control of ignition sources	1 x C = L (P_E = L)	3 x C = M	3 x C = M
CAL2	Large release of bio-gas from CAL	• Overpressure of CAL • Major failure of cover material • Large weld failure • Catastrophic failure of CAL fittings • Significant mechanical impact • Retaining cables cutting cover • De-anchoring of cover	• Dispersion of gas to atmosphere • Gas release, immediate ignition and jet fire • Gas release, delayed ignition and flashfire • Dispersion of hydrogen sulphide and possible human impacts	• Material standards • Inspection regimes esp. on seam welding • Pressure relief devices around CAL perimeter. • Separation distances to vulnerable resources • Low probability of people in area • Lightning protection • Strict control of ignition sources	4 x A = M (P_E = L, P_I = L)	1 x A = L	4 x A = M
CAL3	Small release of bio-gas from CAL	• Overpressure of CAL • Failure of cover material • Weld failure • Failure of CAL fittings • Mechanical impact • Retaining cables cutting cover	• Dispersion of gas to atmosphere • Gas release and immediate ignition • Gas release and delayed ignition • Air ingress to CAL and potential partially	• Construction standards • Inspection regimes • Dip-leg pressure relief devices • Separation distances to vulnerable resources • Low probability of people in area • Open ports only when cover is flat on water,	2 x B = L (P_E = L, P_I = L)	1 x D = M	2 x D = M
		• Partial seam failure of cover with lagoon lining • Open ports in cover when inflated	confined explosion • Legal action by authorities or affected parties				

Table 4. Bio-gas transfer systems

ITEM	HAZARD OR EVENT	POSSIBLE CAUSES	POSSIBLE CONSEQUENCES	DETECTION/PROTECTION MEASURES	RESIDUAL RISKS (*S X F*)		
					PE**	EN	AS
BGT1	Small release of bio-gas from system	• Line minor failure • Poor fabrication practices and weld/joint leaks • Valve/gasket/flange minor failure • Blower leak • Lightning strike • Human failure in leaving KO pot condensate valve open. • External impact	• Ignition and localized jet fire • Radiation impact on nearby equipment • Dispersion to atmosphere with no ignition • Dispersion of hydrogen sulphide and possible human impacts	• Construction standards • Inspection regimes • Isolation of system • Flaring of gas, depending on leak location • Separation distances to vulnerable resources • Low probability of people in area • System earthing • Strict control of ignition sources • Vehicle protection barriers	2 x A = L	2 x B = L	2 x B = L
BGT2	Large bio-gas release from system	• Major line failure (rupture) • Welding/maintenance failure • Lightning strike • Blower failure • Operational failure • External impact	• Ignition and localized jet fire • Radiation impact on nearby equipment • Dispersion to atmosphere with no ignition • Dispersion and delayed ignition leading to flash fire or deflagration • Dispersion of hydrogen sulphide and possible human impacts • Legal action by authorities or affected parties	• Construction standards • Inspection regimes • Isolation of system • Flaring of gas, depending on leak location • Separation distances to vulnerable resources • Low probability of people in area • Strict control of ignition sources • Vehicle protection barriers	2 x A = L (P_E = L, P_I = L)	2 x B = L	3 x B = M

Table 5. Bio-gas utility generation system

ITEM	HAZARD OR EVENT	POSSIBLE CAUSES	POSSIBLE CONSEQUENCES	DETECTION/PROTECTION MEASURES	RESIDUAL RISKS (S X F = R)		
					PE*	EN	AS
UTIL1	Small release of gas in utility generation area	• Line failure • Valve/gasket/flange failure • Drain valve fails open • Pressure relief valve leaks • Engine leaks • Poor maintenance • Operating failure from human error	• Localised jet fires on immediate ignition • Dispersion into room and no ignition • Dispersion and delayed ignition with deflagration • Structural damage and business interruption • Dispersion of hydrogen sulphide and possible human impacts	• Construction and equipment design standards • Gas Act • Hazard zone classifications and equipment • Ventilation systems • Restrictions on entry • Training systems • Location on site • Strict control of ignition sources	3 x A = L (P_E = L, P_I = L)	2 x A = L	3 x B = M
UTIL2	Large gas leak in utility generation area	• Major failure of lines • Significant failure of gas-line components (valves, instruments) • Failure of engine components • Poor maintenance • Operational failure	• Localised jet fires on immediate ignition • Dispersion into room and no ignition • Dispersion and delayed ignition with explosion • Major structural damage, business interruption • Potential for death if people exposed to event via missile impacts or flashfire • Dispersion of hydrogen sulphide and possible human impacts • Legal action by authorities or affected parties	• Construction standards • Ventilation systems • Gas detection • Restrictions on entry • Training systems • Location on site • Strict control of ignition sources • Interlock systems on equipment failures with isolation and flaring	4 x A = M (P_E = L, P_I = L)	2 x A = L	4 x A = M

4.5.1 Explosion events

To estimate impact distances to 7 kPa and 14 kPa overpressure a Multi-energy model (MEM) was used as well as a simple TNT model (TNO 1997). The MEM used a blast strength of 7, which represents a significantly confined vapour cloud situation. Figure 3 shows the overpressure profile from the blast centre, assuming that the building cladding provides no significant attenuation of the blast.

The estimates show:

1. 14 kPa overpressure at ~75m
2. 7 kPa overpressure at ~120m.

The value of 7kPa relates to maximum overpressures at residential locations, whilst 14kPa overpressure relates to nearby industrial activities. The implications are important for locating the enclosed genset facility on the bio-gas site in order to minimize overpressure effects in the case of an accident.

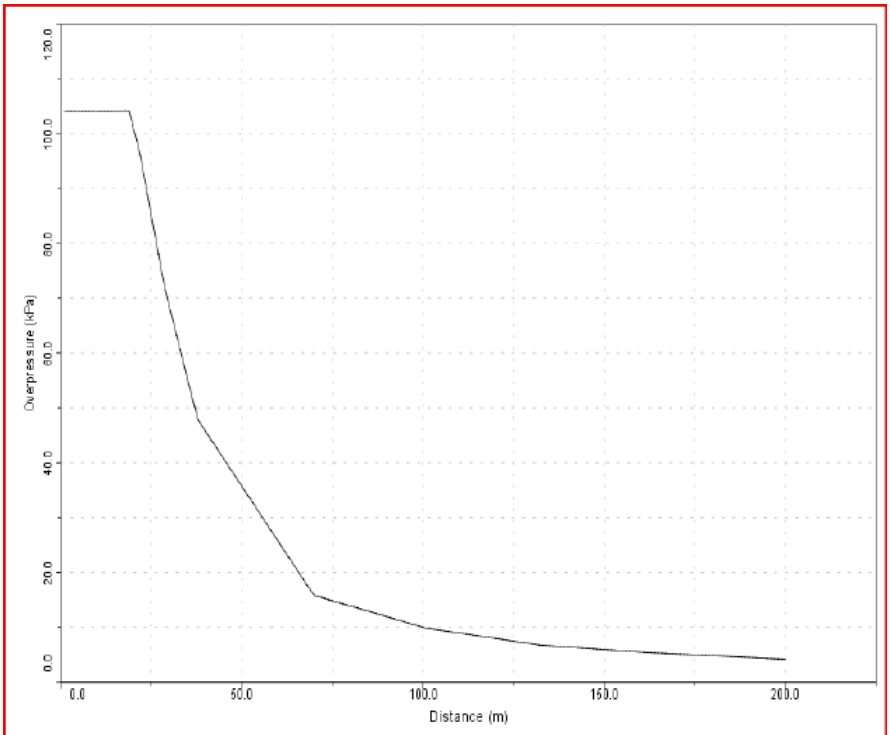


Figure 3 Overpressure from Genset building gas explosion

Note the effect of explosion in the context of distance up to 200m.

Significance:
1. The explosion overpressures from confined bio-gas explosions can have significant on-site implications, and potential off-site impacts depending on location of the genset facility in relation to other land uses.
2. The confinement of flammable vapour greatly increases blast overpressures.
3. It only takes a short time to reach the bio-gas UFL level in the event of ventilation failure and gas release by which time there is sufficient gas to generate an explosion if it is ignited.
4. Siting of facilities is important, both for on-site impacts and for off-site impacts.
5. Human injury or death is most likely due to shrapnel and flying objects rather than the blast overpressure.
6. At an overpressure of 7kPa, significant window breakage will occur.

4.6 Impact of hydrogen sulphide within bio-gas releases

Analysis of hydrogen sulphide (H2S) impacts that occur with bio-gas releases were analyzed for several scenarios:
1. Bio-gas loss of containment from the CAL
(i) 1000mm diameter release with CAL pressure of 100 Pa.g
(ii) 200mm diameter release at 50 Pa.g.
2. Bio-gas loss from transmission systems, after blower
(i) 100mm diameter release at 4 kPa.g
(ii) 200mm diameter release at 5 kPa.g.

The basic assumptions used in predicting downwind concentrations of H2S were:

1. Release concentrations of 2000 ppmv (0.2% by volume, 0.278 wt %) and 50,000 ppmv (5% by volume, 6.627 wt %) of H2S.
2. Horizontal release at a height of 1m above grade.
3. Ambient temperature of 20℃.
4. Rural dispersion conditions, where few obstacles are present.
5. Two atmospheric conditions of unstable atmosphere and moderate winds of 4 m/s (B4), and very stable night time conditions and low wind speed of 2 m/s (F2).
6. Use of a simple, standard Gaussian dispersion model (CCPS, 2000) assuming very low momentum releases.

These assumptions are regarded as conservative. Any detailed studies for particular site configurations should be done with specific assumptions relevant to the situation.

The simulations were done to estimate ground level concentrations down the centerline of the plume (highest downwind concentrations).

Table 9 H_2S impacts from CAL releases

Scenario	Total gas release rate (kg/s)	H_2S release rate (kg/s)		Distances from release (m)	Gas concentrations (ppmv) at various downwind distances for 2 key atmospheric conditions			
		0.2 vol %	5 vol %		0.2 vol % H_2S		5 vol % H_2S	
					B4	F2	B4	F2
1000mm diameter release @ 100 Pa.g	10.7	0.0297	0.7091	50	34	950	821	22694
				100	9	439	208	10492
				500	0.4	24	8	582
				1000	0.09	7.1	2.2	169
200mm diameter release @ 50 Pa.g	0.31	0.00086	0.0205	50	1	27	24	656
				100	0.25	13	6	303
				500	0.01	0.7	0.25	17
				1000	0.003	0.2	0.05	4.9

It can be seen that under a range of conditions, high concentrations of H2S can exist for distances beyond 500m. These events are analyzed more closely in the risk assessment in section 5.4

Table 10 H_2S impacts from bio-gas transmission releases

Scenario	Total gas release rate (kg/s)	H_2S release rate (kg/s)		Distances from release (m)	Gas concentrations (ppmv) at various downwind distances for 2 key atmospheric conditions			
		0.2 vol %	5 vol %		0.2 vol % H_2S		5 vol % H_2S	
					B4	F2	B4	F2
100mm diameter release @ 4 kPa.g	0.67	0.00186	0.0444	50	2.2	60	52	1421
				100	0.55	27	13	657
				500	0.02	1.5	0.5	36
				1000	0.006	0.44	0.13	10.6
200mm diameter release @ 5 kPa.g	3	0.00834	0.199	50	9.7	267	230	6362
				100	2.5	123	58	2942
				500	0.1	6.8	2.4	163
				1000	0.025	2	0.6	47

5.4 Hydrogen sulphide impact risks

Hydrogen sulphide is a toxic gas. As such it can cause a range of physiological responses from simple annoyance to permanent injury and onto death.

There are a number of approaches to deal with the impacts of toxic gases. These include fatality estimates, and also several concentration levels normally applied for off-site emergency response. The next 2 sections deal with these approaches.

5.4.1 Fatality levels

The application of probit functions (Probit = probability unit: a common form of representing toxic dose-response data. The probit value (goes from 2 (0% impact) to 8 (100% impact) with a mean at 5 (50% impact) and is sigmoidal in shape.) that describe dose-response relationships. These are often used for estimating the percentage fatality of an exposed population. A commonly used probit for H2S is given by VROM (2005b) as:

$Pr = -11.5 + \ln(C^{1.9}.t)$

where:
t = exposure time in minutes
C = gas concentration (mg/m3)
Using this probit, the concentration level for different exposure times that leads to a 1% fatality is shown in Table

Table 13 1% fatality concentration for different exposure times to H2S

EXPOSURE TIME (MINS)	H_2S CONCENTRATION FOR 1% FATALITY	
	MG/M3	PPMV
5	743	525
10	516	365
30	289	204
60	200	141

As can be seen in Table 13, short term exposures of 5 to 10 minutes have quite high H2S concentration. Even so, longer term exposures which might be related to off-site situations, are still above 100ppmv.

5.4.2 Emergency response levels

There are two main emergency response level approaches:
1. Emergency Response Planning Guidelines (ERPG) levels
2. Acute Exposure Guideline Levels (AEGLs)

These are primarily used for exposures of the general public to accidental releases of toxic substances. They can be very helpful in land use planning circumstances as well as emergency response to accidental releases.

There are three ERPG levels designated for H2S:

ERPG-1: 0.1 ppm
ERPG-2: 30 ppm
ERPG-3: 76 ppm

ERPGs are for 1 hour exposure. Their definitions are:

ERPG-1 is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hr without experiencing other than mild transient adverse health effects or perceiving a clearly defined, objectionable odour.

ERPG-2 is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hr without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective action.

ERPG-3 is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing or developing life-threatening health effects.

==========

An alternative approach that takes into account exposure time is given by the Acute Exposure Guideline Levels (AEGLs). These are given for H2S as:

Table 14 Acute Exposure Guideline Levels for Hydrogen Sulphide

LEVEL	10 MINS	30 MINS	60 MINS	4 HOURS	8 HOURS
AEGL-1	0.75	0.6	0.51	0.36	0.33
AEGL-2	41	32	27	20	17
AEGL-3	76	59	50	37	31

The definitions are:

AEGL-1 is the airborne concentration, expressed as parts per million or milligrams per cubic meter (ppm or mg/m3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic nonsensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.

AEGL-2 is the airborne concentration (expressed as ppm or mg/m3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.

AEGL-3 is the airborne concentration (expressed as ppm or mg/m3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death.

Significance:

1. Small 200mm diameter CAL H2S releases during day-time and night-time periods at an upper concentration level of 0.2% (2000 ppmv) do not seem to constitute a major problem.

2. Small, 200mm diameter CAL H2S releases at 5% concentration (50000 ppmv) during night conditions could have significant impacts.

3. Large H2S CAL releases of 1000mm diameter at 0.2% (2000 ppmv) during night conditions could in some circumstances be problematic.

4. Large H2S CAL releases of 1000mm diameter at 5% (50000 ppmv) would be of major concern during both day and night periods.

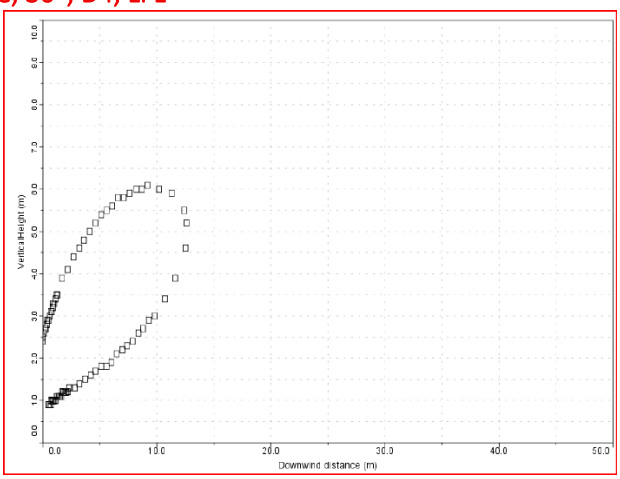
5. Bio-gas transmission releases of 100mm diameter at 0.2% H2S will not have significant impacts for day-time conditions.

6. Bio-gas transmission releases of 100mm diameter at 5% H2S will be problematic for any atmospheric condition.

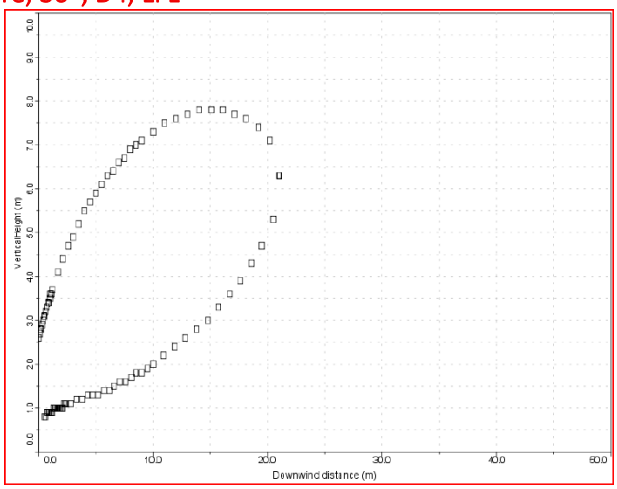
7. For 200mm releases from bio-gas transmission at 0.2% (2000 ppmv) only daytime conditions do not have significant impacts, whilst 5% (50000 ppmv) releases would be problematic.

Note the downwind distances for H_2S effects up to 500m in Cases below:

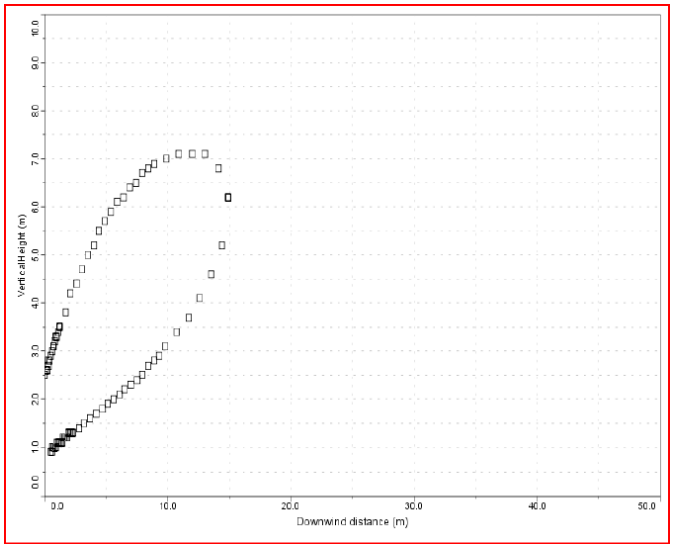
Case 1, 50Pa.g, 1000mm aperture, 30º, D4, LFL



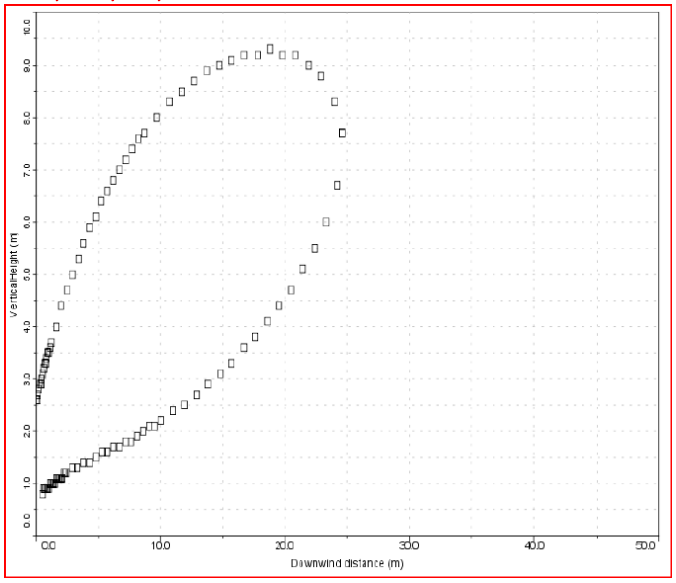
Case 2, 100Pa.g, 1000mm aperture, 30º, D4, LFL



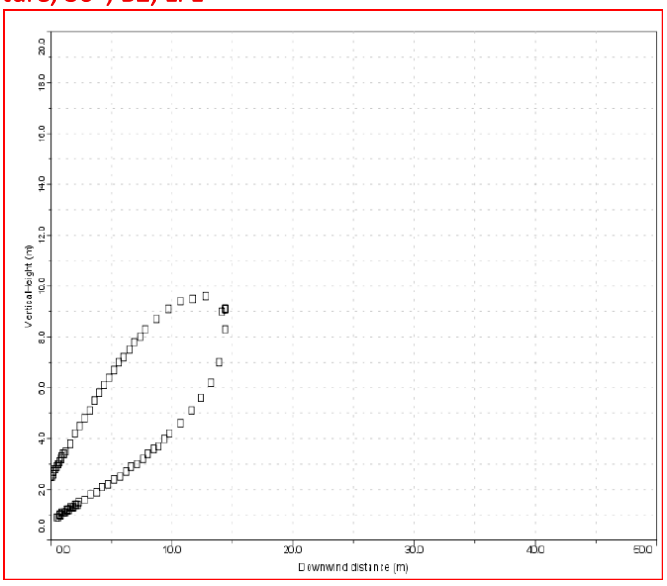
Case 2, 100Pa.g, 1000mm aperture, 30º, D4, LFL



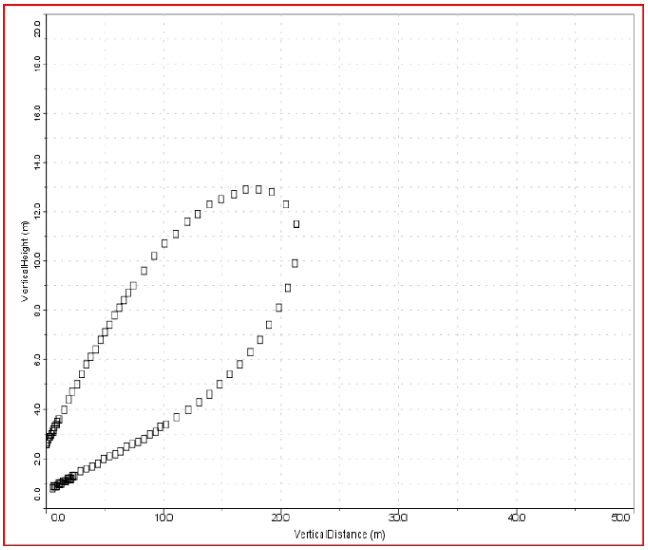
Case 2, 100Pa.g, 1000mm aperture, 30º, D4, half LFL



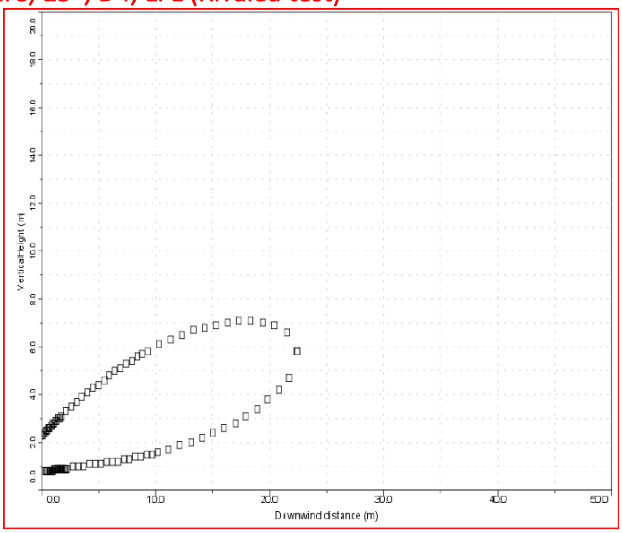
Case 3, 100Pa.g, 1000mm aperture, 30º, B2, LFL



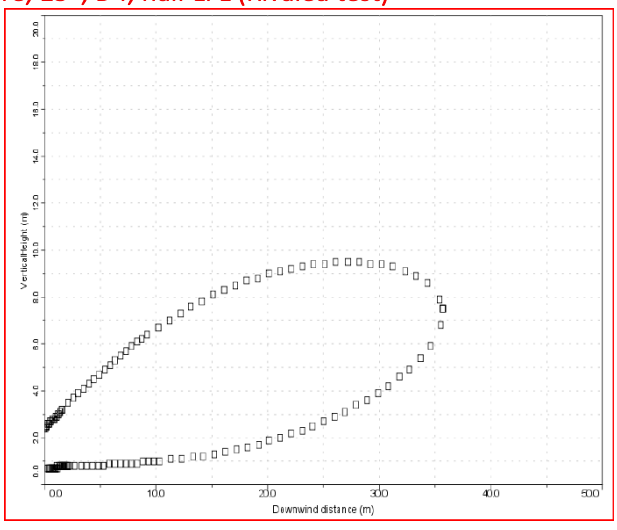
Case 3, 100Pa.g, 1000mm aperture, 30º, B2, half LFL



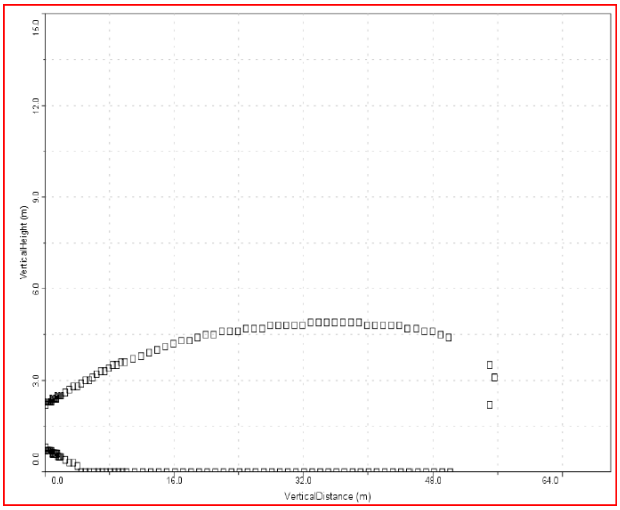
Case 4, 200Pa.g, 1000mm aperture, 15º, D4, LFL (Rivalea test)



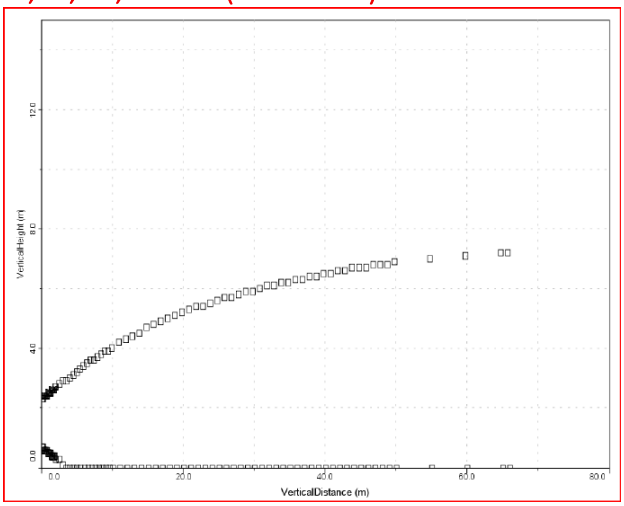
Case 4, 200Pa.g, 1000mm aperture, 15º, D4, half LFL (Rivalea test)



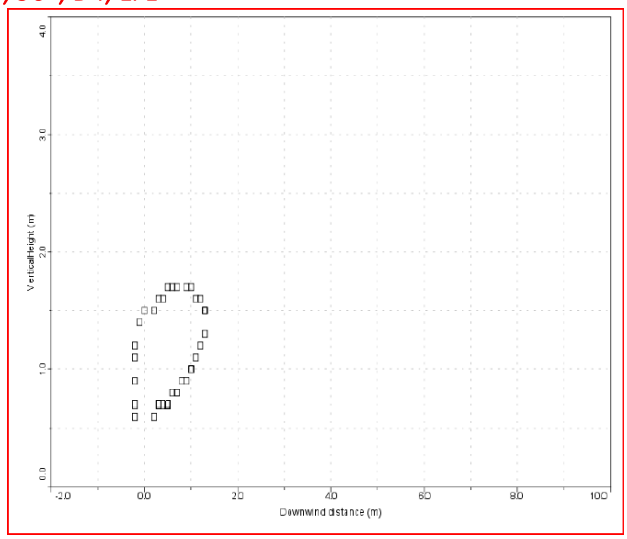
Case 4, 200Pa.g, 1000mm aperture, 0º, D4, LFL (Rivalea test)



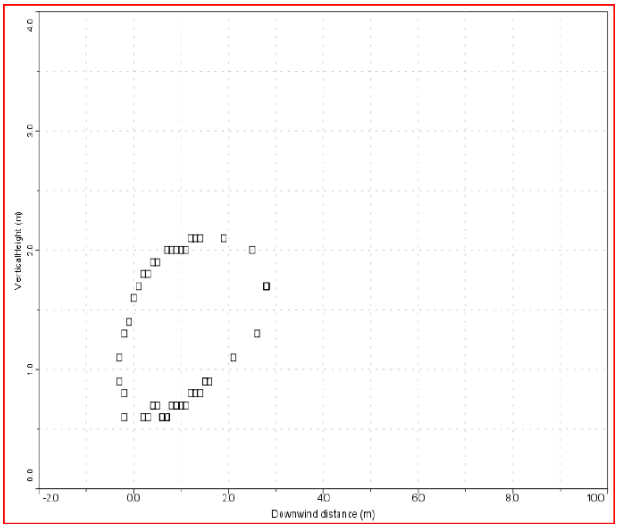
Case 4, 200Pa.g, 1000mm aperture, 0º, D4, half LFL (Rivalea test)



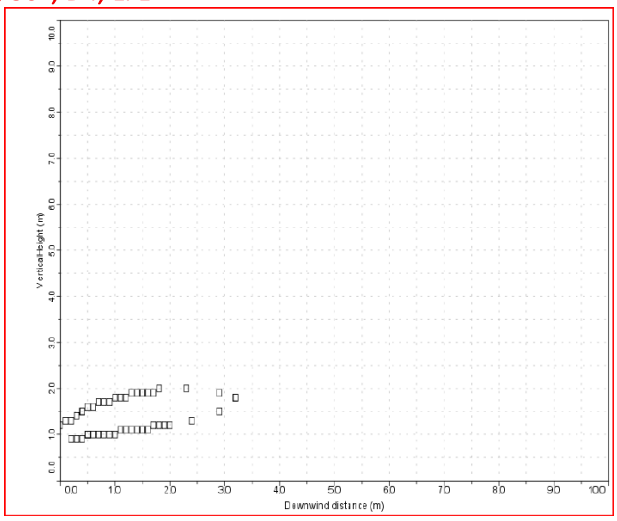
Case 5, 50Pa.g, 200mm aperture, 90º, D4, LFL



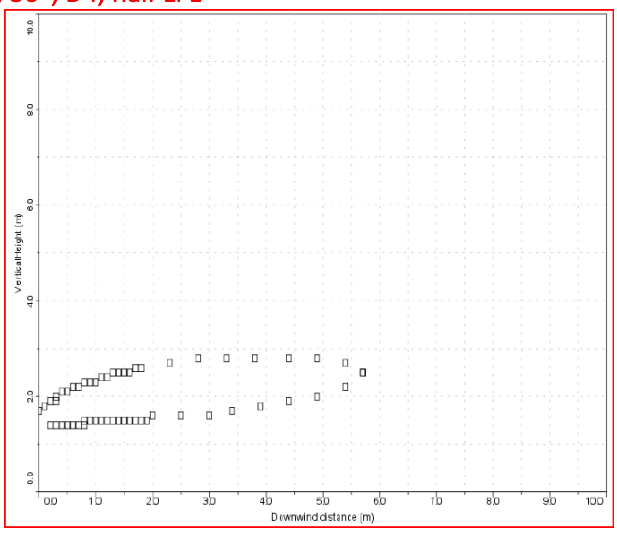
Case 5, 50Pa.g, 200mm aperture, 90º, D4, half LFL



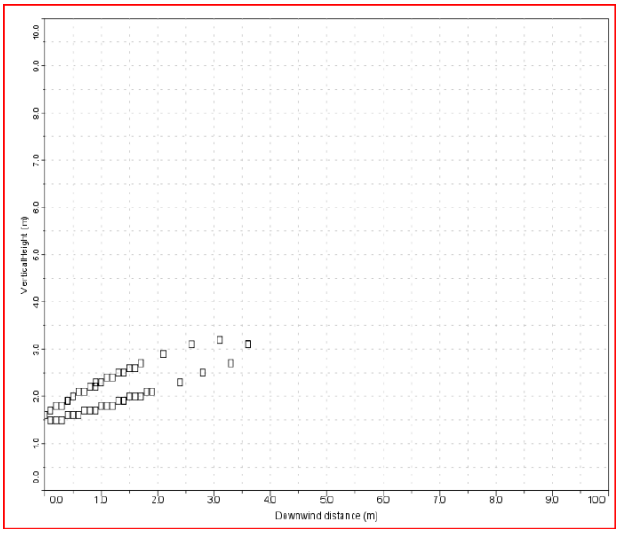
Case 5, 50Pa.g, 200mm aperture, 30º, D4, LFL



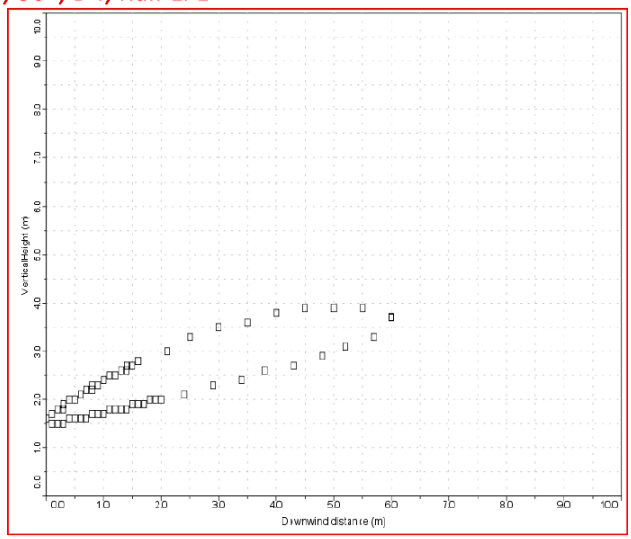
Case 5, 50Pa.g, 200mm aperture, 30º, D4, half LFL



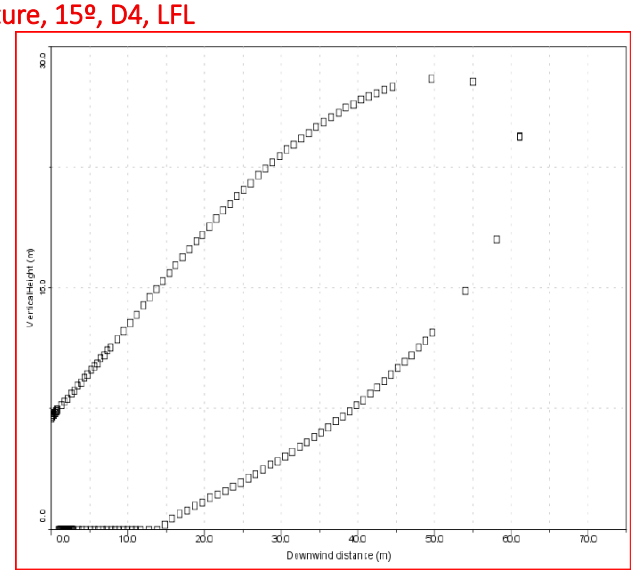
Case 5, 4kPa.g, 100mm aperture, 30º, D4, LFL



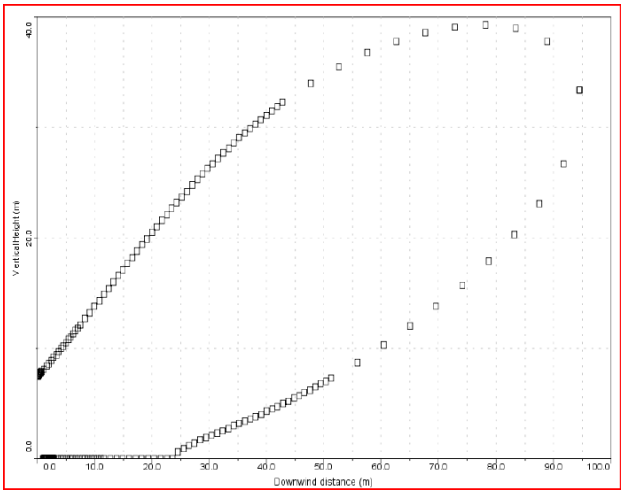
Case 5, 4kPa.g, 100mm aperture, 30º, D4, half LFL



Case 6, 100Pa.g, 5000mm aperture, 15º, D4, LFL



Case 6, 100Pa.g, 5000mm aperture, 15º, D4, half LFL



ISSUE 14:

The applicant submitted an appeal to the decision by Tipperary County Council to refuse planning permission. There were 333 submissions from the public & none of the issues raised in these submissions were addressed. I would ask that these submissions be addressed by ACP as part of this appeal Response.

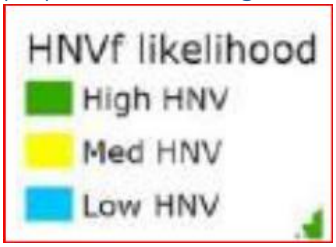
333 Submissions		
Submission	[E] Alan Kelly TD	594 Kb
Submission	[E] Alma Shanahan	102 Kb

Submission	[E] Amanda Flanagan	35 Kb
Submission	[E] Ann Walsh	137 Kb
Submission	[E] Anne Molony	67 Kb
Submission	[E] Anthony & Nicola Murphy	87 Kb
Submission	[E] Anthony & Nicola Murphy	411 Kb
Submission	[E] Brid Gleeson	10533 Kb
Submission	[E] Bridget Cullen	34 Kb
Submission	[E] Bridget Gleeson	38 Kb
Submission	[E] Cara Shanahan	37 Kb
Submission	[E] Catherine Brittain	34 Kb
Submission	[E] Charles Lamb	609 Kb
Submission	[E] Ciara Gleeson	514 Kb
Submission	[E] Ciaran Lynch	339 Kb
Submission	[E] Ciaran Lynch	455 Kb
Submission	[E] Ciaran Lynch	35 Kb
Submission	[E] Deirdre Murphy	86 Kb
Submission	[E] Donal Shanahan	92 Kb
Submission	[E] Eamonn Flanagan	34 Kb
Submission	[E] Jack Murphy	202 Kb
Submission	[E] James Fanning	36 Kb
Submission	[E] Jamie Fanning	36 Kb
Submission	[E] Joan Cummins	35 Kb
Submission	[E] John Flanagan	35 Kb
Submission	[E] Kevin Maher	139 Kb
Submission	[E] Kevin Maher	1351 Kb
Submission	[E] Kevin Maher	8408 Kb
Submission	[E] Kevin Timmons	35 Kb
Submission	[E] Killough Biogas Concern Group	10281 Kb
Submission	[E] Liam Shanahan	81 Kb
Submission	[E] Liam Shanahan	36 Kb
Submission	[E] Lime Tree Farms Limited	34 Kb
Submission	[E] Louise Morgan Walsh	581 Kb
Submission	[E] Mardi Maher	34 Kb
Submission	[E] Margaret Byrne	36 Kb
Submission	[E] margaret carignan	34 Kb
Submission	[E] Maria Fanning	36 Kb
Submission	[E] Mary Ryan	34 Kb
Submission	[E] Michael Brennan	33 Kb
Submission	[E] Michelle Donnelly	133 Kb
Submission	[E] Pat Shanahan	12778 Kb
Submission	[E] Pat Shanahan	732 Kb
Submission	[E] Patricia Flanagan	35 Kb
Submission	[E] Patrick Lambe	75 Kb
Submission	[E] PETER SWEETMAN	177 Kb
Submission	[E] Proinsias & AnneMarie Greene	142 Kb
Submission	[E] Proinsias & AnneMarie Greene	35 Kb
Submission	[E] Rosaleen Fitzgerald	35 Kb
Submission	[E] Thomas & Eileen Gleeson	154 Kb
Submission	[E] Tom Cummins	36 Kb
Submission	16 new submissions received 14/01/26	2313 Kb
Submission	16 Submissions received on 15/1/26	11465 Kb

Submission	2 submissions rec 19/01/26	15690 Kb
Submission	28 submissions received 13/02/25	32970 Kb
Submission	36 submissions received 08/01/26	60630 Kb
Submission	4 submissions received 08/01/26	2724 Kb
Submission	41 Submissions received 10/02/25	68001 Kb
Submission	44 submissions received 17/02/25	98740 Kb
Submission	48 submissions received 14/01/26	16299 Kb
Submission	Alice Coman	766 Kb
Submission	Alice Coman on behalf of Killough Com. Group	17881 Kb
Submission	Alice Coman, Killough Community Group - redacted	21674 Kb
Submission	Alma Shanahan	187 Kb
Submission	Aoife Whelan	4152 Kb
Submission	Brid Gleeson	11834 Kb
Submission	Bridget Cullen - redacted	80 Kb
Submission	Camilla Fogarty	3786 Kb
Submission	Cara Shanahan - redacted	1073 Kb
Submission	Cllr Sean Ryan	61 Kb
Submission	Concerned Residents (C/o Matthew Maher) - redacted	4394 Kb
Submission	Connie and Jean Dunne	1101 Kb
Submission	Deputy Mattie McGrath	108 Kb
Submission	Eamon McBride	13421 Kb
Submission	Eoin Bourke	557 Kb
Submission	Eoin Hassett - redacted	555 Kb
Submission	Ignatius and Kathleen Maher	1017 Kb
Submission	Jack Caesar	2914 Kb
Submission	James Duggan	498 Kb
Submission	James Flanagan, Gaile Community Group	1213 Kb
Submission	John Fanning	2961 Kb
Submission	John Flanagan	756 Kb
Submission	John Fogarty	23104 Kb
Submission	Majella Dwan	1342 Kb
Submission	Martin and Mary Hewitt	2944 Kb
Submission	Martin Lavelle	14949 Kb
Submission	Mary Fanning	3116 Kb
Submission	Mary McCarthy	2423 Kb
Submission	Michael English	4667 Kb
Submission	Paddy Dwan	2404 Kb
Submission	Padraig Shanahan - redacted	81 Kb
Submission	Patricia Dwan	4785 Kb
Submission	Principal Donal Ryan	593 Kb
Submission	Rachel Spillane	1258 Kb
Submission	Sarah Fitzgerald	298 Kb
Submission	Seán Fanning	2064 Kb
Submission	Siobhán Carew	4696 Kb
Submission	Tina Fitzgerald -REDACTED	81 Kb

ISSUE 15

The Map of High Nature Grassland below from Sustainability of Biomethane Production in Ireland : Exploring how Ireland can deliver a sustainable, agriculture-led biomethane industry October 2021 & referenced in the Ireland's National Biomethane Strategy May 2024 (page 29) indicates that the lands to the North, West, East & South of the proposed site are High Nature Value Grasslands & are excluded from Biogas potential areas.



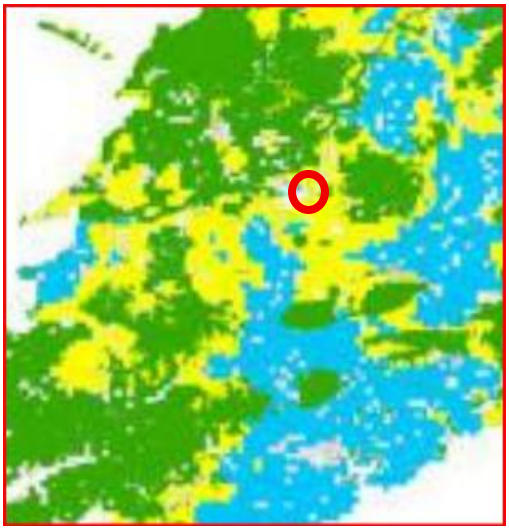


FIGURE 16 MORAN ET AL. (2021) HIGH NATURE VALUE FARMLAND. Note Limerick circled in red & the area to its east is designated as HNV grassland. Limerick City circled in red.

EXCLUSION OF HIGH NATURE VALUE LAND

High Nature Value ("HNV") farmland is extensively managed farmland that has high biodiversity, enhanced ecosystem services and societal value. This farmland is important for the conservation of semi-natural habitats and the plants and animals within them. These farms occur most frequently in areas that are mountainous or areas where natural constraints prevent intensification. Farming is important in these areas as it sustains the biodiversity of these landscapes which is integral for maintaining their HNV.

Research conducted by Moran et al. (2021) mapped the spatial distribution of HNV farmland across Ireland (Fig 16). The paper estimates that there is approximately 1.5 m ha of HNV farmland in Ireland. For this report, the HNV map is used as a proxy to screen for areas that are unlikely to meet the RED II protocol. It should be noted that this is a high level screening exercise and it is recommended that where an area of land is identified within a high HNV zone, enhanced screening or an Environmental Impact Assessment ("EIA") is conducted to ensure that the proposed project would comply with the RED II protocol.

No information has been provided as to what the estimated nutrient content of the digestate fractions will be. A realistic estimate of the Nitrogen and Phosphorus content of the digestate fractions should have been provided in order to assess what lands are required to recover the digestate, and likely fate of nutrients in soils.

No information has been provided regarding the areas of lands available for recovery of the digestate. Expressions of interest in utilising digestate from a number of farmers is not sufficient as this is not a commitment to use a defined amount of digestate on a particular area of lands.

Detailed information on the proposed lands to be used to recover digestate from the proposed development, including a Nutrient Management Plan & Traffic Management Plan & 2-way Sweptpath should have been provided . This should have included maps of each holding, herd numbers, areas of holding suitable for digestate recovery, amount of Nitrogen & Phosphorous that can be imported onto each holding, Nitrogen & Phosphorous statements for 2025 for each holding, a statement from a suitably qualified person that the proposed lands are suitable & have nutrient capacity for sustainable recovery of digestate.

A method statement for the recovery of digestate on each farm is required, with responsibility for the management and compliance of means of recovery defined.

The application is for 90,000tonnes per annum feedstock & 78,000tonnes per annum biobased fertiliser. Where does the 12,000tonnes disappear to?

The applicant has not provided any information on the source and nature of the Chicken manure (3,000tonnes, Pig slurry 30,000tonnes, crops 7,000tonnes, Belly grass 1,000tonnes, Distillery waste 1,500tonnes & Dairy processing waste 1,500tonnes.

Odour sensitive receptors should have bene identified for each such proposed lands proposed for the recovery of digestate with a digestate odour mitigation plan to protect any residential or recreational amenities or receptors from odour impact

The potential odour emissions from vehicles delivering feedstock to the facility or taking account of potential emissions from doors opening to allow traffic to access/exit the feedstock reception building. It is noted that all of the proposed feedstocks have potential to cause odour nuisance in transit.

The 20km radius area is largely dairy farms. The use of digestate from a biogas unit will be continuous over the 12-month period. This will involve a change from grass to tillage with annual crop rotation. This change will remove the carbon sequestration of the grass & totally change the Carbon savings submitted in association with the collection & delivery of biogas & its digestate plus increased tillage farming mechanical plant.

ISSUE 16
Odours & Gas

Reference Number 18: Quantitative Assessment Of Pollution In The Sanitation, Waste Management, And Energy Sectors. Asian Development Bank. February 2026.
Air Pollution: Odour

The main concern of air pollution for sanitation is odour, which is largely associated with sludge handling. Countries stipulated emission standards for the main gases of odour by concentration when they are fugitive emissions, and by amount (e.g., kilograms [kg] per hour) when there are vents or chimneys, effectively a point source discharge. To check if odour emissions meet standards, portable devices can be used to sample and test in a laboratory, though the capacity to test odour gases is less commonly available than that for sulphur dioxide (SO_2), particulate matter (PM) or water pollutants.
The European standard for odour concentration uses a method called dynamic olfactometry, which involves a panel of human assessors and an olfactometer to dilute odour samples with neutral air. The result is expressed in European odour units per cubicmeter (OuE/m3), indicating the dilution level at which the odour is just barely detectable by 50% of the panel. If the sample needs to be diluted 10 times with clean air so that the panel cannot detect the odour anymore, that sample has a concentration of 10 OuE/m3.
This is a widely accepted method for odour globally, e.g., in the US and the People's Republic of China (PRC). In addition, the PRC emission standard for odour also sets limits on the main gases that constitute odour (Table 2). This is out of concern that judgments by human assessors can be easily subject to dispute. However, many localities have

difficulty testing some odour gases, which become the prevailing parameters used. The standard has been undergoing revision and updating to be more consistent with the latest air quality standard, and is likely to bring it more in line with international practice, which is more practical and easier to enforce.

Table 2: Excerpts of Odour Emission Standards at Facility Boundaries

			Class II		Class III	
Pollutant	Unit	Class I	New, rehab	Existing	New, rehab	Existing
Ammonium gas	mg/m³	1.0	1.5	2.0	4.0	5.0
Hydrogen sulfide	mg/m³	0.03	0.06	0.10	0.32	0.60
Methanethiol	mg/m³	0 004	0.007	0.010	0.020	0.035
Odor concentration	OuE/m³	10	20	30	60	70

mg/m³ = milligrams per cubic meter, OuE/m³ = European odor units per cubic meter, rehab = rehabilitation.

Notes: Class I limits apply to protected areas and scenic areas. Class II limits apply to residential and commercial areas. Class II limits mainly apply to industrial zones and rural areas.

Source: Government of the People's Republic of China. *National Odor Emissions Standard* (GB14554-93).

While the PRC standard in Table 2 is an emissions standard for odour emitters (the PRC air quality standard does not include odour), the odour standards in some European countries found by internet search are mostly for receptors, essentially an ambient standard. For example, in Germany, the Technical Instructions on Air Quality Control 2021 sets limits for residential and mixed areas at a maximum of 10% of annual hours where odour may be perceptible. The Environment Agency of the United Kingdom recommends different limits based on the offensiveness of odour, ranging from 1.5 OuE/m3 for the most offensive to 6 OuE/m3 for less offensive odours at the point of receptor. Slovenia's emission standard on odour is 500 OuE/m3 for emitters as well. These two types of standards are incomparable, though related. For a detailed explanation, see Box 1 related text and the 2023 ADB study of this series (footnote 1).

On the other hand, human senses can easily detect odours. Noses can detect odour gases at very low concentrations, which is 400 times lower than the threshold harmful to human health. Thus, efforts have been rightly prioritized to prevent and control odour.

Reference Number 19: AERMOD Model description: Source Athenry Gas Peaking Plant. Ref. – ACP 26-324113

The AERMOD dispersion model has been developed in part by the U.S. Environmental Protection Agency (USEPA) (EPA, 2020; USEPA, 1995; USEPA, 2005; USEPA, 2022). The model is a steady-state Gaussian model used to assess pollutant concentrations associated with industrial sources. The model is an enhancement on the Industrial Source Complex-Short Term 3 (ISCST3) model which has been widely used for emissions from industrial sources. Improvements over the ISCST3 model include the treatment of the vertical distribution of concentration within the plume. ISCST3 assumes a Gaussian distribution in both the horizontal and vertical direction under all weather conditions. AERMOD with PRIME, however, treats the vertical distribution as non-Gaussian under convective (unstable) conditions while maintaining a Gaussian distribution in both the horizontal and vertical direction during stable conditions. This treatment reflects the fact that the plume is skewed upwards under convective conditions due to the greater intensity of turbulence above the plume than below. The result is a more accurate portrayal of actual conditions using the AERMOD model. AERMOD also enhances the turbulence of night-time urban boundary layers thus simulating the influence of the urban heat island.

In contrast to ISCST3, AERMOD is widely applicable in all types of terrain. Differentiation of the simple versus complex terrain is unnecessary with AERMOD. In complex terrain, AERMOD employs the dividing-streamline concept in a simplified simulation of the effects of plume-terrain interactions. In the dividing-streamline concept, flow below this height remains horizontal, and flow above this height tends to rise up and over terrain. Extensive validation studies have found that AERMOD (precursor to AERMOD with PRIME) performs better than ISCST3 for many applications and as well or better than CTDMPLUS for several complex terrain data sets (USEPA, 1999).

Reference Number 20: AERMET : Source Athenry Gas Peaking Plant. Ref. – ACP 26-324113

AERMOD incorporates a meteorological pre-processor AERMET (USEPA, 2018). AERMET allows AERMOD to account for changes in the plume behaviour with height. AERMET calculates hourly boundary layer parameters for use by AERMOD, including friction velocity, Monin-Obukhov length, convective velocity scale, convective (CBL) and stable boundary layer (SBL) height and surface heat flux. AERMOD uses this information to calculate concentrations in a

manner that accounts for changes in dispersion rate with height, allows for a non-Gaussian plume in convective conditions, and accounts for a dispersion rate that is a continuous function of meteorology.
The AERMET meteorological preprocessor requires the input of surface characteristics, including surface roughness (z0), Bowen Ratio and albedo by sector and season, as well as hourly observations of wind speed, wind direction, cloud cover, and temperature. A morning sounding from a representative upper air station, latitude, longitude, time zone, and wind speed threshold are also required.
Two files are produced by AERMET for input to the AERMOD dispersion model. The surface file contains observed and calculated surface variables, one record per hour. The profile file contains the observations made at each level of a meteorological tower, if available, or the one-level observations taken from other representative data, one record level per hour.
From the surface characteristics (i.e. surface roughness, albedo and amount of moisture available (Bowen Ratio))AERMET calculates several boundary layer parameters that are important in the evolution of the boundary layer, which, in turn, influences the dispersion of pollutants. These parameters include the surface friction velocity, which is a measure of the vertical transport of horizontal momentum; the sensible heat flux, which is the vertical transport of heat to/from the surface; the Monin-Obukhov length which is a stability parameter relating the surface friction velocity to the sensible heat flux; the daytime mixed layer height; the nocturnal surface layer height and the convective velocity scale which combines the daytime mixed layer height and the sensible heat flux. These parameters all depend on the underlying surface.
Response from MLavelle: The data inputs for both Aermod & Aermet have not been provided in Planning Application.

Modelling data has to be provided as part of the lacunae. CJEU Case 258/11 at 44
"So far as concerns the assessment carried out under Article 6(3) of the Habitats Directive, it should be pointed out that it cannot have lacunae and must contain complete, precise and definitive findings and conclusions capable of removing all reasonable scientific doubt as to the effects of the works proposed on the protected site concerned."

Judgement of the Court Case 258/11

Article 6(3) of Council Directive 92/43/EEC of 23rd May 1992 on the conservation of natural habitats and of wild fauna and flora must be interpreted as meaning that a plan or project not directly connected with or necessary to the management of a site will adversely affect the integrity of that site if it is liable to prevent the lasting preservation of the constitutive characteristics of the site that are connected to the presence of a priority natural habitat whose conservation was the objective justifying the designation of the site in the list of sites of Community importance, in accordance with the Directive. The precautionary principle should be applied for the purposes of that appraisal.

ISSUE 17:
Noise

The WHO Standard of 37dBA should apply to such infrastructure

Table 10-11: Summary of Noise Source Sound Power Data.

Grouping	Item	Octave Band (Hz) Sound Power Levels Lw (dB)								
		63	125	250	500	1k	2k	4k	8k	Weighting
Digester (Primary)	Agitator motor	44	58	65	73	77	77	73	58	A
Digester (Secondary)	Agitator motor	44	58	65	73	77	77	73	58	A
Digestate Storage	Agitator motor	44	58	65	73	77	77	73	58	A
Pasteurisation Unit	Agitator motor	85	78	77	76	82	80	73	66	Z
CHP	Biogas Blower	65	73	83	86	80	78	77	55	A
CHP	Exhaust Stack	76	70	79	84	92	86	83	77	A
CO2 Liq. System	Biogas Blower	65	73	83	86	80	78	77	55	A
Odour Abatement	Fans	85	78	77	76	82	80	73	66	A
Biogas Boiler		49	64	76	71	45	53	53	48	A

Note that this Table excludes the dB(A) levels for each item of plant. The current ACP Application for the Athenry Gas Peaking Plant: Appendix 9. Noise and Vibration from Bord Gas provides dB(A) levels (below) and they are far greater than those provided in Table 10.11. The applicant fails to provide manufacturers guidance levels for such numbers & we can only assume is that they are a guestimate.

All of this machinery should have CE certification and compliant with the Machinery Directive. Why has this not been submitted with the application?

Sound Power Emissions from Gas Turbine (without acoustic treatment). Source Athenry Gas Peaking Plant. Ref. – ACP 26-324113

Source	Lw - Octave Band Centre Frequency Overall									
	31	63	125	250	500	1k	2k	4k	8k	dB(A)
Inlet	124	123	123	130	134	152	147	143	137	154
Exhaust	141	141	143	145	146	151	161	151	140	162
Enclosure (Breakout)	112	122	117	118	114	119	131	125	117	133

Sound Power Emissions from Gas Turbine (with acoustic treatment). Source Athenry Gas Peaking Plant. Ref. – ACP 26-324113

Source	Lw - Octave Band Centre Frequency Overall									
	31	63	125	250	500	1k	2k	4k	8k	dB(A)
Inlet	124	118.3	97.4	96.6	94.6	93.6	92.6	88.6	104.5	105
Exhaust	131.6	116.5	88.4	86.9	84.8	83.8	84.3	79.7	73.4	95.7
Enclosure (Breakout)	83	93	88	89	85	90	102	96	88	104

Sound Power Emissions from Diesel Generator. Source Athenry Gas Peaking Plant. Ref. – ACP 26-324113

Source	Lw - Octave Band Centre Frequency Overall									
	31	63	125	250	500	1k	2k	4k	8k	dB(A)
Diesel Generator (Emergency)	87.2	87.2	91.9	94.8	92.8	90.7	88.5	86.1	85.5	100.1

Sound Power Emissions from Other Sources. Source Athenry Gas Peaking Plant. Ref. – ACP 26-324113

Source	Overall dB(A)
Unit Transformer	85
GSU Transformer	85
Compressed Air Skid	85
Shunt Reactor	94

Power Emissions from API (American Petroleum Institute) Noise Sources. Source Athenry Gas Peaking Plant. Ref. – ACP 26-324113

Source	Unit Sound Power (dB(A))	Quantity	Sub – Total (dB(A))
Boiler	48	10	58
Pump	43	1	43
Pressure Reduce Kiosk	96	1	96
Generator	95	1	95
		Total	99
Sound reduction of enclosure			26
		Resultant	73

Table 10 A-1
Noise Levels Commonly Found in the Environment

Sound Level	Location
0dB(A)	Threshold of hearing
20 to 30dB(A)	Quiet bedroom at night
30 to 40dB(A)	Living room during the day
40 to 50dB(A)	Typical office
50 to 60dB(A)	Inside a car
60 to 70dB(A)	Typical high street
70 to 90dB(A)	Inside factory
100 to 110dB(A)	Burglar alarm at one metre away
110 to 130dB(A)	Jet aircraft on take off
140dB(A)	Threshold of Pain

thority - Inspection Purposes

The site is in a quiet noise location for over night noise. From this Table, it is obvious that a quiet bedroom at night would be in the range 20-30dBA. A 10dBA increase in noise is a doubling of noise.

Table 10-10: Survey Results at N03 Unattended Monitoring Location

Measurement Details			Ambient sound level dB $L_{Aeq,T}$		Background sound level dB $L_{A90,T}$	
Day Date Range	Period	Time HH:MM	Range	Typical*	Range	Typical*
Wed 23/10/2024 - Thu 31/10/2024	Day	07:00 - 19:00	31 - 55	47	26 - 52	40
	Evening	19:00 - 23:00	24 - 56	35	21 - 51	32
	Night	23:00 - 07:00	21 - 60	35	20 - 55	34
**Based on modal values occurring within each stated time period*						

10.65 The following observations are made in respect of unattended noise measurements at N03 (verified through post survey analysis of recorded audio files):

- Noise from Killough quarry site activities was audible intermittently during the daytime period, during the nighttime period noise from the limestone plant was audible and comprised the dominant background noise source (specific noise estimated at 34 dB L_{A90}) ;

13/01/2025 Inspection Purposes Only

Response from MLavelle: The assessment of background noise at nighttime is influenced by the noise from the quarry. Noise levels should have been provided with all quarry activities closed down. That noise level is the real background noise. It can be seen from Table 10-10 that 20-23 dB is the background night time noise. The noise limit for nighttime should be a maximum 30dB.

Impact Classification Terminology (IGI, 2013)

Impact	Characteristic	Term Description
Quality	Positive	A change which improves the quality of the environment
	Neutral	A change which does not affect the quality of the environment
	Negative	**A change which reduces the quality of the environment**
Significance	Imperceptible	An impact capable of measurement but without noticeable consequences
	Slight	An impact which causes noticeable changes in the character of the environment without affecting its sensitivities
	Moderate	An impact that alters the character of the environment in a manner consistent with existing and emerging trends
	Significant	**An impact, which by its character, magnitude, duration or intensity alters a sensitive aspect of the environment**
	Profound	An impact which obliterates sensitive characteristics
Duration	Short-term	Impact lasting one to seven years
	Medium-term	Impact lasting seven to fifteen years
	Long-term	**Impact lasting fifteen to sixty years**
	Permanent	Impact lasting over sixty years
	Temporary	Impact lasing for one year or less
Type	Cumulative	The addition of many small impacts to create one larger, more significant impact
	'Do Nothing'	The environment as it would be in the future should no development of any kind be carried out
	Indeterminable	When the full consequences of a change in the environment cannot be described
	Irreversible	When the character, distinctiveness, diversity, or reproductive capacity of an environment is permanently lost
	Residual	Degree of environmental change that will occur after the proposed mitigation measures have taken effect
	Synergistic	Where the resultant impact is of greater significance than the sum of its constituents
	'Worst Case'	**The impacts arising from a development in the case where the mitigation measures may substantially fail**

This Biogas Application is Negative, Significant, Long-term & Worst case

The default values for EFNH3-N for digestion at biogas facilities, its open storage of digestate, and the nitrogen content of various feedstock are provided and have been converted to kg/t in this study for easier use in practice (Table 7).

Table 7: Emission Factors of Digestion

Pollutant	Emission Factor (kg/t Nitrogen)	Feedstock	Dry Mass in Fresh Matter (kg/t)	Nitrogen in Fresh Matter (kg/t)
NH_3 of digestion	27.5	Organic MSW	400	6.8
95 % interval of confidence	16.3–50.1	Green waste (grass)	NA	4.6
NH_3 of digestate open storage	26.6	Poultry manure Pig manure	500 250	17.5 6
95 % confidence	15.2–46.5	Cattle manure	250	5.2
		Pig slurry	60	4.8
		Cattle slurry	100	5.2

kg/t = kilograms per ton, MSW = municipal solid waste, NH_3= ammonia.
Source: European Environment Agency. 2023. Air Pollutant Emission Inventory Guidebook 2019. 5.B.2, Biological treatment of waste – anaerobic digestion at biogas facilities.

With the CH4 emission factor for digestion (27.5 kg/t) and N content of organic MSW (6.8 kg/t), NH3 emission can be estimated as 227 kg NH3/ton of organic MSW (= 1 x 6.8 x 27.5 x 17/14). Based on Table 7, the digestion of poultry manure emits the highest NH3, three times that of organic MSW.

Soil Quality Standard and Discharge Standard

Many countries have soil quality standards. The report by researchers from the Netherlands is a good source as it compiles the standards in some developed countries in Europe and North America (Tamis and Karman 2008).

United States Standards on Land Application of Sludge (Excerpt) (all max. in dry weight)

Pollutant	Ceiling Limit (mg/kg of soil)	Monthly Average (mg/kg of soil)	Cumulative Load (kg/ha)	Annual Load (kg/ha/365 days)
Cadmium	85	39	39	1.9
Mercury	57	17	17	0.85
Lead	840	300	300	15
Chromium	3,000	1,200	3,000	150
Arsenic	75	41	41	2.0
Copper	4,300	1,500	1,500	75
Zinc	7,500	2,800	2,800	140
Nickle	420	420	420	21
Selenium	100	36	100	5

kg/ha = kilograms per hectare, mg/kg = milligrams per kilogram.
Source: United States Environmental Protection Agency. 1994. Land Application of Sewage Sludge, EPA/831-B-93-002b.

Standards for Land Application and Utilization of Sludge in the People's Republic of China (all max. in dry sludge or sediment, mg/kg)

Pollutant	For Agriculture Use[a]		In Forest Land[b]
	pH <6.5	pH ≥6.5	
Total cadmium	5	20	20
Total mercury	5	15	25
Total lead	300	1,000	1,000
Total chromium	600	1,000	1,000
Total arsenic	75	75	75
Total copper	250	500	1,500
Total zinc	500	1,000	4,000
Total nickel	100	200	200
Mineral oil	3,000	3,000	NA
Benzopyrene	3	3	NA
PAHs	NA	NA	NA

a Control standard for pollutants in sludge for agricultural use (GB4284-84), 1984.
b Quality of sludge used in forest land (CJ/T362-2011), 2011.

Reference Number 21: ENVIRONMENT AGENCY UK: SR2021 NO 6: GENERIC RISK ASSESSMENT FOR ANAEROBIC DIGESTION FACILITY, INCLUDING USE OF THE RESULTANT BIOGAS – INSTALLATIONS

UPDATED 26 FEBRUARY 2026

This generic risk assessment is based on the following parameters.

Parameter 1
Permitted activities s5.4 A(1)(b)(i) are:

- the storage and recovery of waste (R13, R1, R3)
- incineration on land (D10)

Parameter 2
The permitted wastes are biodegradable wastes suitable for digestion.

Parameter 3
The maximum quantity of waste received each day shall not exceed the designed storage capacity of the site.

Parameter 4
Except for the auxiliary flare, the aggregate rated thermal input of all appliances used to burn biogas must be less than 5 megawatts.

Parameter 5
The maximum quantity of animal waste, including animal carcasses, shall be limited to 10 tonnes per day, this excludes manures and slurries.

Parameter 6
These rules do not allow any point source emission into land, surface waters or groundwater under control of the permit.

Parameters 7 to 15
The activities shall not be carried out within:

- 200 metres of the nearest receptor as measured from any combustion stack or stacks, unless the stacks are at least 7 metres high and the effective stack height of each stack is greater than 3 metres
- 250 metres of the nearest sensitive receptor where any further treatment takes place by composting digestate fibre in the open
- 500 metres of a European site (within the meaning of Regulation 8 of the Conservation of Habitats and Species Regulations 2017) or a Site of Special Scientific Interest, including candidate or proposed sites
- a groundwater source protection zone 1 or 2, or if a source protection zone has not been defined then within 50 metres of any well,
- spring or borehole used for the supply of water for human consumption (including private water supplies)
- 250 metres of the presence of great crested newts, where it is linked to the breeding ponds of the newts by good habitat
- 10 metres of any watercourse
- 50 metres of a Local Nature Reserve, Local Wildlife Site, Ancient Woodland or Scheduled Monument
- 50 metres of a site that has species or habitats of principle importance (as listed in Section 41 of the Natural Environment and Rural Communities Act 2006) that the Environment Agency considers at risk to this activity, these are also often referred to as priority habitats and species
- a specified Air Quality Management Area (AQMA)

LIKELIHOOD OF EXPOSURE

THIS IS THE LIKELIHOOD OF THE RECEPTORS BEING EXPOSED TO THE HAZARD. THE MEANING OF THE DEFINITIONS ARE:

- HIGH – EXPOSURE IS PROBABLE – DIRECT EXPOSURE IS LIKELY WITH NO OR FEW BARRIERS BETWEEN THE HAZARD SOURCE AND THE RECEPTOR
- MEDIUM – EXPOSURE IS FAIRLY PROBABLE - FEASIBLE EXPOSURE IS POSSIBLE AS THE BARRIERS TO EXPOSURE ARE LESS CONTROLLABLE

- LOW – EXPOSURE IS UNLIKELY – SEVERAL BARRIERS EXIST BETWEEN THE HAZARD SOURCE AND RECEPTOR TO REDUCE EXPOSURE
- VERY LOW – EXPOSURE IS VERY UNLIKELY – EFFECTIVE, MULTIPLE BARRIERS ARE IN PLACE TO REDUCE EXPOSURE

RISK TO LOCAL HUMAN POPULATION

1.1 Releases of emissions NOx, SOx, CO and other gases

NOx, SOx, CO and other gases travel through the air and can be inhaled.
We have assessed the potential harm to human health as follows:

- respiratory irritation
- illness

Judgement of risk

We have judged the:

- likelihood of the hazard affecting the receptor as **medium**
- overall severity of potential consequences as **medium**
- overall risk rating as **medium**

The reasons for giving the activity this rating is because there is potential for exposure to:

- anyone living close to the site
- members of the public at locations to which they could be regularly exposed

Managing the risk

The following manages the risk:

- set back distances apply for effective stack height and open processing of waste
- lagoons must be covered with a fixed cover and an appropriately designed air abatement and gas capture system
- monitoring of emission levels from biogas driven combined heat and power plants and specified generators as required by the permit and in accordance with guidance 'Monitoring stack emissions' (formerly M2) and 'Monitoring stack emissions: low risk MCPs and specified generators' (formerly M5)
- activities shall be managed and operated in accordance with a management system (including the inspection and maintenance of equipment and engines) and the point source emissions to air with emission limits requirement
- other monitoring shall be reported as permit requirements
- the activities shall not be carried out within a specified AQMA for NOx
- leak detection and repair programmes will be in place to mitigate and prevent methane emissions
- gas pressure will be monitored to minimise the release of biogas and all pressure relief systems will be inspected and calibrated as required by the permit

Taking these actions will control the risk and rate it as '**low'.**

1.2 RELEASE OF MICRO-ORGANISMS (BIOAEROSOLS)

Bioaerosols travel through the air and can be inhaled.
We have assessed the potential harm to human health as follows:

- respiratory irritation
- illness

Judgement of risk

We have judged the:

- likelihood of the hazard affecting the receptor as **low**
- overall severity of potential consequences as **low**
- overall risk rating as **low**

The reasons for giving the activity this rating is because there is potential for release:

- when waste is received
- because digestate fibre can be treated by open composting
- during storage of digestate

Managing the risk

The following manages the risk:

- the permit does not allow anaerobic digestion activities to be carried out within 200 metres of the nearest sensitive receptor
- open composting of digestate fibre is not permitted within 250m – set back distances are sufficiently precautionary so that bioaerosols are at background level
- air abatement of feedstock reception needs to be deployed to mitigate channelled emissions
- open composting can only be done where the windrows are covered or where there is static aeration with appropriate filters or a scrubbing system
- air abatement needs to be deployed to mitigate channelled emissions
- bio-filters are monitored for efficiency

Taking these actions will control the risk and rate it as **'low'.**

1.3 Odour

Odour travels through the air and can be inhaled.

We have assessed the potential risk to the local population as:

- nuisance
- loss of amenity

Judgement of risk

We have judged the:

- likelihood of the hazard affecting the receptor as **medium**
- overall severity of potential consequences as **medium**
- overall risk rating as **medium**

The reasons for giving the activity this rating is because local residents are sensitive to odour. Odour can result from:

- a wide range of waste, particularly when the site receives it
- the release of biogas
- digestate

Managing the risk

The following manages the risk:

- an odour management plan is required
- fugitive emissions are not permitted
- all waste reception areas and storage areas will be in enclosed or covered with a designed and monitored air extraction system where the air is treated and abated to reduce odours and other gaseous compounds
- all channelled emissions will be treated before release
- operators will take additional measures to ensure ammonia release is controlled
- fugitive source emissions of biogas shall be minimised by implementing a leak detection and repair programme
- all appropriate measures and Best Available Techniques shall be implemented
- stored digestate will be stable
- all storage tanks, lagoons, digestate and contaminated water will be covered
- all abatement systems are designed, monitored and maintained to treat specified emissions and off-gases

Taking these actions will control the risk and rate it as 'low'.

1.4 Noise & Vibration

Noise travels through the air and vibration through the ground.

We have assessed the potential risk to the local population as:

- nuisance
- loss of amenity
- loss of sleep

Judgement of risk

We have judged the:

- likelihood of the hazard affecting the receptor as **medium**
- overall severity of potential consequences as **medium**
- overall risk rating as **medium**

The reasons for giving the activity this rating is because local residents can be sensitive to noise and vibration. However, there is low potential for exposure.

Managing the risk

The following manages the risk:

- noise and vibration shall be minimised and not cause nuisance
- fans and condensate traps will be checked for water
- fans and extraction systems will be checked and maintained
- flares must be kept to a minimum to reduce noise impact and a record of use kept and reported
- a noise and vibration management plan may be required

Taking these actions will control the risk and rate it as **'low'.**

2. RISK TO LOCAL HUMAN POPULATION, LIVESTOCK AND WILDLIFE

2.1 Gaining unauthorised access to site

There is a risk of direct physical contact with all on-site hazards such as wastes, machinery and vehicles. There is a risk of causing injury to humans or livestock.

Judgement of risk

We have judged the:

- likelihood of the hazard affecting the receptor as **low**
- overall severity of potential consequences as **low**
- overall risk rating as **low**

The reasons for giving the activity this rating is because it is carried out within enclosed digesters so physical contact is minimised.

Managing the risk

The following manages the risk:

- activities shall be managed and operated in accordance with a management system which includes site security measures to prevent unauthorised access
- all sites will have a DSEAR assessment which covers unauthorised access to site
- maintenance workers or contractors are not permitted on site without a suitable qualification and they must have permission to do the work

Taking this action will control the risk and rate it as **'low'.**

. RISK TO LOCAL HUMAN POPULATION AND LOCAL ENVIRONMENT

3.1 Arson and vandalism

Arson and vandalism risk causing the release of polluting materials to the air (smoke or fumes), water or land.
Arson and vandalism can cause:

- smoke to travel through the air
- spillages and contaminated firewater to run-off from the site and through surface water drains and ditches

We have assessed the potential harm as:

- respiratory irritation, illness and nuisance to local population
- injury to staff, fire fighters, arsonists or vandals
- pollution of water or land

Judgement of risk

We have judged the:

- likelihood of the hazard affecting the receptor as **medium**
- overall severity of potential consequences as **medium**
- overall risk rating as **medium**

The reasons for giving the activity this rating is because:

- biogas is flammable
- the risk of direct physical contact is reduced by the activity being carried out within enclosed systems
- the consequences of an incident may be serious, including risk to the safety and wellbeing of people and loss of containment causing releases to the environment

Managing the risk

As risk 2.1 plus the following manages the risk:

- an accident management plan is required as part of the management system (covers fire and spillages)
- all areas of risk are identified in the DSEAR assessment
- a Hazard & Operability Study (HAZOP) or similar risk identification technique is done to produce a schedule of planned maintenance (as identified by the HAZOP or risk assessment or suppliers), and is documented
- warning signs are clearly displayed and personnel know gas alarm procedures
- visitors shall be accompanied
- repair and maintenance can only happen if the plant manager gives permission and signs to the effect
- fire control processes and procedures as set out in the DSEAR plan and they shall be communicated to the local fire service
- leak detection schemes are in place to prevent and minimise fugitive biogas release
- the site shall be secure
- any breaches shall be reported
- contingency measures must be in place in the event of loss of plant

Taking these actions will control the risk and rate it as '**low'.**

3.2 ACCIDENTAL EXPLOSION OF GAS

An explosion of biogas risks causing fire and smoke to travel through the air.
We have assessed the potential harm as:

- respiratory irritation, illness and nuisance to the local population
- injury to staff or fire fighters
- air, water or land pollution

Judgement of risk

We have judged the:

- likelihood of the hazard affecting the receptor as **low**
- overall severity of potential consequences as **medium**
- overall risk rating as **medium**

The reasons for giving the activity this rating is because the risk is reduced by an effective management system being in place, as required by the permit.
However, biogas is flammable, and the consequences are likely to be serious, including risk to:

- safety and wellbeing of those working or in close proximity to the site
- loss of containment may be detrimental to the environment

Managing the risk

The following manages the risk:
This risk is managed in the same way as risks 2.1 and 3.1 and these additional measures:

- the management system is required to include the risk management measures specified in the HAZOP and DSEAR plans and cover planned maintenance
- the measures and procedures for any potential accidents are fully documented in the accident prevention and management plan, as part of the management system
- training and regular 'tool-box' talks are given to site operators and all staff understand their role in an emergency
- the management system must include measures for bunding of tanks
- leak detection and repair is required

Taking these actions will control the risk and rate it as '**low'.**

3.3 ACCIDENTAL FIRE

Fire can cause polluting materials (smoke or fumes) to travel through the air, water or land. We have assessed the potential harm as:

- respiratory irritation, illness and nuisance to local population
- injury to staff or fire fighters
- air, water or land pollution

Judgement of risk

We have judged the:

- likelihood of the hazard affecting the receptor as **low**
- overall severity of potential consequences as **medium**
- overall risk rating as **medium**

The reasons for giving the activity this rating is because the risk is reduced by an effective management system.

Managing the risk

This risk is managed in the same way as risks 2.1, 3.1 and 3.2 along with:

- assessing the need for lightning conduction equipment which must be put in place where necessary or required for insurance purposes
- safe storage of activated charcoal and other combustible materials is required

Taking these actions will control the risk and rate it as '**low'.**

3.4 ACCIDENTAL RELEASE OF CO2

A loss of containment from CO2 storage from venting or a breach loss to travel through the air.
The Environment Agency is not the responsible regulator for assessing impacts of accidents from CO2 losses to human receptors.
Potential harm to human health is outlined by the HSE as:

- **illness and loss of consciousness**
- **fatalities from asphyxiation**

Judgement of risk

We have judged the:

- likelihood of the hazard affecting the receptor as **low**
- overall severity of potential consequences as **medium**
- overall risk rating as **medium**

The reasons for giving the activity this rating is because the risk is reduced by an effective accident management plan being in place, as required by the permit.
However, the consequences are likely to be serious, including risk to:

- safety and wellbeing of those working or in close proximity to the site

Managing the risk

The following manages the risk:
This risk is managed in the same way as risks 1.1, 2.1, 3.1 and these additional measures:

- emergency venting must be designed, planned and managed for safety to prevent risk of impacts on and off-site with reference to the HSE guidance and relevant industry good and best practice such as the Energy Institute guidance
- the measures and procedures for any potential accidents are fully documented in the accident prevention and management plan, as part of the management system
- the accident management plan shall assess risk from venting and loss of containment scenarios
- operators must store CO2 on site at locations at a safe distance away from offsite sensitive receptors and must determine these safe distances with reference to relevant HSE guidance, to address concerns expressed by the HSE:
    - Major hazard potential of CCS
    - General hazards of carbon dioxide

Taking these actions will control the risk and rate it as **'low'.**

4. RISK OF LAND BANK CONTAMINATION

There is a risk of:

- plastic in digestate and chemicals of concern contaminating the land bank
- operators landspreading contaminated digestate

Judgement of risk

We have judged the:

- likelihood of the hazard affecting the receptor as **medium**
- overall severity of potential consequences as **medium**
- overall risk rating as **medium**

The reasons for giving the activity this rating is because there is a risk of:

- long term impact on soil quality
- loss of an end market for digestate

Managing the risk

The following manages the risk, there is a requirement to:

- exercise a high level of control on waste inputs
- remove plastic contamination prior to digestion
- sample and check end material to make sure plastic is removed and that chemicals of concern are not present
- monitor efficiency of removal
- submit quarterly returns of recovered outputs

Taking these actions will control the risk and rate it as '**low'.**

5. RISK TO SURFACE WATERS CLOSE TO AND DOWNSTREAM OF SITE

5.1 Spillage of digestate tank failure liquids, including oil – acute effects

We have assessed the acute effects as:

- water supply pollution
- fish kills

We have assessed the harm as:

- direct run-off from the site across the ground and through surface water drains and ditches

Judgement of risk

We have judged the:

- likelihood of the hazard affecting the receptor as **medium**
- overall severity of potential consequences as **medium**
- overall risk rating as **medium**

The reasons for giving the activity this rating is because of the potential for spillage from digestion tanks and storage vessels.

Managing the risk

The following manages the risk:

- digestion tanks require appropriate design and validation
- an impermeable surface is required for storage of all wastes
- no point source emissions are allowed to water
- run-off is restricted to clean surface water using appropriate measures
- the site drainage plan is documented
- all staff are trained in the event of an emergency or accident
- primary infrastructure is bunded in line with CIRIA 736 and industry standards
- run-off is restricted by the 'emissions of substances not controlled by emission limits' rule
- all biogas condensate shall be discharged into a sealed drainage system
- condensate taps are checked daily

Taking these actions will control the risk and rate it as '**low'.**

5.2 SPILLAGE OF DIGESTATE TANK FAILURE LIQUIDS, INCLUDING OIL – CHRONIC EFFECTS

We have assessed the chronic effects as deterioration of water quality.
We have assessed the harm as:

- direct run-off from the site across the ground surface and through surface water drains and ditches
- spillages and digestate through direct run-off from site and through surface water drains and ditches
- indirect run-off through the soil layer or from loss of containment

Judgement of risk

We have judged the:

- likelihood of the hazard affecting the receptor as **medium**
- overall severity of potential consequences as **medium**
- overall risk rating as **medium**

The reasons for giving the activity this rating is because of the potential for spillage from digestion tanks and storage vessels.

Managing the risk

The following manages the risk:

- controls on site location
- preservation of critical infrastructure requirements
- all storage areas shall be constructed to an approved standard
- secondary containment is in place and validated by a chartered engineer to CIRIA 736 standard
- all lagoons are constructed to CIRIA 736 standard
- lagoons are inspected to ensure appropriate freeboard is maintained
- all transfer of digestate and material is supervised

Taking these actions will control the risk and rate it as '**low'.**

6. RISK TO WATER ABSTRACTED FROM A WATERCOURSE

These risks relate to watercourses downstream of a facility and to water for agricultural or potable use.
This receptor is at risk from spillage of digestate liquids due to tank failure.
There is a risk of contaminants travelling through direct run-off from the site across ground surface, via surface water drains and ditches and finally through abstraction. This could have acute effects and cause the closure of abstraction intakes.

Judgement of risk

We have judged the:

- likelihood of the hazard affecting the receptor as **medium**
- overall severity of potential consequences as **medium**
- overall risk rating as **medium**

The reasons for giving the activity this rating is because of the potential for spillage from digestion tanks and storage vessels.

Managing the risk

Risk management is as set out in risks 5.1 and 5.2 along with:

- the activities cannot take place within groundwater source protection zone 1 or 2 or if a source protection zone has not been defined then within 50 metres of any well, spring or borehole used for the supply of water for human consumption (including private water supplies)
- an impermeable surface is required for the site
- all primary tanks undergo a delegated inspection regime and the process parameters are monitored and understood by site operatives

Taking these actions will control the risk and rate it as 'low'.

Risk to groundwater

Groundwater is at risk from spillage from digestate tanks and storage vessels.
There is a risk of contaminants travelling through soil to groundwater which can then be abstracted from a borehole.
This could have a chronic effect resulting in the groundwater requiring treatment or causing closure of a borehole.

Judgement of risk

We have judged the:

- likelihood of the hazard affecting the receptor as **medium**
- overall severity of potential consequences as **medium**
- overall risk rating as **medium**

The reasons for giving the activity this rating is because of the potential for spillage from digestion tanks and storage vessels.

Managing the risk

Risk management is as set out in risks 5.1, 5.2 and 6.1 and:

- process parameters are monitored and understood by site operatives

Taking these actions will control the risk and rate it as **'low'.**

8. RISK OF DIFFUSE EMISSIONS FROM POLLUTING AND GREENHOUSE GASES SUCH AS METHANE AND AMMONIA

There is a risk of fugitive releases of volatile organic compounds such as methane from storage of gas bags, lagoons, tanks, vents and pipe work.

We have assessed the harm as:

- acute effects and long term effects on air quality
- longer term effects of volatile organic compound releases and adding to global climate change

Judgement of risk

We have judged the:

- likelihood of the hazard affecting the receptor as **medium**
- overall severity of potential consequences as **medium**
- overall risk rating as **medium**

The reasons for giving the activity this rating is because:

- biogas contains high levels of methane and is a known contributor to climate change
- digestate and digestate storage releases ammonia which can severely impact air quality
- burning biogas and biomethane can produce harmful pollutants

Managing the risk

The following manages the risk:

- storage tanks and lagoons are covered and where necessary emissions are abated
- venting is minimised by correctly fitting under and over pressure relief valves and is recorded as abnormal events
- gas pressures are continually measured within the design of the plant
- leak detection and repair is employed
- gas holders are maintained and replaced as needed
- emissions are controlled by emission limit values with a requirement to monitor and report
- no fugitive releases are permitted
- operators must install a surplus gas burner or flare to combust surplus biogas

Taking these actions will control the risk and rate it as **'low'.**

9. RISK TO PROTECTED SITES

Protected sites include:

- National Parks and Areas of Outstanding Natural Beauty
- Marine Conservation Zones
- Sites of Special Scientific Interest
- Special Areas of Conservation
- Special Protection Areas
- Ramsar wetland sites

Protected sites can be at risk from any source and by any pathway. However, the main risk is from ammonia and NOx. The risk of harm to protected sites include (but are not limited to) the following:

- toxic contamination
- nutrient enrichment
- leachate
- contaminated surface water run-off
- smothering
- disturbance
- predation from pests and vermin

Judgement of risk

We have judged the:

- likelihood of the hazard affecting the receptor as **low**
- overall severity of potential consequences as **low**
- overall risk rating as **low**

The reasons for giving the activity this rating is because waste composting operations may cause harm to and deterioration of nature conservation sites.

Managing the risk

The following manages the risk:

- the parameters listed at the beginning of this document do not allow operations to take place in close proximity of conservation sites
- emissions of substances not controlled by emission limits (excluding odour and noise) shall not cause pollution
- the operator shall not be taken to have breached this rule if BAT and appropriate measures, including, but not limited to, those specified in any approved emissions management plan, have been taken to prevent or where that is not practicable, to minimise, those emissions
- emission limits as set in the permit
- all lagoons and tanks shall be covered- new sites are required to have a fixed covering
- an ammonia reduction plan will be implemented where necessary
- emission limits for stack gases are specified

Taking this action will control the risk and rate it as **'low'.**

"'Perfect explosive mixture' was flagged years before fatal water plant blast: 1 April 2025. Martin Jones,BBC West Investigation sand Alon Aviram, BBC News, Bristol

It has been more than four years since an explosion at a water treatment plant killed four workers, including a 16-year-old apprentice. No official explanation has yet been published.

Now a BBC West investigation has uncovered reports which expressed serious concerns about conditions in parts of the site, long before the incident.

"If these reports are even half correct, then this was an accident waiting to happen," an industry expert said.

Under the agreement of anonymity, he has studied two leaked reports provided to the BBC about safety at the Wessex Water Avonmouth plant near Bristol.

They were written for and provided to the company five years before a storage tank explosion killed Michael James, 64, Brian Vickery, 63, Raymond White, 57, and Luke Wheaton, 16, in December 2020.

The reports highlight a "perfect explosive mixture", "serious risk to personnel" and a smell of gas so strong, the authors claimed they could not stay in the area to complete their report.

Wessex Water said it has "robust process controls on site" and the matters identified by the reports - produced nearly 11 years ago - "have been resolved". It added that the reports relate to a different part of the site from where the explosion occurred.

The site processes waste water, sifting out solids, and produces biogas and a form of fertiliser.

The reports, written by a consultant brought in to assess the site in 2014 and 2015, warned Wessex Water about safety concerns across parts of the plant, including digesters, gas holders and biogas pipework.
Both reports explicitly flagged an explosion risk.
The author – who also spoke to the BBC on the agreement he would not be named - said he wanted to make his findings public because he had twice tried to contact the Health and Safety Executive (HSE) but had not had any reply.
"I think it [the explosion] could have been prevented," he said.
The areas of the plant covered by the reports are separate from the storage silo that exploded in 2020, but the reports' author, an experienced consultant in the anaerobic digestion industry, said he had been concerned about large parts of the site.
"From the start of the plant all the way through to the holding tank, the complete biogas system was dangerous," he said.
An investigation by Avon and Somerset Police was dropped in July 2024. A spokesperson at the time said the evidence gathered did not reach the "extremely high threshold to prosecute" for manslaughter.
Meanwhile, families and colleagues continue to wait for answers as the HSE has yet to release its findings, which are unlikely to come before July this year, but which could still result in criminal charges.
Coming forward to BBC West's investigations team, the reports' author said that following his inspections in 2014 and 2015 he would not have been happy for one of his family members to work there.
"Four years on, I thought... there would be some sort of closure for the families," he said.
The reports are highly technical and raised a number of safety issues in 2014 and 2015. The claims include:

- *A bio dome with a gas leak, meaning a fan had to be switched on constantly, creating a "perfect explosive mixture" with the fan being a potential source of ignition*
- *A powerful smell of gas around the roofs of digestion tanks, so strong the authors said they could not stay in the area to complete their report*
- *Corroded pressure valves and bird screens, along with some valves that are "greatly undersized"*
- *Gas possibly flowing the wrong way around the site because of inadequate measuring tools*

Another concern was the alleged emission of hydrogen sulphide (H_2S), which the report described as a "serious risk to personnel". H_2S is a toxic gas that, in high concentrations, can be lethal.
The author said: "It wasn't just the explosive atmosphere, it was the toxic atmosphere created by the valves venting.
"Any gas discharge will create a hazardous environment or potentially a hazardous environment."
The reports also state that none of the vessels they looked at were fitted with flame arresters – safety devices designed to stop flames from igniting flammable gases.
While some industry experts consider these essential, others believe they are not always necessary and there is no legal obligation to fit them.
The reports' author said: "I think all the digesters should have flame arresters.
"The industry seems to oppose it, but flame arresters... would have prevented a spark being taken back into the vessel and causing a large explosion."
The BBC has not been able to establish whether Wessex Water took remedial action between these warnings in 2015 and the explosion in 2020. It is not clear whether the silo that exploded was fitted with a flame arrester at any point.
In January 2024 - three years after the explosion - the Health and Safety Executive served the company with an Improvement Notice.
It said: "The operator has failed to demonstrate... that it has taken all measures necessary to prevent major accidents and limit their consequences.
"Their Major Accident Prevention Policy does not address the necessary measures and major hazards management system elements required."
In response, Wessex Water said the notice was "unrelated to the subject matter of the reports" and that the HSE was "satisfied" with steps taken by the company and confirmed compliance on 9 February 2024.
The author of the reports confirmed his findings were shared with management at Wessex Water in 2014/15 and said he believed that the issues were a systemic failure, rather than the fault of staff on the ground.
"I think they didn't do the correct assessment... on the complete system from start to finish," he said.
He believes high levels of gas were produced in the holding tank that exploded, which may have been ignited by a spark on the day of the incident.
Many industry figures and Wessex Water staff have been reluctant to comment publicly for fear of jeopardising future work in an industry with few employers.
One, who studied the reports but spoke on condition of anonymity, said: "I'm looking at this thinking I wouldn't want to operate this plant. There are too many things wrong.

"The number of places they're venting gas from is scary. If these reports are even half correct, then this was an accident waiting to happen."
'Wrong standard'
Another source, who knows the Avonmouth site well, said safety problems in the industry were widely known before the explosion.
He said: "It feels like the whole water industry was working to the wrong standard.
"We always thought it would be one of the other water companies [where there would be a disaster] but it was Avonmouth."
He added that safety had improved dramatically in the years following the fatal blast.
The Health and Safety Executive said it could not comment on the BBC's findings because its investigation remained "live".
The exact cause of the explosion has not yet been made public.
But Prof Clifford Jones, a specialist in combustion risk at the University of Chester, said dust released from the storage silo could have been ignited by a spark.
He said: "There might have been an area at the top of the silo of high concentration of dust. That would have been susceptible to a spark.
"Methane which was there would make [the explosion] all the more powerful."
For the families of those who lost their lives, the community in Avonmouth and the water industry more broadly, the wait for answers will hopefully come to an end when the HSE publishes its investigation later this year.

Issue 19:

Wheelwash facilities at farmyards are not indicated. Sight-Distance-Triangles for farmyard entrances were not included.

Issue 20:

The Retail Property Value of surrounding houses will be seriously affected. As a result of potential death from explosion; asphyxiation; high odour levels as at Ballybofey; health risks from noise & particulate matter in the flaring process; pollution of drinking water sources and the high level of vermin.
Who will purchase a house in the surrounding area?

ISSUE 21

Vermin – 6.4.7 Human Health (On-Site Receptors)- Exposure to disease due to Pests onsite
Rodents can be harmful since they may transfer viruses, micro-organisms, parasites etc. and may, therefore, represent an important factor for the spreading of various diseases. Control of rodents is a mandatory prerequisite for any waste management facility. Flies and birds can also pose a problem, where they are attracted to raw waste.
Due to the nature of wastes being accepted at the site, feral animals, flies and other vermin may be attracted to the site. Vermin maybe attracted to the facility in search of food sources. Pests such as rodents and flies can not only be a nuisance to users and neighbours, but they can also transfer germs and disease and affect the ecological balance of an area.
Sources of potential public health risks associated with vermin and other pest animals include:

- Transmission of disease.
- Threat to native flora and fauna.
- Threat to livestock.

The following Scientific Reports indicate the serious hazards from emissions for health issues & death from a Biogas plant close to existing houses.

Reference Number 22: Safety Precautions for Anaerobic Digestion Systems. UPDATED: 2020/12/18
Whether you are designing, constructing or operating a biogas plant, you need to identify health and safety risks and plan measures accordingly to either eliminate or mitigate them to make your facility as safe as possible. It is a crucial step to avoid injuries and deaths.

Frequently, however, human errors, equipment breakdowns or equipment misuse are the causes of accidents. Thus, accidents are often avoidable if you anticipate the risks or you plan rigorously your project.
The summary below identifies the major hazards associated with an AD facility, presents some necessary safety measures, shows schemas of an AD facility and gives a few examples of past accidents that occurred in the industry.

Biogas

The biogas produced by an anaerobic digestion plant is composed of combustible gases methane (50-75%), carbon dioxide (25-50%), water (H_2O), nitrogen (N_2), oxygen (O_2), hydrogen sulfide (H_2S), ammonia (NH_3), and trace elements (organo-halogenated, siloxanes, etc.). H_2S, CO_2, and water make the biogas very corrosive.
The composition can vary according to the nature of the incoming substrates and the operating conditions.

Properties of biogas

Name	Chemical Formula	Biogas Content
Methane	CH4	50 to 75%
Carbon Dioxide	CO2	25 to 45%
Hydrogen sulfide	S equivalent H2S	Raw Biogas: <20 000 ppm Upgraded Biogas: <100 ppm
Ammonia	NH3	<100 ppm
Nitrogen	N2	< 2%
Hydrogen	H2	< 1%
Carbon monoxide	CO	< 1000 ppm
Oxygen	O2	5 to 12% of air and <2% O2
Volatile organic compounds	COV	Low concentrations < 1% v/v
Water	H2O	Saturated (between 2 and 7%)

Reference Number 23: Source: Institut National de l'Environnement Industriel et des Risques (INERIS) – Translated

Biogas composition based on its source

Name	Chemical Formula	Household Waste	Sludge	Crop Residues	Industrial food waste
Methane	CH4	50-60%	60-75%	60-75%	68%
Carbon Dioxide	CO2	34-38%	19-33%	19-33%	26%
Nitrogen	N2	0-5%	0-1%	0-1%	-
Oxygen	O2	0-1%	< 0,5%	< 0,5%	-
Water	H2O	6% (at 40 °C)	6% (at 40 °C)	6% (at 40 °C)	6% (at 40 °C)
Hydrogen sulfide	H2S	70-650ppm	700-2900ppm	2100-7100ppm	290ppm
Ammonia	NH3	-	-	70-140ppm	-

Reference Number 24: Source: Institut National de l'Environnement Industriel et des Risques (INERIS) – Translated

Health & safety risks associated with a biogas plant

All the following risks are easily mitigated if health & safety are taken into account at all phases of a biogas project development. The risks include, for example:

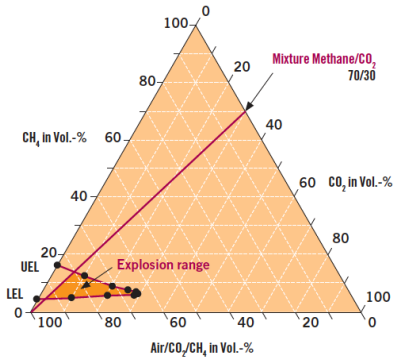
- Fire and explosion
- Confined space hazards
- Risk of Asphyxiation
- Risk of gas poisoning (H_2S, NH_3)
- Risk of high-pressure gas or liquid leaks
- Risks associated with rotating mechanical equipment
- Risks associated with pathogens (diseases)

Fire and explosion

Under certain conditions, biogas in combination with air can form an explosive gas mixture. The risk of fire and explosion is particularly high close to digesters and gas reservoirs. It can occur because of a gas leak, creation of an explosive zone, welding, clogged or frozen pipes or others.
To generate an explosive atmosphere, the following conditions are met simultaneously:

- Presence of a combustible gas: methane (CH_4)
- Presence of an oxidant: oxygen from the air
- Presence of an ignition source
- Concentration of the combustible gas included in its explosive range (LIE-LSE)
- Presence of a confinement.

Explosion triangle for biogas



Source: German Biogas Association
For a biogas composed of 60% methane and 40% carbon dioxide, the range of biogas concentrations in the air necessary to reach the explosive range is between 8.5 and 20.7.

Risk of asphyxiation

Biogas generation, transportation and flaring can lead to oxygen-deficient atmospheres. The biogas accumulation in a confined space can significantly reduce the level of oxygen (anoxia) and result in poisoning or asphyxiation symptoms, even death.
The minimum regulatory oxygen content is 19%. The asphyxiants that are typical constituents of biogas are carbon dioxide (CO_2) and methane (CH_4).

Chemical hazards

Due to their toxicological properties, ammonia, hydrogen sulphide or carbon dioxide expose operators to safety hazards. To reduce the risks, it is essential to maintain the threshold limit value (TLV).
Someone that is exposed to H_2S concentrations of over 50 parts per million can get serious injuries or die. Such concentrations also cause pipes or steel tanks corrosion or breakdowns of the biogas engine.

Occupational exposure limit values (OELs) of the main hazardous gases in biogas

Substance	OEL on 8 hours		Toxicological Sheet	Observations
	ppm	mg.m^{-3}		
Ammonia (NH^3)	10	7	FT 16	Compulsory regulatory limit value
Hydrogen Sulphide (H^2S)	5	7	FT 32	Compulsory regulatory limit value
Carbon dioxide (CO^2)	5000	9000	FT 238	Indicative regulatory limit value

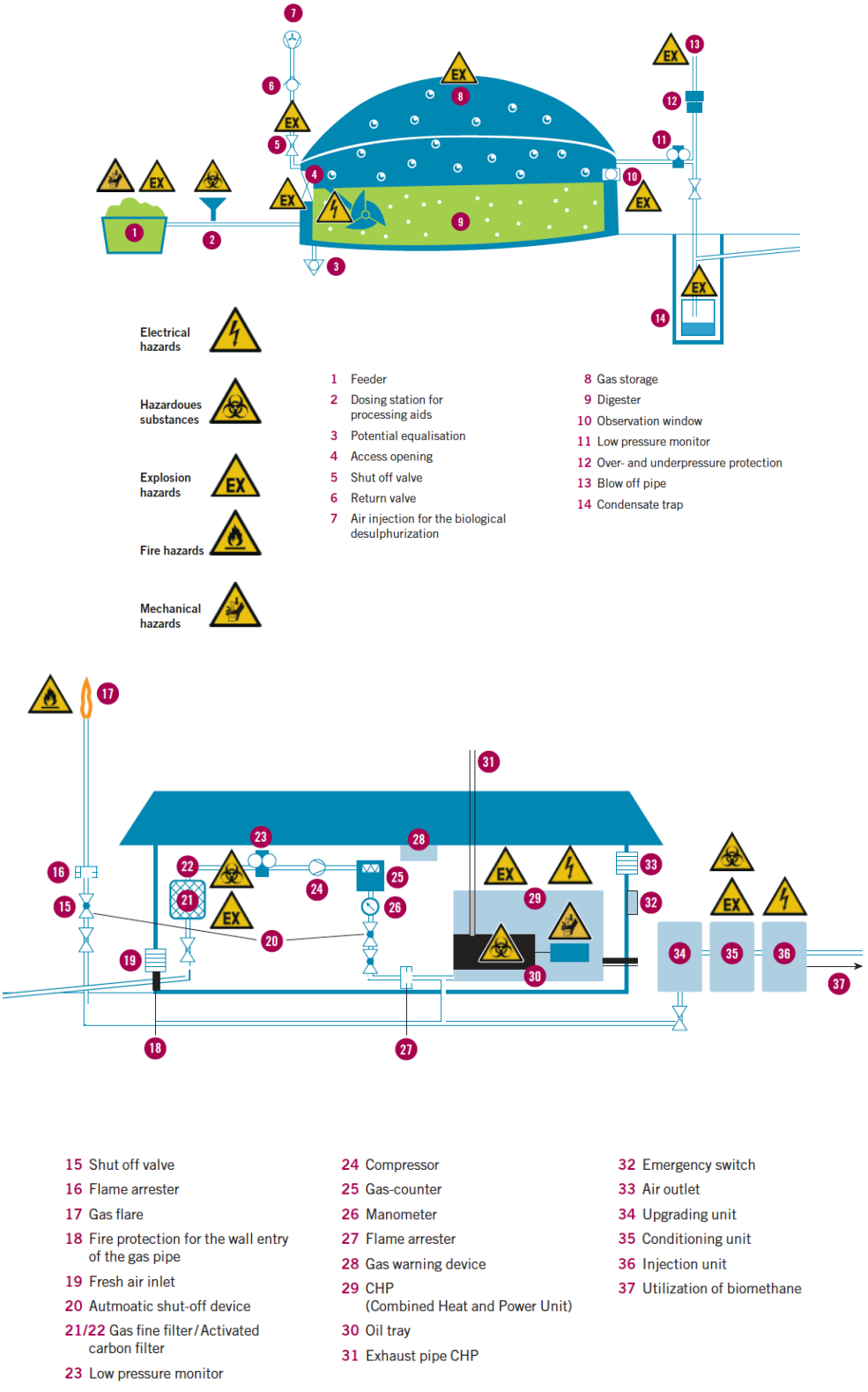
Reference Number 25: Source : Institut National de Recherche et de Sécurité (INRS) – Translated

High-pressure gas or liquid leaks

High-pressure gas or liquid leaks occur when pressure goes lower or high than normal in tanks. For example, a tank breakdown can cause a flooding of digestate on site. The digestate spreads on nearby lands if the flood is not contained on time.

Biological hazards (pathogens)

Wastes of animal and human origin, used as AD feedstock, contain various pathogenic bacteria, parasites and viruses. Pathogenic species that are regularly present in animal manures, slurries and household waste are bacteria (e.g. Salmonellae, Enterobacter, Clostridiae, Listeria), parasites (e.g. Ascaris, Trichostrangylidae, Coccidae), viruses and fungi. For example, a tank spilling into a slurry tank can create projections and aerosols containing microorganisms.
Overview of hazards in biogas plants



Reference Number 26: Source: German Biogas Association
Zones at risks of explosion

Equipement	ATEX Zone		Possible Failure
Digestor Post-digestor	Interior: gaseous sky	Zone 2	Air Introduction
	Outside: case of a flexible membrane	Zone 2: envelope of 3 m radius	Outside leak
	Outside: case of a hard cover	Zone 2: envelope of 3 m radius around the openings (porthole, man trouble, stirring passage...)	
Biogas storage tank	Interior	Zone 2	Air introduction
	Outside	Zone 2: envelope of 3 m radius	Outside leak
Valves of digestor/post-digestor/tanks	Spherical zones centered on the emission point	Zone 2 of 3m radius integrating a zone of 1 of 1m radius	Internal overpressure causing gas leak to the outside
Combustion unit	Interior of the combustion room	Not classified (see ventilation and detection)	Leak in the biogas supply
Buried condensate well	Interior: sky of the condensate well	Zone 2	Accumulation of gas
Digestate trench covered	Interior: gaseous sky	Zone 2	Accumulation of gas
Technical room	Interior	Not classified (see ventilation and detection)	

Reference Number 27: Source : Institut National de l'Environnement Industriel et des Risques (INERIS) – Translated

Safety precautions

General

- Use corrosion-resistant material to water or sulphur products
- Equipment should be designed not to let biogas in or out
- Electrical installations must comply with standards and regulations

Regarding the fire hazards:

- The constituent materials, in particular digesters or the combustion unit, must be non-combustible
- The installations must comply with the provisions of Article R4216 of the Labor Code: provide specific extinguishing systems inside the premises of the detection systems.
- Storage inside the premises must be avoided
- Petrolium products storage should respect the Decree as of July 1, 2014 setting up the technical rules and applicable security for storage of petroleum products

Digesters, post-digesters and biogas storage tanks

- Install a device to protect against risks of explosion
- Safety valve: digesters and biogas storage tanks must be equipped with safety devices (safety valves) that prevent excessive vacuum or overpressure
- Sluice gates: have 2 sluice gates for one digester in the case one of them breaks down. Moreover, there should be a possibility to lock one of the sluice gates manually
- Mixer: get a backup power supply.
- Biogas desulphurization through the injection of air
- Inside the digester or post-digester, air metering pump should be set so that the air flow does not exceed 8% of biogas volume produced at the same period
- Digester inlet piping should be equipped with a check valve that will prevent the biogas from flowing back.

Flares

The flares are necessary in risk control on a biogas plant. If there are problems or the plant is on start-up phase, the flares have to treat the biogas. The biogas cannot be sent in the atmosphere.

- Gas flares must be equipped with a flame arrester
- It must have a ventilation device

Condenser

- Make sure that during steam dump no biogas leaks outside

- Install detectors of high and low levels connected to the pump stop

Digestate storage tank

- If the tank is covered, it is important to ensure that it is sufficiently ventilated
- Install the detector of high level connected to the digestate supply.

Technical premises

Technical premises should be sufficiently ventilated.

Piping

Separate biogas and substrate piping. Biogas piping should be as well:

- Airtight and tested before first use
- Fluid, pressure and corrosion resistant
- Easily accessible and preferably placed on the surface
- Should consist of welded sections and not to go out of confined spaces, especially the premises
- Provide the slopes to evacuate the corrosive and condensate
- Piping holding the substate should be protected against freezing
- Security valves should be placed upstream of the installations intended for production, storage, treatment and use of biogas
- Systems that trigger security valves should be installed in easy-to-access places

How to minimize risks and ensure safety during every step of your biogas project?
The operator and the plant designer have to take certain measures at every step of a project. The goal is to ensure safety and minimize risks.

Plant design

This step is particularly important to ensure the safety of the biogas plant. The operator and the plant designer have to pay attention to:

- The norms, guidelines and all other codes that apply to biogas plants
- The classification of explosion zones, since the electric system installed on the biogas must be suited according to the risks of explosion
- Avoiding confined space
- Potential risks that can happen during the operation of the plant

Project construction

- Make sure to plan the project rigorously
- Hire an onsite expert to insure the workers apply the health and safety measures that are established

Biogas plant commissioning

Commissioning of a biogas plant can be the most dangerous step of a project.
Accidents that can happen include:

- Structural failure rarely happens when the tank is being filled or the high-pressure pipes are being tested
- Accidental hydraulic discharge during the pre-operation test of the pumps and valves
- Lack of calibration of the health and safety equipment
- Higher risks of explosion when the air inlets are opened and the air reach biogas

Biogas plant operation

During this step, a lot of accidents and incidents happen. To avoid them, the operator must:

- Train every operator of the plant for the work in confined space, portable gas detection, process and equipment use
- Apply strict procedures for equipment locking
- Regularly verify health and safety equipment to make sure they are calibrated and offer precise measurements
- Do a visual screening of all equipment to detect leaks and verify the state of equipment
- Make sure all workers apply health measures to avoid pathogen diseases
- Train all plant workers for basic firefighting skills and CPR

Examples of past accidents on biogas plants

In Europe, there were about 800 accidents on biogas plants between 2005 and 2015. Fortunately, less than a dozen of them had consequences on humans. Here are some examples.

Farm plant, Saint-Fargeau, France

In 2018, an explosion followed by a fire occurred at the level of the gasometer in the post-digestor of the farm plant in Saint-Fargeau, France. The accident happens during the initial test for the operation of the agitator when its propeller was replaced.

Consequences

- Breakdown of the gasometer
- Melting of the power cable of the agitators
- Sealing damage of the head veil

Causes

- Error made during the installation of the agitator
- Supporting system of the agitator is not connected to the ground
- Electric arc during the power interruption of the agitator, an ignition and flames source
- Non-efficient monitoring from certified organizations during the initial and periodic visits

Biogas plant of Rhadereistedt, Germany

In 2005, a large quantity of H_2S leaks in the charging hall of the biogas plant of Rhadereistedt, Germany. The workers don't follow the procedure to discharge the truck because of a breakdown of the lid covering the tank. The tank containing animal and dairy waste is left opened.

Consequences

- Death of the truck driver and of 3 other workers
- Injuries and hospitalization of another worker

Actions taken

- Apply safety measures to avoid the operation of the agitators when the lid of the tank is left opened
- Make new streams to avoid sending liquid digestate through the trench
- Optimize ventilation system
- Install gas detectors
- Avoid intermediate storage in the trench during the nights and weekends
- Avoid mixing materials
- Train workers

Complementary guidelines about risks and safety measures on anaerobic digestion plants

There is a number of guidelines on required safety measures for an anaerobic digestion plants. You can read them to get more information on this topic.

The document Safety rules for agricultural biogas plants (l'Institut national de l'environnement industriel et des risques de la France) (In French only) include information about the operation and maintenance of a biogas plant. It contains critical measures to prevent risks during the operation, reception, starting, testing and maintenance of biogas plants, to intervene in confined spaces, in the digestors, post-digestors and storage tanks.

Depending on your region, here are a few guides that you might find useful:

- United States: Safety Practices for On-Farm Anaerobic Digestion Systems (EPA)
- Germany: Safety Rules for Biogas Systems (German Agricultural Occupational Health and Safety Agency) and Biogas: Safety First (German Biogas Association)
- Quebec: Lignes directrices pour l'encadrement des activités de biométhanisation (Gouvernement of Quebec) (In French only)

Reference Number 28: Biogas impurities: environmental and health implications, removal technologies and future perspectives. Adhena Ayaliew Werkneh. Heliyon 8 (2022) e10929. Science Direct, Renewable and Sustainable Energy Reviews Volume 135, January 2021, 110225. www.cell.com/heliyon

The biogas impurities, for example, carbon dioxide and NOx, have different environmental impacts such as climate change that results in malnutrition, flooding, the spread of communicable diseases and other disasters. With respect to the public health point of view, for example, hydrogen sulphide, which is among the main contaminants of biogas, is characterized as heavier than air, highly toxic and flammable gas, while upon inhalation, it reacts with the biological enzymes within the blood stream and results in inhibiting cellular respiration to cause sudden collapse, pulmonary paralysis, and death (L_opez et al., 2012). The odour threshold limit of hydrogen sulphide is about 0.00047 ppmv (Aroca et al., 2007), whereas at higher concentrations of 200–300 ppm, the hydrogen sulphide may cause respiratory arrest that leads to unconsciousness (Syed et al., 2006). Due to the corrosive and toxic nature of hydrogen sulphide, sulphur dioxide emissions are caused by biogas use in combustion (Lopez et al., 2012). As it was described by Macor and Benato (2020a), biogas is on average 10 times more toxic than natural gas in terms of dioxins and furans toxicity, and exhausts three times more NOx emissions than the natural gas standard. SOx emissions contributed about 6% of the imposed biogas human health toxicity.

As a general overview, human health damage from biogas impurities has been imposed through regulated and unregulated emissions, where "the regulated emissions are substances that have regulatory limits for their maximum levels, while the unregulated emissions (which have higher toxicity impacts) are compounds without fixed regulatory limits" (Macor and Benato, 2020b). Those of the biogas impurities considered as regulated emissions are SOx, NOx, HCl, CO, VOCs, particulate matters, while the polycyclic aromatic hydrocarbons, furans, dioxins, and aldehydes are considered as unregulated emissions. Furthermore, SOx, NOx, and H2S are responsible for human health damage (Macor and Benato, 2020a, 2020b, 2021). The main challenges of the biogas impurities to human health are mainly due to the absence of a widely adopted and common emissions standard (e.g. at EU level) for both regulated and unregulated emissions. This is a point of concern for the stakeholders, as each country (mostly in developed nations) independently defines the impurities that need to be "tracked and their maximum levels", which is considered the most challenging (Macor and Benato, 2020a, 2020b).

Reference Number 29: Potential hazards posed by biogas plants. Katarzyna Stolecka, Andrzej Rusin. Renewable and Sustainable Energy Reviews Volume 135, January 2021, 110225. https://doi.org/10.1016/j.rser.2020.110225

The biogas production technologies are now highly developed, especially at the level of local biogas plants. Unfortunately, it has been impossible to avoid in-service fatal accidents. Therefore, the design and construction of new technological installations intended for biogas large-scale production have to take account of the plant safe operation. In the first place, this applies to the course of industrial processes and to potential failures that may occur in them due to the flammability and toxicity of biogas constituents. This paper is focused on the hazards that biogas poses to human health and life. It presents the hazard zones arising due to possible scenarios following a release of biogas from a biogas plant.

The failures and accidents that occurred in biogas plants in the past prove that total elimination of hazards in this sector is impossible. The example analyses of failures of typical elements of a biogas plant presented in the paper demonstrate possible hazardous scenarios following an uncontrolled release of biogas. The flammable constituents of biogas can contribute to the creation of a large zone posing fire or explosion hazards.

Reference Number 30: Quantitative analyses of biogas plant accidents in Europe.
Petr Trávníček, Luboš Kotek, Petr Junga, Tomáš Vítěz, Karel Drápela, Jan Chovanec. Renewable Energy Volume 122, July 2018, Pages 89-97

Rapid grow of biogas stations numbers across the Europe could be seen in recent past. This is also associated with an increase in the absolute number of operational accidents. In the opinion of experts who deal with safety engineering in the field of bioenergy installations, the number of accidents on biogas stations is growing faster than energy production from these stations. The aim of this paper is to open a discussion about interpretation and uncertainty of quantitative accidents assessment. For this purpose, 208 accidents of biogas stations were collected across Europe from 2006 to 2016. These data were statistically analysed.

Reference Number 31: MITIGATING TECHNICAL AND OPERATIONAL FAILURES IN THE DESIGN AND MAINTENANCE OF BIOGAS PLANTS. Silva Lozančić, Josip Radić, Držislav Vidaković, Marijana Hadzima-Nyarko. *15th International Conference on Industrial Engineering and Environmental Protection IIZS 2025 Technical Faculty "Mihajlo Pupin" Zrenjanin, October 2-3, 2025, Zrenjanin, Serbia*

CLASSIFYING COMMON SOURCES OF HAZARDS AND INCIDENTS IN BIOGAS PLANTS

Common sources of hazards in biogas plants

This chapter provides an overview of the main sources of hazards in biogas plants. The history of failures and accidents in biogas plants demonstrates that the total elimination of hazards in this sector is not feasible. However, it is possible to influence some of the hazards during the construction process itself, with examples of poorly executed works presented in Table 1.

Table 1. Common hazards in biogas plants: failures due to construction

Hazard	Failures due to construction	Consequences
Fire and explosion	Instability of the gas storage components, incorrect assembly of gas storage elements, unevenness on the concrete crown of the storage tank	
Biohazard	Improper and insufficiently executed protection and waterproofing of surfaces through which dangerous substances penetrate into the soil—floors and walls of the storage tank, fermenter (digester), lagoon	
Electric	Improper execution and protection of electrical installations, penetration of moisture and water into areas where the installations are located	
Mechanical	Improperly prepared foundation and installation for positioning mechanical equipment, as well as pipes that transport raw materials, gas, and digestate	

Although biogas production has significant environmental benefits, these facilities involve risks related to fires, explosions, and biological and mechanical hazards. These hazards will now be described, covering those that are possible during the exploitation of a biogas plant. For a better overview, Table 2 with the listed hazards, their causes, and mitigation techniques is provided.

Table 2. Sources of hazards in biogas plants, their contributing factors, and mitigation techniques Hazard	Contributing factors	Mitigation technique
Fire and explosion	The risk of a fire or explosion, exist when the concentration of methane in the air is within the range of 5% to 15%	Monitoring and control Ignition source control System design and maintenance
Biohazard	Presence of microorganisms, such as bacteria, viruses, fungi, and parasites, in the organic waste feedstock	Monitoring and control Hygiene standards Disinfection
Electric	Electrical equipment that is not properly installed or maintained	Regulations and standards Design and installation Maintenance
Mechanical	Frequent use of heavy gear and equipment with moving parts	Proper machine guarding Regular maintenance Adequate training

Biogas is a flammable gas that presents a fire and explosion risk if it encounters a spark or flame. Mixtures of air and methane pose a particular danger and can ignite at a methane concentration between 5% and 15%. Under ideal conditions, when the mixture is near its stoichiometric ratio, a powerful explosion can occur, making it crucial to monitor and manage gas concentration within the plant. Biohazards stem from the nature of the raw materials used, including manure, food waste, and sewage sludge. These materials can contain various microorganisms like bacteria, viruses, and fungi that can threaten workers' health, potentially causing gastrointestinal illnesses or skin and respiratory infections. To prevent these risks, it is essential to use appropriate personal protective equipment, adhere strictly to hygiene standards, and perform regular disinfection of equipment and work areas. Mechanical hazards at the plants are significant due to the use of heavy equipment and moving parts. Workers are at risk of crushing, entanglement, and amputation injuries. It is vital to carefully assess and mitigate these risks through proper machine guarding, regular maintenance and inspections, and providing adequate training for staff. Electrical hazards are present due to the extensive use of electrical equipment. Improper installation or maintenance can lead to electric shock or fire. Because of this, strict standards and regulations have been developed by international organizations and national governments. These regulations ensure the safe design, installation, operation, and maintenance of electrical systems, thereby protecting workers and the environment.

Common causes of incidents

Incidents in biogas plants, which can range in severity, are typically caused by a variety of factors. These can include human errors in operations and maintenance, equipment and component failures, and natural or technological disasters. The severity of these incidents, which can manifest as accidents, is determined by factors such as the type and location of the event, as well as the effectiveness of the existing safety measures. Accidents in the biogas sector are typically caused by equipment and component failures, design errors, and improper operation or maintenance. Across the broader bioenergy sector, a majority of accidents are a result of fires (53%) and explosions (40%), with a smaller percentage (7%) related to toxic releases.

As previously mentioned, accidents can be the result of a combination of various factors, including maintenance error, equipment failure, operational error, component failure, and natural disasters (Table 3).

Table 3. Common types of accidents and their descriptions Accident	Description
Maintenance error	Improperly inspecting or replacing equipment. Regular maintenance is essential for safe and efficient operation
Equipment failure	Leaks or malfunctions (electric and mechanical hazards), can occur, resulting in occurrences and injuries
Operational error	Misinterpreting data or failing to follow proper protocols can lead to significant causes of biogas plant occurrences
Component failure	Component failure is a common cause. Parts can fail due to normal wear and tear, corrosion, and fatigue
Natural occurrences	Natural occurrences such as floods, earthquakes can cause equipment damage or structural failures

Since biogas plants are a relatively new type of industrial facility, safety regulations for them have not been fully developed. Understanding the range of hazards and causes of accidents in biogas plants is essential for ensuring safety. It is also important to recognize that the unique variables of biogas facilities can make their occurrences distinct from

those in other industries. Therefore, further research is needed to overcome the challenges of data underreporting and to establish clearer causal relationships to continue to enhance safety protocols.
The construction and operation of a biogas plant is a highly complex process, requiring diverse expertise and facing an extremely aggressive operating environment that threatens material integrity. While biogas production offers significant environmental benefits, **the inherent nature of the process means the complete elimination of hazards is not feasible. Risks such as fire, explosion, biohazards, and mechanical/electrical failures are constantly present, often stemming from design flaws, equipment failure, or human error.**
Response from MLavelle: In the absence of understanding the range of hazards, the Precautionary Principle applies.

Although biogas plants are conceived as a smart and ecological way to manage waste and generate environmental profit, they can sometimes turn into the site of ecological and material disasters. The most crucial element throughout the entire process of plant construction and operation is the human factor. Project designers and contractors bear immense responsibility, as irregularities in execution can significantly contribute to poor operating outcomes.
To ensure both safety and long-term viability, a proactive strategy is essential. This includes careful analysis of system element placement during design to prevent cascade failures, employing effective mitigation techniques (like gas content monitoring and regular maintenance), and upgrading existing technological options. Furthermore, the successful implementation of biogas projects requires an integrated approach to managing the entire supply chain and logistics, alongside crucial investment in training programs for technicians and operators to ensure the availability of a skilled workforce for long-term success.
Response MLavelle: Basically, it is criminally negligent to place an industry with such risks in an active quarry restoration & recycling centre with blasting, seismic vibration, machinery, staff, drinking water, pollution & death for the nearby population.

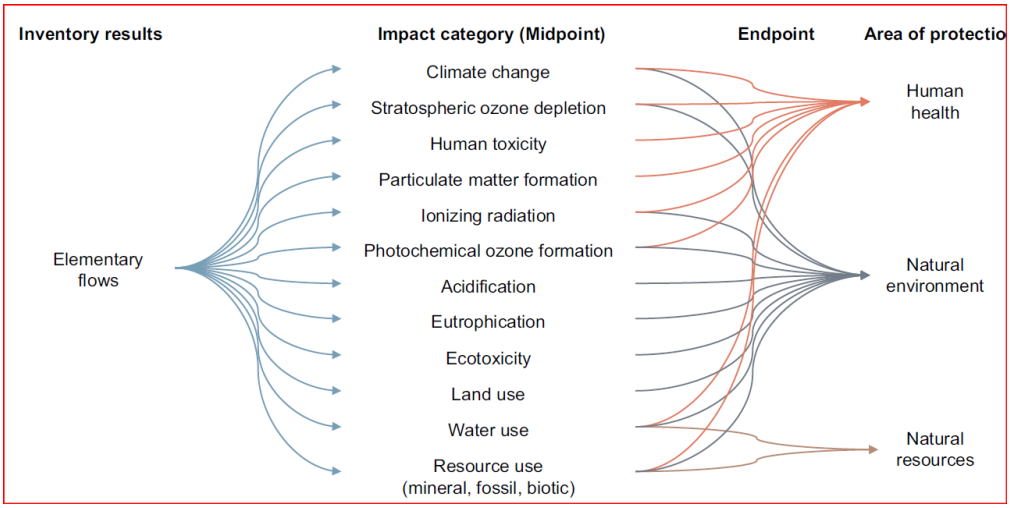
Reference Number 32: *Life cycle assessment of biogas production. Fabian Gievers, Meike Walz, Tobias Röther, and Matia Mainardis. DOI: https://doi.org/10.1016/B978-0-443-33679-9.00003-5 © 2026 Elsevier Ltd.*

Life cycle assessment standards
The international standards ISO 14040:2006 (ISO, 2006) and ISO 14044:2006 (ISO, 2006) describe the preparation of LCAs and thus form a basis for a comparable and standardized procedure for the evaluation of environmental impacts. The standardization of the LCA ensures that all studies are carried out according to uniform criteria, which is essential for the comparability and transparency of the results. This involves modelling the entire system from which products are created or in which processes and activities take place (Hauschild & Huijbregts, 2015).
In addition to the ISO standards, there are other instruments for assessing the environmental compatibility of biogas systems, depending on the topic and objective. These specific application guidelines, such as the as the European EN 16760 standard for bio-based products, the EU Renewable Energy Directive (RED), the framework of Environmental Product Declarations (EPD), the ILCD handbook, and the EU Product Environmental Footprint (PEF) guide are all based on the main features of the ISO standards.
Currently, the most widely used method for assessing the life cycle performance of biogas is the RED framework , as it is commonly used by biofuel producers in Europe for compliance reporting and the awarding of financial support that depends on meeting certain sustainability criteria (Brandão et al., 2022; van den Oever et al., 2021). This Directive sets out the rules for calculating greenhouse gas emissions, proposes default values and defines the objective and scope of the environmental assessment.

Standards and guidelines that apply to life cycle assessment in the context of biogas systems.

Standard/Regulation/Guideline	Abbreviation	Impact categories considered or recommended	Specific rules for biogas systems	References
ISO 14040:2006 Environmental management—Life cycle assessment—Principles and framework	ISO 14040 standard	No specification or guideline	No	ISO (2006)
ISO 14044:2006 Environmental management—Life cycle assessment—Requirements and guidelines	ISO 14044 standard	No specification or guideline	No	ISO (2006)
International Reference Life Cycle Data System (ILCD) handbook – General guide for life cycle assessment	ILCD handbook	No specification or guideline	No	European Commission (2010b)
European Renewable Energy Directive (RED)	RED	Only the greenhouse gas emissions (CO_2, CH_4, and N_2O)	Yes	European Parliament and Council (2018, 2023)
Environmental Product Declaration (EPD)	EPD	General Guidance based on PEF framework (EF 3.1)	No specific product category rule (PCR) for biogas systems. Only allocation rules based on certified biogas volumes.	EPD (2024)
Product Environmental Footprint (PEF)	PEF	Addressing 16 impact categories	No specific product category rule (PCR) for biogas systems	European Commission (2012, 2021)
EN 16760:2015 Bio-based products – Life cycle assessment	EN 16760 standard	General Guidance	No. Only general guidance for handling biogenic carbon	EN (2015)

Response from MLavelle: The Application does not indicate compliance with these Standards.



Framework of the international reference life cycle data system linking elementary flows from the inventory results to the impact results at midpoint level and endpoint levels. Adapted from JRC European Commission. (2010). International Reference Life Cycle Data System (ILCD) Handbook: Framework and requirements for life cycle impact assessment models and indicators. Publications Office. https://eplca.jrc.ec.europa.eu/uploads/ILCD-Handbook-LCIA-Framework-Requirements-ONLINE-March-2010-ISBN-fin-v1.0-EN.pdf.

Cultivation of biomass

When cultivating biomass, field work comprises a range of activities that also have a significant environmental impact (Bacenetti et al., 2016). These include soil preparation, sowing, crop care, and harvesting (Rana et al., 2016). Soil preparation and sowing require the use of machinery that burns fossil fuels, and therefore emits greenhouse gas and other pollutants. Intensive tillage can also lead to the release of soil carbon into the atmosphere as CO_2.

Other direct emissions include the release of chemicals into the environment, which can harm nontarget organisms and contribute to soil and water contamination (Birkved & Hauschild, 2006).

The use of arable land for energy crops generally leads to a change in land use. This could lead to deforestation or conversion of natural habitats, and have an impact on biodiversity and carbon stocks, not only where the land was converted, but possibly also on other areas worldwide (De Baan et al., 2013; Warner et al., 2013). In addition to the effects of the change in land use, another variable and influencing factor regarding the environmental impacts of biomass cultivation is the type of crop, the crop rotation, and its yield efficiency for the evaluated conditions (Ingrao et al., 2019; Nilsson et al., 2024). The increased use of biomass to produce biogas may require the use of valuable arable

land and therefore compete with food production, and thus have a negative impact on regional biodiversity (Ingrao et al., 2019). However, depending on the distance and the choice of transportation, the delivery of the biomass also plays an important role in the overall emissions from biogas production chains (Muradin & Kulczycka, 2020).

Process technology

The technology used in biogas production (e.g., anaerobic digestion regimes such as mesophilic or thermophilic temperature, pretreatment processes) affects the energy yields of the biogas, the efficiency of the whole process chain, and therefore the overall environmental impact.

How emissions, especially methane slippage (unburned methane emissions), are managed plays a significant role. Methane is a potent greenhouse gas, and its management is critical for environmental sustainability. Methane leakage from the biogas production supply chain not only contributes to increased greenhouse gas emissions into the atmosphere but also affects the overall efficiency of the biogas system. Typical methane leakage is reported to be in the range of 1.7 to 5.2% (Wechselberger et al., 2023).

Moreover, they concluded that biogas plants with lower gas production emitted a larger proportion of their production compared to larger plants, which can be partly explained by the absence of gas collection from digestate storage normally observed in smaller plants. Therefore, the effect of methane leakage can be a main contributor to the global warming potential (GWP) of biogas systems (Li et al., 2021). Besides the GWP, freshwater eutrophication is also an environmental burden of biogas systems caused by the electricity consumption of the digesters (van den Oever et al., 2021).

Reference Number 33: Biogas plants accidents: Analyzing occurrence, severity, and associations between 1990 and 2023. Hala Hegazy, Noori M. Cata Saady, Faisal Khan, Sohrab Zendehboudi, Talib M. Albayati. Safety Science 177 (2024) 106597. www.elsevier.com/locate/safety

Safety standards of typical biogas plants.

Safety Standard	Description	Reference
ISO 14,001	Environmental Management Systems	(Standardization, 2015)
OSHA 29 CFR 1910.119	Process Safety Management	(Administration, 2013)
NFPA 820	Standard for Fire Protection in Wastewater Treatment and Biogas Plants	(Association, 2021)
IEC 60,079	Explosive Atmospheres – Equipment and Protection Systems	(Commission, 2020)
ASME B31.3	Process Piping Code	(Engineers, 2019)
ATEX Directive 2014/34/EU	Equipment for Use in Potentially Explosive Atmospheres	(ATEX, 2014)
ANSI/ASSE Z244.1	Control of Hazardous Energy (Lockout/Tagout)	(Administration, 2018b; Institute, 2017)
API 521	Pressure-relieving and De-pressuring Systems	(Institute, 2014)
IEC 61,508	Functional Safety of Electrical/ Electronic/Programmable Electronic Safety-related Systems	(Commission, 2010)
IEC 61,511	Functional Safety – Safety Instrumented Systems for the Process Industry	(Commission, 2003)

Fire and explosion hazards

Biogas is flammable and can ignite in the presence of a spark or flame, creating a fire or explosion hazard (Europa, 2014; Rusín J., 2022). Fig. 3 presents the signages used for fire and explosion hazards. hazardous conditions develop when a significant quantity of air is coupled with methane concentrations between 5% and 15% (Scarponi et al., 2015). An explosion is one of the most dangerous possibilities in biogas facilities. It can be triggered by igniting combustible gases, such as methane and hydrogen, created during anaerobic digestion. Poor ventilation, equipment failure, and human mistakes can increase the explosive potential of these gases.

Biohazard

Biogas plants convert organic waste into renewable biofuel and energy. Yet, using these wastes can pose severe risks to those operating and maintaining biogas plants. Biohazard is frequently observed in biogas plants. According to the United States Occupational Safety and Health Administration (OSHA), biohazards are biological substances or agents

that can endanger human health. Many microorganisms, including bacteria, viruses, fungi, and parasites, can be found in the feedstock of biogas plants, including animal manure, food waste, and sewage sludge. If not managed properly, these microorganisms can result in gastrointestinal illnesses and skin and respiratory infections (Abuhena et al., 2022; Scarponi et al., 2015). Moreover, the environment at a biogas plant may support the growth of harmful microbes, raising the risk of illness.

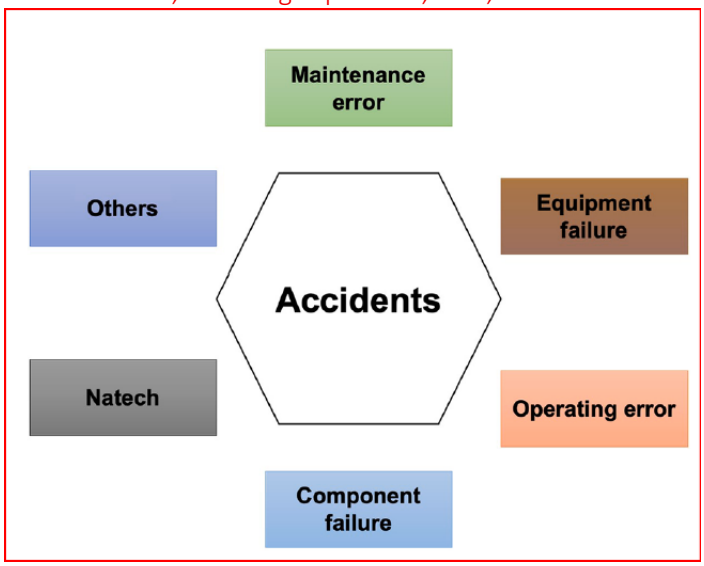
Toxic release (biohazard) is another critical situation that might occur in biogas facilities. Anaerobic digestion processes produce toxic gases (biohazard), such as hydrogen sulfide and ammonia, seriously threatening employees and the environment. Exposure to these gases can result in significant health consequences such as respiratory distress, nausea, and even death. When workers at biogas plants are exposed to a lack of oxygen, they may suffer from asphyxia (biohazard). This can be caused by oxygen displacement by other gases generated during the anaerobic digestion, such as methane and carbon dioxide.

Mechanical hazard

In biogas plants, mechanical risks are substantial. Heavy gear and equipment are frequently used in biogas plants to manage the feedstock, mix, and pump. Workers using such equipment could be seriously endangered by crushing, entanglement, and amputation injuries. Other mechanical risks are that workers may encounter falling objects, moving parts (augers, shafts, bearings, and cranes), and high-pressure systems (Energypedia, 2010; Teodourita et al., 2008).

Electric hazard

Biogas plants use electrical equipment, posing a risk of electric shock or fire if not properly installed and maintained (Agency, 2020; Akbulut et al., 2021). Therefore, electric hazards are a significant concern in biogas facilities. Malfunctions (electric and mechanical hazard) can arise in biogas plants due to equipment failure or human error. Malfunctions can result in various situations, including explosions, fires, and toxic releases (biohazard).



Common causes of occurrences in biogas plants

Common causes of occurrences in biogas plants.

Occurrence common cause	Description
Maintenance error	Biogas plants require regular maintenance to operate safely and efficiently. However, maintenance problems such as forgetting to examine or replace equipment properly might occur. Maintenance errors are a key factor in biogas plant occurrences (Hewitt et al., 2022).
Component failure	Biogas plants use components such as valves, pipes, sensors, controllers, and other parts to transport and process feedstock, biogas, and byproducts. Wear and tear, corrosion, fatigue, and other factors may cause these components to fail. Component failure is a common cause of occurrences in biogas plants (Cheng et al., 2014).
Operational error	Biogas plants are sophisticated systems that require trained operators to operate efficiently. However, operational errors such as misinterpreting data or failing to follow protocols can occur. Operational mistakes are a significant cause of biogas plant occurrences (Hewitt et al., 2022).
NaTech	Natural calamities such as floods, earthquakes, and storms can cause mishaps in biogas plants, according to NaTech. These occurrences can cause equipment damage or structural failures, resulting in occurrences and injuries. Natural-technological (NaTech) occurrences are a significant risk factor for biogas plant occurrences (Travnicek et al., 2019).
Equipment failure	Biogas plants employ a variety of equipment, including digesters, pumps, and gas storage tanks. Equipment failures, such as leaks or malfunctions (electric and mechanical hazards), can occur, resulting in occurrences and injuries. Equipment failure is a significant cause of occurrences in biogas plants (Wang, 2019b; Cheng et al., 2014).
No PPE	PPE such as gloves, helmets, and respirators can shield employees from hazardous materials or equipment. Failure to utilize PPE can raise the chance of an accident. The lack of PPE is a common contributing factor in biogas plant occurrences (Khattak et al., 2021).

NaTech = Natural-technological; PPE = Personal protection equipment.

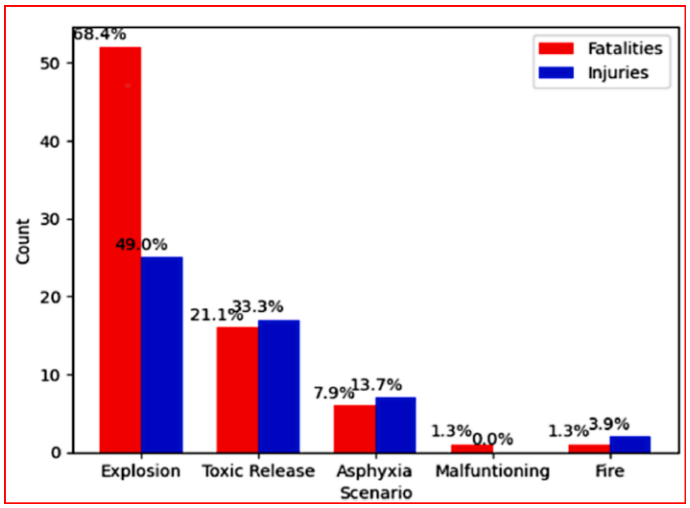
Case study on severity.

An example of how serious an occurrence in biogas plants could be is the catastrophic disaster that occurred on August 17, 2020, in Chateau lin, Finistere, France, when a digester at a biogas facility spilled, releasing a substantial volume (400 m3) of digestate into the nearby River AULNE. The leak caused a severe environmental crisis, polluted the river, and significantly threatened aquatic life and the local ecosystem (Mignaux, 2021). The occurrence was reported to the French Ministry of Ecology, which sent a team of experts to examine the damage and perform an emergency reaction. The long-term implications of the digestate leak on the River AULNE's environment are unknown, as it can take years for a river ecosystem to recover from a spill of this magnitude. The spill, however, is likely to have had long-term effects on the river's water quality, aquatic life, and general environment (Analysis, 2020). Digestate is a nutrient-rich material that, when released in a large mass to a water body, can significantly alter the chemical composition of water. The spill undoubtedly decreased the oxygen levels significantly, causing detrimental effects on the fish and other aquatic organisms inhabiting the river. Furthermore, the digestate's high nitrogen content could have caused an overpopulation of algae and other plant life, affecting the river's ecosystem even more. The ammonia nitrogen pollution that caused aquatic mortality seriously affected the nearby community. The pollution was severe enough to force the closure of a drinking water intake, resulting in a prefectural ordinance prohibiting drinking water use in 50 villages, affecting around 180,000 people. The facility had to remain operational to maintain water pressure, worsening the problem (Mignaux, 2021). Swimming and seaside fishing were forbidden, and drinking water intake was closed due to water safety concerns. Fishing is a vital source of income and enjoyment for many people in the area. Therefore, these restrictions substantially impacted the local population and tourism operators. Mitigation measures were implemented to contain and remove the contaminated material, and ongoing monitoring of the river's water quality and ecosystem is expected to continue in the coming years to assess the spill's long-term effects and ensure that appropriate measures are implemented to restore the river to its natural state (Analysis, 2020; Mignaux, 2021).

Fatalities and injuries

The number of fatalities and injuries caused by each scenario is indicated by a bar on the graph below, along with the percentage of total fatalities caused by each scenario. The number of people killed by explosions is (53) > toxic

releases (biohazard) (17) > asphyxia (biohazard) (7) > fire (2). Malfunctioning (electric and mechanical hazard) did not result in any fatalities. The ranking of scenarios in terms of the percentage of the total number of deaths is explosions (49%) > toxic release (biohazard) (33.3%) > asphyxia (biohazard) (13.7%) > fire (3.9%) > malfunctioning (0%). Explosions caused the most injuries (52). The ranking of causes of injuries is explosions (68.4%) > toxic release (biohazard) (21.1%) > asphyxia (biohazard) (7.9%) > fire (1.3%). It is crucial to highlight that injuries caused by various events might range in severity and influence individuals and the environment.



Fatalities and injuries by scenario.

Reference Number 34: Risk Assessment of Biogas Production from Sugarcane Vinasse: Does the Anaerobic Bioreactor Configuration Affect the Hazards? Rogeri, R.C.; Stolecka-Antczak, K.; Maradini, P.d.S.; Camiloti, P.R.; Rusin, A.; Fuess, L.T. Biomass 2025, 5, 79. https://doi.org/10.3390/ biomass5040079

Anaerobic digestion of sugarcane vinasse is integral to enhancing ethanol distilleries' environmental and energy performance by converting organic waste into biogas; however, the flammable and toxic nature of biogas has led to significant safety concerns, particularly in anaerobic bioreactors where biogas is produced and stored. This study provides a comparative risk assessment of different anaerobic reactor configurations—a covered lagoon biodigester (CLB), a continuous stirred-tank reactor (CSTR), an upflow anaerobic sludge blanket reactor (UASB), and an anaerobic structured-bed reactor (AnSTBR)—processing vinasse, focusing on fire, explosion, and hydrogen sulfide (H_2S) toxicity hazards. Jet fire scenarios posed the most severe threat, with fatal outcomes extending up to 66 m, while the fireball scenario exhibited no lethal range. The risks to human life from explosions were minimal (1.2%). H_2S toxicity was identified as the most critical consequence, with particularly severe impacts in CLB systems, where the hazardous zone was up to 20 times larger than in AnSTBR. Therefore, the design of anaerobic bioreactors for vinasse treatment must primarily address the risks associated with H_2S-rich biogas, as reactor configuration plays a key role in mitigating or amplifying these hazards—high-rate systems such as AnSTBR and UASB demonstrating safer profiles due to their compact design and lower gas storage volumes.

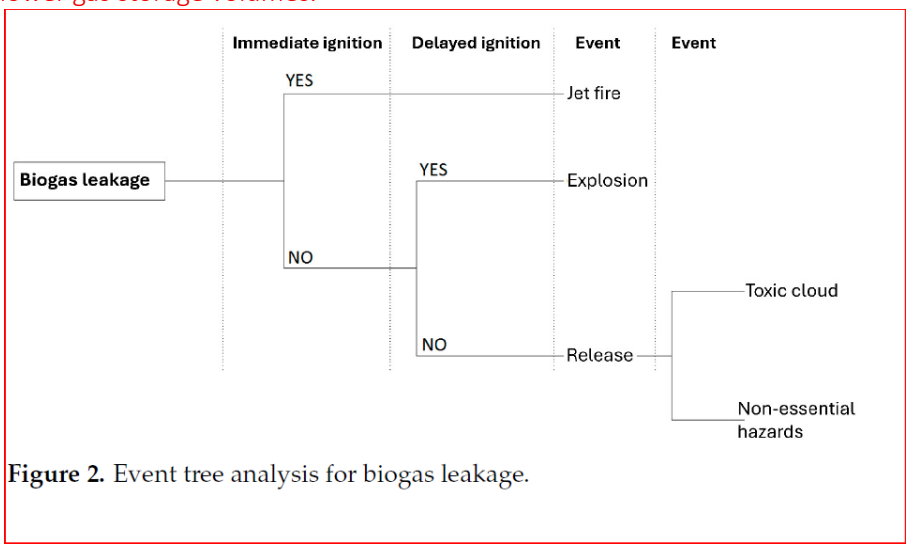
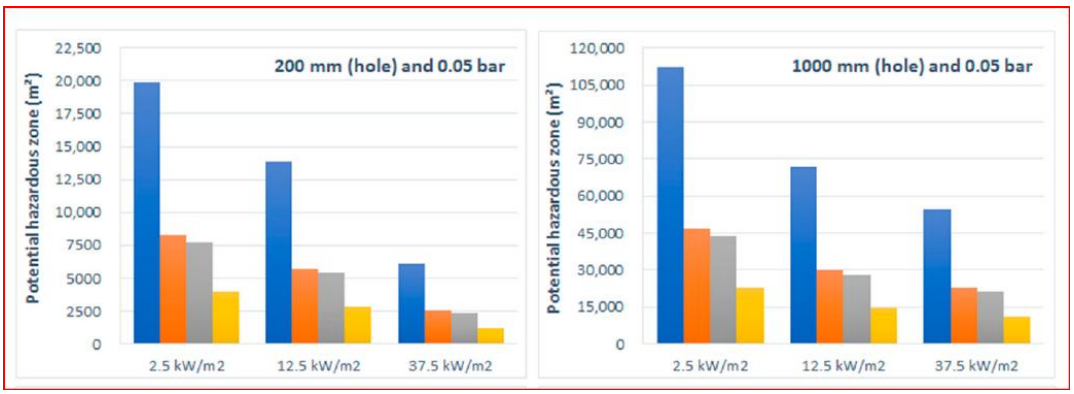
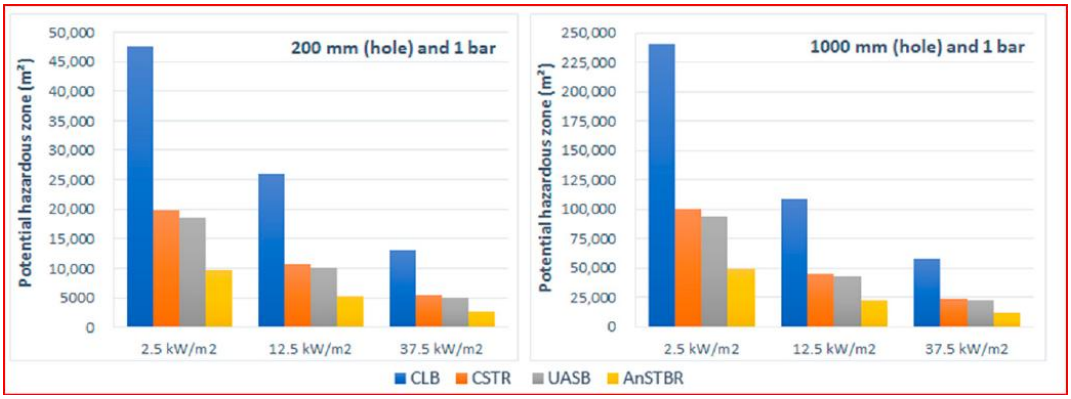


Figure 2. Event tree analysis for biogas leakage.

Beyond technological implications, the composition of biogas poses critical safety risks. The bioenergy sector (i.e., ethanol, biodiesel, biomass, and biogas) records the highest number of accidents resulting in severe injuries and fatalities in biogas facilities.

Quantitative analyses reveal that accident rates in Europe have grown faster than the sector itself In these risk assessments, the "critical event" are biogas leakages, which may lead to explosive mixtures when CH_4 is released into the atmosphere in the presence of air and potential ignition sources. For biogas composed of 60% CH_4 and 40% CO_2, explosive atmospheres may form at concentrations between 8.5% and 20.7% of the mixture in air.
In turn, H_2S poses severe risks to human health, even at relatively low concentrations. High-level exposure can lead to olfactory paralysis, respiratory failure, and death. H_2S is the second leading cause of inhalation-related fatalities after carbon monoxide, and lethal concentrations are reported at approximately 300 ppm. Quantitative studies confirm that intoxication by H_2S is one of the main causes of death in accidents in biogas plants. Even moderate exposures can trigger acute symptoms such as headaches, dizziness, and eye irritation, underscoring the need for strict monitoring.
The critical unit in biogas plants is the anaerobic reactor due to the high concentration of biogas produced and stored. Moreover, in a quantitative study almost all accidents occurred in anaerobic reactors integrated with or without gasholders.
The safety assessment of anaerobic digestion systems involves analyzing two main accident scenarios to evaluate the consequences of uncontrolled biogas releases. **The first scenario focuses on the partial rupture of the bioreactor, leading to biogas leakage through openings of different sizes and pressures, and subsequent hazardous events such as fire, explosion, or toxic exposure. The second scenario represents a more critical condition characterized by the total structural failure of the bioreactor and the complete release of stored biogas to the atmosphere**. By comparing both scenarios, the analysis aims to identify how variations in leak size and operating pressure influence the magnitude of hazardous zones and potential risks to workers, providing key insights for preventive design and emergency planning.
The identification of hazardous event scenarios was based on previous research that applied event tree analysis (ETA) and identified the uncontrolled biogas leak as a critical event. Figure 2 summarizes all hazardous events that follow the biogas leakage from a partial rupture condition, like immediate ignition (jet fire), delayed ignition (explosion), or no ignition (H_2S intoxication). In this study, a 200 mm rupture was selected as a conventional reference diameter widely used in risk assessment methodologies, whereas a 1000 mm tear was included to represent more severe, yet realistic membrane failures reported by operators of covered lagoons. Similarly, the pressures of 0.05 bar and 1 bar correspond to typical operating conditions and an abnormal overpressure scenario, enabling a broader evaluation of potential accident consequences.
Hazards in biogas plants are significantly related to the geometry of the plant, the parameters of its operation, and the composition of the biogas produced, i.e., the content of flammable and/or toxic compounds. Fires caused by biogas ignition can occur in the form of a jet fire in the case of partial rupture. A jet fire occurs when biogas released from a pressurized source is ignited close to the source of the release. This type of fire is characterized by a long and stable flame. Each of the fires has negative effects on humans and the environment related to the direct impact of the flame and the generated heat flux. For example, the lower values of this heat flux at 2.5 kW m−2 cause human pain and the breaking of glass after a sufficiently long period of exposure. Higher values at 12.5–15 kW m−2 cause first-degree burns and melting of plastics. In turn, values at 25 kW m−2 cause significant injuries, and values above 37.5 kW m−2 can result in human deaths.





The probability of death resulting from various types of fires is shown in Figure 5 in the case of partial rupture (i.e., jet fire), because the fireball did not generate a level of heat flux capable of causing human death. A 100 probability of human death was noted for both analyzed levels of biogas pressure and the larger hole size (1000 mm) in the event of a biogas jet fire. The range of areas associated with 100% human deaths will be approximately 32 and 65 m for 0.5 and 1 bar, respectively. In the case of lower pressure and a smaller diameter of damage (200 mm), the probability of human death will be no more than approximately 55% and will extend to a range of about 5 m. In the case of higher pressure, the probability will be about 90% and will extend to a range of about 16 m.

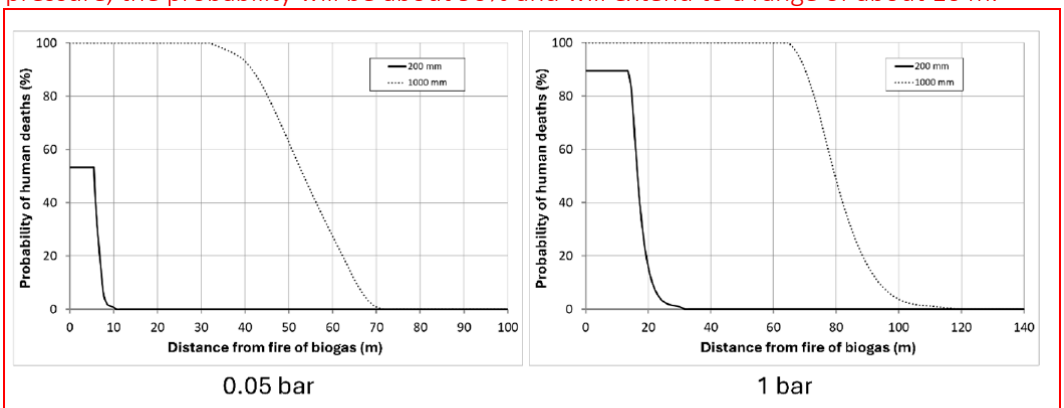


Figure 5. Probability of human deaths caused by a heat flux from jet fire.

An explosion is another type of hazard associated with the flammable properties of biogas components. Under favorable conditions, it may be a consequence of the biogas installation's partial or complete failure. The negative effects of this phenomenon are generated overpressure and flying debris from the ruptured installation. For example, overpressure of 0.21 kPa causes large glass windows to crack, 4.8 kPa damages building construction, and 20.7 kPa causes minor damage to heavy machinery and equipment. Higher values of the overpressure generated by the explosion, i.e., at 99.9 kPa, 137.8 kPa, and 199.8 kPa, result in 1%, 50%, and 99% human fatalities from lung damage, respectively.

Similarly to the fireball scenario, no Hazardous Zone or Hazardous Range were associated with a pressure wave causing the death of humans in the complete rupture explosion simulations. Nonetheless, the range covered by the pressure wave of 4.8 kPa (damage to building construction) and 20.7 kPa (damage to heavy machinery and equipment) was considerably greater than the consequences caused by the partial rupture pressure wave or even the consequences of the fireball. In this case, considerable monetary loss and impact on buildings in the vicinity can occur as a consequence of a complete rupture and the following explosion. In this scenario, the Hazardous Zone and Hazardous Range were also affected by the reactor size and resulting biogas stored in the headspace. The 4.8 kPa pressure wave covered an area of up to **2.4 million m² and 877 m** range under 1 bar of pressure and **1.57 million m² and a 708 m** range under 0.05 bar of pressure for CLB technology. Conversely, for the high-rate AD bioreactors (UASB and AnSTBR), the consequences of the pressure wave were 11- and 3.5-fold lower for Hazardous Zone and Hazardous Range, respectively.

The probability of death as a consequence of partial or complete rupture followed by an explosion and pressure wave was very low for all conditions (1.2%). However, the distance from the bioreactor associated with this death risk increased, along with the hole size (partial rupture) and the volume of biogas stored in the different technologies (complete rupture). The overpressure scenario (from 0.05 to 1 bar) did not significantly impact these distances, unlike in the jet fire scenarios. On the other hand, unlike a fireball, despite the low probability, a complete rupture explosion can result in human death.

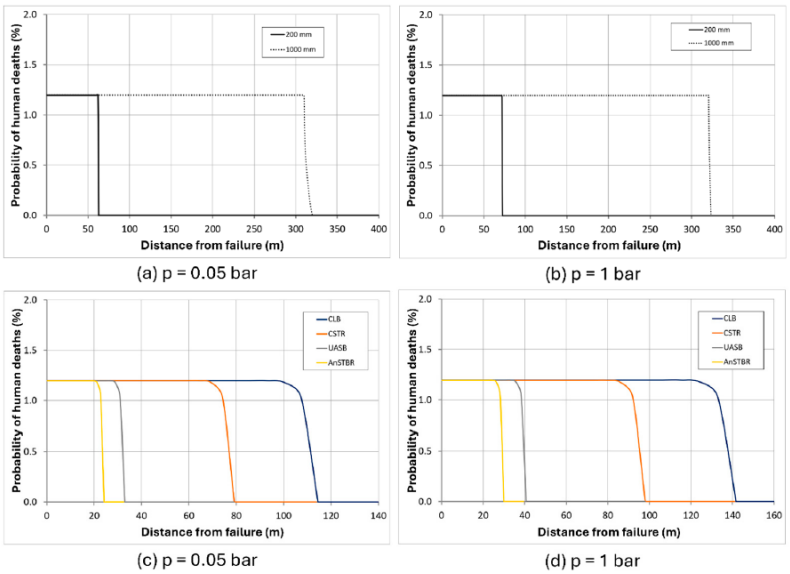


Figure 8. Probability of human deaths resulting from an explosion of biogas. Partial rupture (**a**,**b**), complete rupture (**c**,**d**).

Intoxication by H_2S is one of the main causes of death in accidents in biogas plants. There is no report in the literature that evaluates the impacts of the high H_2S concentration usually found in the biogas evolved from vinasse on the health and safety of workers and operators of sugarcane vinasse biogas plants. H_2S is extremely toxic: concentrations of 20–50 ppm can cause eye irritation (conjunctivitis) and lung irritation; concentrations of 150–200 ppm can affect one's sense of smell and severely irritate the eyes and lungs; 500 ppm may cause sudden loss of consciousness ('syncope'); and concentrations above 1000 ppm are fatal. Among the potential hazards presented in biogas plants in the partial rupture scenarios, H_2S intoxication presented a higher Hazardous Range (Table 4) and Hazardous Zone (Figure 9) with risk of death.

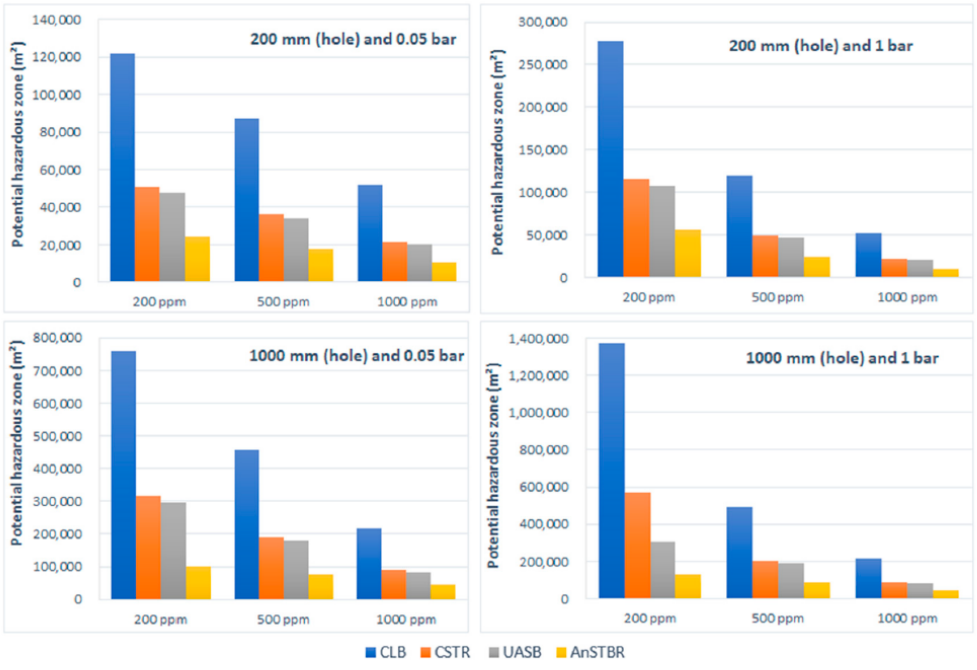


Figure 9. Potential hazardous zones for H_2S intoxication (partial rupture).

H_2S intoxication was also associated with a larger hazardous zone, with a risk of death reported to be among the consequences of a complete rupture scenario, according to the evaluation performed in this study.
The 'death Hazardous Range'(1000 ppm) increased up to 20-fold from the smaller (AnSTBR) to the bigger (CLB) reactor at both pressures tested. The death Hazardous Zone was up to 753 and **14,963 m²** for the AnSTBR and CLB reactors, respectively, under 0.05 bar of pressure. Meanwhile, the death Hazardous Zone increased to 2420 and **51,336 m²** for the AnSTBR and CLB reactors, respectively, along with the increased pressure (1.0 bar). It is worth highlighting the impact that the H_2S concentration could have on the vicinity of the biogas plant in the case of a complete rupture. The

lower concentrations considered in the simulations (200–500 ppm) can still be significantly hazardous to human life. A range of up to 1.7 km was achieved in the case of a complete rupture of a CLB under 1 bar of pressure. Meanwhile, the range of the high-rate AD reactors in the same condition was between 148 and 248 m for UASB and AnSTBR.

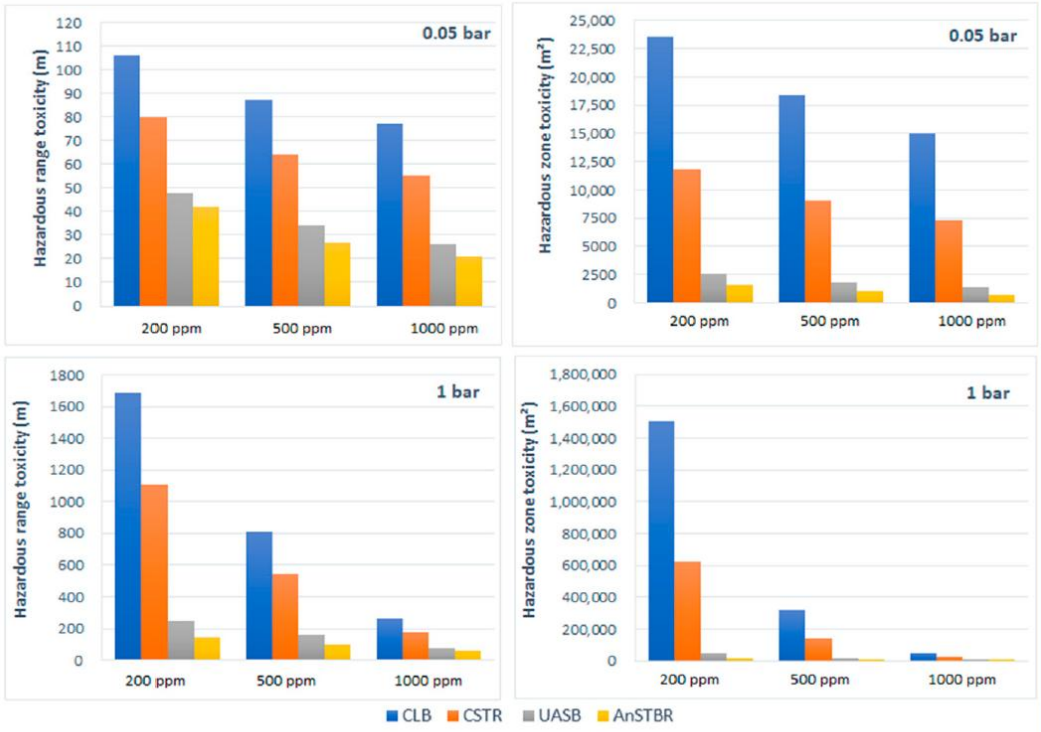


Figure 10. Hazardous zone and range for H_2S intoxication (complete rupture).

The probability of human death as a consequence of a partial and complete rupture followed by a toxic cloud of H_2S at the sugarcane vinasse biogas site is extremely high and is impacted by the hole size (Figure 11a,b) and reactor configuration (Figure 11b,c), respectively. For the partial rupture scenarios, the overpressure scenario tested (from 0.05 to 1 bar) did not impact the probability of death as a function of the distance from the reactor either, but the hole size increased significantly. The range of the hazard zone related to a 100% probability of human deaths increased from 20 to 80malong with the hole sizes (200 to 1000 mm; Figure 11a,b). Though no differences in the death zone ranges among the reactor technologies are presented for partial rupture scenarios (Table 4; 1000 ppm), the specific construction of the equipment can make each reactor configuration more susceptible to smaller or larger holes in the case of an uncontrolled biogas leak. In CLB technology, a plastic or HDPE covering is fixed on the sides of the lagoon, which is often inadequate and results in uncontrolled biogas leakage resulting in greater susceptibility to larger holes in the cover fixation areas. For the complete rupture simulations, the high-rate AD. bioreactors, i.e., UASB and AnSTBR, presented a 100% probability of human death within the 15–20 m range (0.05–1.0 bar; Figure 11c,d). Therefore, the complete rupture scenario of a high-rate AD bioreactor resulted in a death zone similar to a biogas leakage from a 200 mm hole size (Figure 9). On the other hand, the bigger bioreactor and biogas volume stored (CLB) showed a 100% probability of human deaths within the 60–80 m range (0.05–1.0 bar; Figure 11c,d) or 4-fold higher than the UASB and AnSTBR.

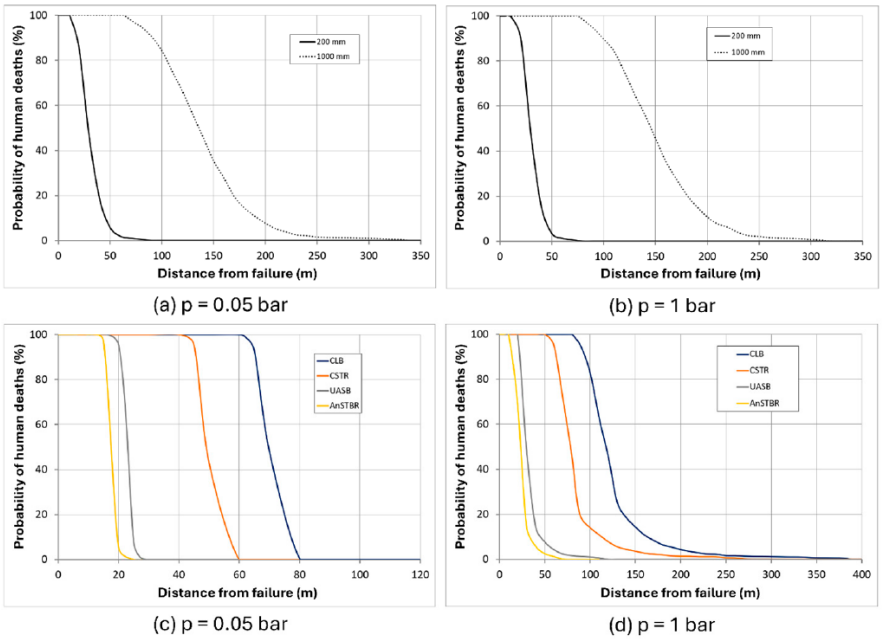


Figure 11. Probability of human deaths from a toxic concentration of biogas. Partial rupture (**a**,**b**), complete rupture (**c**,**d**).

Response from MLavelle: Some of the existing neighbours to the proposed Biogas plant are within these distances & as shown above & are exposed to 100% probability of death from a toxic concentration of biogas.

Reference Number 35: *Safety Practices for On-Farm Anaerobic Digestion Systems. USEPA. Office of Air and Radiation Code 62071, 2011*

2.3 HAZARDS ASSOCIATED WITH BIOGAS

AD biogas is composed of three main constituents: methane, hydrogen sulfide, and carbon dioxide. Each of these gases can be dangerous under certain circumstances. Common hazards associated with biogas include asphyxiation and fire or explosion potential.

2.3.1 Asphyxiants

Gases that prevent the uptake of oxygen into human cells are referred to as asphyxiants. There are two categories of asphyxiants: simple and chemical. A simple asphyxiant displaces oxygen, and chemical asphyxiants "reduce the body's ability to absorb, transport, or utilize inhaled oxygen. Asphyxiants are often active at very low concentrations (a few ppm)" (Lawrence Berkeley National Laboratory, 2008). Asphyxiant gases are present wherever there is storage of an organic material; therefore, manure pits or any other areas for organic material storage become potentially dangerous. Following are the various asphyxiants that are typical constituents of biogas.

- Simple asphyxiants – carbon dioxide and methane
- Chemical asphyxiants – ammonia and hydrogen sulfide

2.3.2 Immediately dangerous to life and health

Within confined spaces and other covered areas, the potential exists for atmospheric concentrations to develop that become immediately dangerous to life and health (IDLH). An IDLH condition can be defined as an atmospheric concentration of any toxic, corrosive, or asphyxiant substance (simple or chemical) that "poses an immediate threat to life or would cause irreversible or delayed adverse health effects or would interfere with an individual's ability to escape from a dangerous atmosphere" (OSHA, 2008C). Following are the main IDLH concerns when handling the production of biogas (Center for Disease Control and Prevention, 1995).

- Oxygen deficiency – less than 19.5 percent by volume air
- Hydrogen sulfide – more than 100 ppm
- Ammonia – more than 300 ppm
- Carbon dioxide – more than 40,000 ppm

2.3.3 Explosion potential

Methane, the main component of biogas, is flammable when it mixes with air. Upper and lower explosive limits (LEL) are established to provide an identifiable range of concentrations that will produce a flash fire when an ignition source is presented. The LEL is often referred to as a flammable limit. For methane, the lower and upper explosive limit is 5 percent and 15 percent by volume of air, respectively (Linde Gas LLC, 1995).

2.4 ELECTRICAL SYSTEM HAZARDS

The generation of large quantities of electricity at an AD facility creates electrical hazards, most of which can be found near the gen set, transformer, and electrical panels. The only personnel with the authority to service and repair electrical systems are licensed electricians. In addition, the facility should post signs identifying general electrical hazards near the electrical generation system.

2.4.1 High voltage

Any electrical source above 600 volts is considered high voltage (NEC, 2005). Typically, transmission lines from the transformer are the source of the highest voltage on a farm. A transformer is a piece of machinery used to increase the voltage, allowing for more efficient transport of the electricity. When dealing with such high voltage, the main hazard is contact with exposed leads, which could be fatal.

2.4.2 Low voltage

All electrical sources less than 600 volts are considered low voltage (NEC, 2005). Typically, switches, controllers, fuses, breakers, wall outlets, and electrical panels are considered low-voltage devices. One major hazard associated with electrical panels is arcing, which occurs when electricity from an energized source jumps a gap of air and discharges into an adjacent conductive surface, typically metal. If an individual happens to be in the pathway of the arc, they can be seriously burned or killed.

Reference Number 36: Guidance for Evaluating Human Health Effects in Impact Assessment: AIR QUALITY. Health Canada. December 2023. Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario.

5.2 PARTICULATE MATTER

The general term “particulate matter” (PM) can be defined as particles (solid or liquid, or a mixture of both) less than 100 micrometres (µm) in diameter. Particles of 10 µm or less in diameter are referred to as PM10. Particles of 2.5 µm or less in diameter are referred to as PM2.5 or fine PM. Particles intermediate in size (i.e., PM10-2.5) are generally known as the coarse fraction of PM10. All three size designations (PM10, PM10-2.5 and PM2.5) have been demonstrated to affect various aspects of human health, such as the respiratory and cardiovascular systems. The fine (smaller) particles pose a greater risk to human health, as they can be inhaled deeply into the lungs and into the blood. Despite the overlap between each of these size fractions (i.e., the PM10 size fraction includes the PM2.5 size fraction), there is also variation in the deposition patterns within the lungs because of differences in the physical and chemical composition (WHO, 2003). Particulate matter can be primary or secondary in nature; primary particles are emitted directly from a source, while secondary particles form in the air during chemical and physical processes from precursors gases such as SO2, NO2 and volatile organic compounds (VOCs).

Health Canada (2022a) conducted an extensive review of the literature on the health effects of PM2.5, succeeding two previous analyses on this subject (Environment Canada and Health Canada, 2012; Health Canada, 2013a). That latest assessment concluded that there were distinguishable effects for both short- and long-term exposures, and that the evidence, while highlighted by epidemiological studies of associations in the Canadian (and other) population for premature mortality and hospital admissions, was supported by evidence from controlled exposure studies using both animal and human models providing a clear causal chain at Canadian exposure levels. For instance, short-term (hours to days) exposure to PM2.5 can cause serious heart and lung events like heart attacks, heart failure, stroke, asthma attacks and premature death. Effects also include increased emergency room visits and hospitalizations for cardiovascular and respiratory problems. Long-term (months to years) exposure to PM2.5 can cause premature death, and can likely cause lung cancer, and heart and lung diseases. Exposure to PM2.5 may also lead to neurological and developmental outcomes. Additionally, the evidence pointed to adverse effects that are indicative of non-threshold relationships at the population level. The WHO *Air Quality Guidelines* (2021) also provided an extensive review of the scientific literature describing the relationship between ambient PM and various health endpoints. These guidelines note that a threshold could not be identified below which no adverse effects on health occur but provide a series of interim targets and guidelines for both PM10 and PM2.5 for 24-hour and annual periods. The CAAQS for PM also recognize that there is no population health threshold for human health effects; therefore, any increase in exposure will result in an incremental population risk (Environment Canada and Health Canada, 2012). Health Canada has concluded that the risk associated with PM2.5 is higher than the health risks associated with coarse PM or total suspended particulates (TSP) and constitutes the bulk of the health impact associated with PM, though there may be effects resulting from exposure to particles in the 2.5 to 10 µm range. Total suspended particulates, while having no specific health effects beyond that of PM2.5 and PM10, can have soiling effects that may be of concern to communities, and may contribute to deposition of substances that have consequences for soil and country foods quality, and thus should be assessed.

Given there is no level of exposure below which there is no risk to population health, everyone's health can be affected by PM2.5. Children, older adults, smokers, people carrying certain gene variants (e.g., antioxidant enzyme) and those with pre-existing cardiovascular and respiratory conditions (e.g., asthma) are at greater risk (Health Canada, 2022a). In addition, those engaged in greater levels of outdoor activity are more likely to be exposed for lengthier periods and are thus more vulnerable to the effects of PM.

6.2 IDENTIFY AND CHARACTERIZE HUMAN RECEPTORS

The identification and description of all existing and reasonably foreseeable human receptors that may be affected by project-related air emissions, including individuals temporarily exposed during specific uses of the areas (e.g., cabins, recreational use, seasonal occupancy, transient use), are necessary for an assessment of potential air quality impacts on human health. Local information on the frequency of use of temporary habitations, as well as frequency of seasonal and transient use may be of help in better characterizing the health implications of a project, especially in areas where such use is a common cultural feature. It is good practice to select the most sensitive or exposed individuals in determining these potential impacts. Some individuals are more susceptible to contamination exposure due to the following:

Physiology (e.g., newborns, children, pregnant or breastfeeding women and elderly people);

Health status (e.g., immune-compromised persons, and persons suffering from heart disease, respiratory conditions or allergies);

Behaviour (e.g., amount of time spent outdoors); and

Lifestyle (e.g., smoking, Body Mass Index (BMI) and exercise status).

It is important to clearly describe the location and distance from the project site(s) of all potential human receptors (permanent, seasonal or temporary)—taking into consideration the different types of land uses (e.g., residential, recreational, industrial); and identifying all sensitive people (e.g., in schools, hospitals, retirement complexes or assisted care homes). Note that the types of residents and visitors in a particular area will depend on land use, and may include members of the general public and/or members of specific population subgroups (e.g., Indigenous peoples, campers, hunters).

Reference Number 37: Analysing the Impact on Health and Environment from Biogas Production Process and Biomass Combustion: A Scoping Review. Marco Tamburini, Roberta Pernetti, Manuela Anelli, Enrico Oddone, Anna Morandi, Adam Osuchowski, Simona Villani, Cristina Montomoli and Maria Cristina Monti. Process and Biomass Combustion: A Scoping Review. Int. J. Environ. Res. Public Health 2023, 20, 5305. https:// doi.org/10.3390/ijerph20075305.

3.3.1. Residential Setting Studies

Of the two studies carried out in residential settings, one is a cross-sectional study from Thailand [17], which aimed at exploring the impact of air pollution from the activity of two biomass power plants on nearby residents' health. Both plants employ the same biomass type, i.e., rice husks. This study was performed on a population of 392 residents (households aged _ 15 years). Exposure was determined by the distance between the residential communities and the biomass power plants. Accordingly, three groups were identified: Group 1, residents living at a distance of 0–0.5 km from the plants; Group 2, residents living 0.5–1.0 km away from the plants, and Group 3, residents living at >1 km distance who were regarded as the reference category. The households reported their own health symptoms during the past week and answered questions about chronic diseases for each member of the household, resulting in 1254 participants. People working in the plants were excluded from the survey.

	Main Features of the Study by Juntarawijit (2013) [17]	Main Features of the Study by Lee et al. (2021) [18]
Study population	Total of 392 residents: 181 living near Plant I (steam turbine technology), and 211 living near Plant II (gasification technology and internal combustion engine) in Thailand.	NYS residents aged 1–85 living within 20 km from biorefineries and in the reference areas who had ED visits (n = 547,437) for lower respiratory diseases during the period January 2011–December 2015. Study areas: 2 corn biorefineries, 2 soybean biorefineries, and 11 wood biorefineries located in NYS. Reference areas: 15 sites with no biorefineries located in NYS.
Exposure	Living near biomass power plants. Exposure Group I: 0–0.5 km; II: 0.5–1.0 km; and reference group: >1 km.	1. Residential proximity to biorefineries [straight-line distances expressed in km (0−5; >5−10; >10−15; and >15−20 km)]; 2. air dispersion-modelled concentrations of multiple pollutants ($PM_{2.5}$, SO_2, and NO_2).
Outcomes	Chronic diseases (allergy, asthma, heart disease, COPD, tuberculosis, and cancer) and health symptoms (itching/rash, eye irritation, cough, stuffy nose, allergic symptoms, sore throat, and difficulty breathing).	Lower airway diseases (asthma, chronic bronchitis, emphysema, and chronic airway obstruction).
Data sources	Data on chronic diseases and health symptoms: self-reported questionnaire; air quality measured by air monitoring stations (dust, TSP, PM_{10}, NO_2, SO_2, and O_3).	1. SPARCS database (respiratory hospital ED visits); aggregated number of ED visits due to the following respiratory diseases: asthma, chronic bronchitis, emphysema, and chronic airway obstruction. 2. AERMOD dispersion model (concentration of air pollutants). 3. U.S. EPA (seasonal mean temperature and relative humidity and annual mean air pollutant concentrations).
Biomass type	Rice husks	Corn, soybean, and wood
Production	Electricity generation	Biofuel
Health symptoms	Chronic diseases (allergy, asthma, and COPD), allergic symptoms, cough, difficulty breathing, eye irritation, itching/rash, sore throat, and stuffy nose	Asthma, chronic bronchitis, emphysema, and chronic airway obstruction
Exposure level measured by	Plant proximity	Plant proximity
Outcome identification	Self-reported questionnaire	Hospital data
Results	There is an association between living in the vicinity of the two biomass power plants and the aforementioned respiratory and health symptoms	Respiratory ED visit rates among residents living within 10 km of biorefineries were significantly higher than those living in the reference areas according to residential proximity and air pollutants. This relationship considered biorefinery types, seasons, air pollutant types, and respiratory subtypes (highest for emphysema)

Main features of the included epidemiological studies in residential settings.

	Schlünssen et al. (2011) [19]	Basinas et al. (2012) [20]
Study population	232 energy plant workers: 94 straw workers, 138 woodchip workers, and reference group (107 working in a conventional power plant) from Denmark.	176 biofuel workers (woodchip and straw) from Denmark.
Exposure	Working in a (straw or wood) plant. Exposure to dust, airborne endotoxins, cultivable fungi, and *Aspergillus fumigatus*. Personal mean exposure to dust, endotoxins, and cultivable fungi (3 levels: low, medium, and high).	Endotoxin exposure in a straw/wood power plant. Four exposure groups: low (<50 EU/m^3), low mediate (50–200 EU/m^3), high mediate (200–1000 EU/m^3), and highly exposed (>1000 EU/m^3); the lowest exposure group taken as the reference group. Median estimated average endotoxin exposure: 0.01–294 EU/m^3.
Outcomes	Respiratory diseases (asthma symptoms, current asthma, rhinitis, chronic bronchitis, work-related asthma/wheeze, and work-related rhinitis symptoms).	Asthma, chronic bronchitis, hay fever, allergy, organic dust toxic syndrome, wheezing, and atopy.
Data sources	Data on respiratory diseases: ECRHS study; stationary work areas measurements (work areas surveyed: boiler room, combined reception and storage hall, repair room, office, outdoor work, and weighing room).	Data on respiratory diseases: self-reported questionnaire; stationary dust samples collected in all working areas.

Main features of the included epidemiological studies in occupational settings.

5.1. Epidemiological Studies

5.1.1. Residential Setting Studies

Both residential setting studies analysed the impact of living near industrial facilities using biomass on residents' respiratory diseases and health symptoms. As mentioned before, the studies by Juntarawijit (2013) and Lee et al. (2021) appeared markedly different, especially because the former was carried out in two plants producing electricity from the same biomass type (rice husks) but by means of two distinct technologies (steam turbine and gasification with an internal combustion engine, respectively).The latter, instead, analysed 15 biorefineries producing ethanol from three biomass types: corn, wood and soybean. Despite these striking differences, both studies focused on the association between living in the vicinity of the facilities under study and the risk of respiratory morbidity (as

well as other health symptoms) for the nearby communities. Additionally, the air pollutants taken into consideration were similar: particular matter (PM10 by Juntarawijit and PM2.5 by Lee et al.), sulphur dioxide, nitrogen dioxide, and ozone only in Juntarawijit (2013)
The health effects of these pollutants are often well known. PM exposure has been linked to cardiovascular and respiratory negative outcomes, as well as cancer. In particular, exposure to PM 2.5 has raised wide concern regarding mortality and premature death due to both long- and short-term exposures. Ozone is an oxidative gas with strong irritative effects on airways, with proven association to hospital admission and mortality, although the health effects of long-term exposures still remain a matter of debate. Exposure to nitrone dioxide has also been observed to be linked to respiratory, cardiovascular, and metabolism-related diseases, resulting in an increased mortality among those exposed. Moreover, exposure to sulphur dioxide seems to exert its health effects on respiratory diseases and related mortality.
Consistent with these observations, the results of the study from Thailand revealed that living in proximity of the two biomass power plants was associated with an increased risk of suffering from respiratory diseases and other health symptoms.
Similar results are shown in the study by Lee et al. (2021), which dealt with the health impact of living in the vicinity of biorefineries using different types of biomasses. We decided to include this study in our review not only because one of the stages involved in the biofuel production is represented by biomass fermentation, but also because of the high methodological quality of the study itself. In fact, in this study, information about respiratory diseases was retrieved from objective hospital data. Additionally, the large sample size analysed increased the statistical validity of the analysis.
Secondly, the association between biorefinery exposures and respiratory diseases was investigated according to two exposure indicators, that is, residential proximity and AERMOD-modelled air pollutant concentrations, to validate the findings.
Thirdly, seasonal difference was taken into consideration in the association between residential exposure and lower airway diseases: as a matter of fact, respiratory ED visit rates among residents living within 10 km of the biorefineries were significantly higher than those living in the reference areas in spring and winter. These data contribute to the high methodological quality of the study, even though some parameters must be taken into account: (I) increasing air pollution levels during spring and winter can be due to photochemical decomposition rates of air pollutants at cold temperatures; (II) during cold seasons, there are higher air pollution concentrations due to the stagnation of air pollutants; and (III) tree and grass pollens cause respiratory symptoms, such as asthma, in spring.
In conclusion, the high-level methodology adopted by Lee et al. (2021) should be considered as a reference model for other residential setting studies: the same methodological approach may also be used for the assessment of health risk among workers in industrial facilities, with the administration of an ad hoc, standardised, and validated questionnaire to investigate participants' lifestyle. If this study has an occupational setting counterpart, a complete model about human health risk will be available.
Workers and populations living near biogas plants could be potentially exposed to different pollutants, namely PM10 and PM2.5, ozone, nitrogen dioxide, sulphur dioxide, some bacteria and fungi, endotoxins, and some VOCs.
The health effects of short-term exposures to PMs, ozone, nitrogen dioxide, and sulphur dioxide are generally well known, although the effects of long-term exposures are not always completely understood. Thus, environmental monitoring should not be neglected in these populations.
Some health issues could also arise from microbiological exposure to bacteria, fungi, and endotoxins. In particular, endotoxins could expose workers to some health risks, considering their high biological activity and thermic resistance.
Even though VOCs are compounds which toxicity is generally well known, some exposures could occur in biogas plant workers, and thus, environmental monitoring should not be neglected.
be neglected.
Through environmental measurements, the monitored biogas plants included in the study highlighted the release of VOCs, gaseous pollutants, and particulate.

Reference Number 38: Flaring from Unconventional Oil and Gas Development and Birth Outcomes in the Eagle Ford Shale in South Texas Lara J. Cushing, Kate Vavra-Musser, Khang Chau, Meredith Franklin,and Jill E. Johnston. Environmental Health Perspectives. July 2020. https://doi.org/10.1289/EHP6394.

Our findings suggest that living within 5 km of OGD wells and flaring activity may have had a significant adverse effect on birth outcomes among pregnant women in the Eagle Ford region. The fact that much of the region is low income and approximately 50% of residents living within 5 km of an oil or gas well are people of colour raises environmental justice concerns about the potential health impacts of the oil and gas boom in south Texas (Johnston et al. 2016).

Measures to minimize flaring—such as more stringent regulation of flaring or investments in renewable energy and energy efficiency measures that reduce reliance on fossil fuels overall—could protect the health of infants.

Reference Number 39: Fracking linked to low-weight babies. Ann Gibbons 13 Dec 2017.

A growing number of studies suggests that living near oil and gas developments is associated with a wide range of negative outcomes, from higher rates of asthma and migraines to more hospitalizations for cardiovascular disease, neurological disorders, and cancer. Earlier studies have also found associations with low–birth weight babies, but those were plagued by low sample sizes or a failure to show that health effects got worse closer to drilling sites, as expected if fracking were to blame.

Now, health economist Janet Currie at Princeton University and her colleagues have tried to overcome those problems by looking at birth certificates for all 1.1 million infants born in Pennsylvania between 2004 and 2013—a period that spanned the drilling of thousands of fracking wells in the state, which now has more than 10,000 of them. The birth certificates included addresses and vital statistics for each infant, such as birth weights, total months of gestation, birth defects, and other abnormal conditions. The researchers overlaid those data on maps showing when and where wells were drilled in Pennsylvania. They then drew concentric circles around each site: one at 1 kilometer, one at 2 kilometers, and one at 3 kilometers.

They found that infants born within 1 kilometer of a well were 25% more likely to have low birth weights (less than 2500 grams or 5.5 pounds) than infants more than 3 kilometers away, they report today in *Science Advances*. Babies born in the first circle also showed significantly lower scores on a standard index of infant health. Infants born in the outer circles—between 1 and 3 kilometers away—were smaller and less healthy than those who lived farther away, but they weren't as badly off as babies born closest to the wells.

To rule out other factors that could lead to poor health outcomes, including race and socioeconomic status, the team removed babies born in urban areas like Pittsburgh and Philadelphia, which have comparatively high rates of lower birth weight babies. They also compared siblings born to the same mothers who lived near fracking sites before and after it started. Although this sample size was small—only 594 infants exposed to fracking had unexposed siblings—it showed that the exposed infants were smaller and less healthy.

The good news is that the effects don't extend far beyond the fracking sites, Currie says. The study found no decrease in infant weight or health past 3 kilometers. But the team doesn't know what aspect of fracking caused the low birth weights, which put babies at higher risk for infant mortality, asthma, attention deficit hyperactivity disorder, lower test scores, and lower lifetime earnings. Currie, who studies air pollution and health, says it's likely air pollution from chemicals or the increased truck traffic and industrialization associated with fracking. Water pollution is an unlikely culprit because many people in the study got their water from municipal sources not close to fracking sites. Infants, who are essentially the "canaries" near the fracking mines, probably aren't the only victims. If they are experiencing negative effects, the elderly and other vulnerable people near wells are likely to also be at risk.

Reference Number 40: Living near active oil and gas wells in California tied to low birth weight and smaller babies. Rachel Morello-Frosch,Professor, Department of Environmental Science, Policy and Management & School of Public Health, University of California, Berkeley, Joan Casey, Assistant Professor, Columbia University, Kathy Tran, Ph.D. Candidate in Environmental Health, University of California, Berkeley, Lara Cushing, Assistant Professor of Environmental Health Sciences, Fielding School of Public Health, University of California, Los Angeles. June 18, 2020.

In a California study, it was found that pregnant women living near active high-production oil and gas wells have an elevated chance of having low birth-weight babies. This finding adds to a growing body of research on potential public health impacts from oil and gas operations.

Analysis of the birth records of nearly 3 million babies born to people living within 6.2 miles (10 kilometers) of at least one oil or gas well in California's Sacramento, San Joaquin Valley, South Central Coast and South Coast regions – the state's oil production epicenters – between 2006 and 2015.

The analysis found that in rural areas, pregnant women who lived within 0.62 miles (1 kilometer) of the highest-producing wells were 40% more likely to have low birth-weight babies compared to pregnant women living farther away from wells or near inactive wells only. Rural women living near the highest-producing wells were 20% more likely to have babies who were small for their gestational age, which is an indication of reduced fetal growth.

Among full-term births, babies born to rural women living within 0.62 miles of a well were 1.3 ounces (36 grams) smaller, on average, than those of their counterparts. This decrease in birth weight may seem minor from an individual clinical perspective, but such a downward shift at the population level can have significant implications for overall neonatal and infant health.

Reference Number 41: Safety in biogas plants: An analysis based on international standards and best practices. Hala Hegazy, Noori M. Cata Saady, Sohrab Zendehboudi, Process Safety and Environmental Protection200(2025)107390 www.journals.elsevier.com/process-safety-and-environmental-protection.

The operation of biogas plants is fraught with various hazards that can pose significant risks to personnel and the surrounding environment. These hazards stem from the complex interactions among the plant's components, including inputs, processes, and outputs. For instance, the anaerobic digestion process can produce explosive gases such as methane (CH_4), hydrogen (H_2), and hydrogen sulfide (H_2S), necessitating stringent safety measures to prevent fire and explosion incidents (Marjolaine, 2020; Yu et al., 2021). Recent statistics indicate that incidents related to biogas plants are not uncommon. For instance, between 2015 and 2020, over 30 reported explosions and fires in the UK's biogas plants caused injuries and property damage (Hegazy et al., 2024; HSE, 2024b). Similarly, in Germany, the Federal Institute for Occupational Safety and Health reported 18 serious accidents involving biogas plants in 2019 alone, highlighting the need for stringent safety protocols (BAUA, 2022).

A comprehensive understanding of biogas plant components is essential for identifying potential hazards. Typical biogas plant components include feedstock reception areas, anaerobic digesters, biogas storage tanks, combined heat and power generation units (CHP), and digestate treatment units. Each component presents unique risks; for example, digesters operate under anaerobic conditions and produce toxic, flammable, and explosive gases such as CH_4, H_2, and H_2S that can lead to pressure buildup, while biogas storage tanks require careful monitoring to prevent overpressure and leaks (Eric, 2024; Tamburini et al., 2023; Wei et al., 2025). Furthermore, electrical systems integral to the operation of biogas plants can introduce electrical hazards if not properly managed. A study found that electrical failures were responsible for approximately 25 % of industrial accidents in biogas plants in the United States of America (USA) (EPA, 2014b).

Mechanical hazards are predominantly associated with the plant system's feeder, CHP unit, and other machinery (GAOHSA, 2008). Explosion and fire hazards can arise in several key areas, including the feeder, the space between the return valve and shut-off valve, and the access.

Additional risk zones include the connections between overpressure and under-pressure protection systems and the blow-off pipe, as well as the segments between the shut-off valve and the condensate trap, the shut-off valve on the CHP unit, the gas flare, and the gas fine filter/ activated carbon filter within the CHP unit. Hazards may also occur in the conditioning unit used for biogas upgrading to the natural grid system (GAOHSA, 2008; Marjolaine, 2020). Biogas hazards are similar in the conditioning unit for biogas upgrading, the oil tray in the CHP unit, the gas fine filter/activated carbon filter within the CHP unit, and the dosing station for processing aids at the beginning of the process. Finally, the potential for electrical hazards exists in the digester, all electrical equipment, the CHP unit, and the injection unit within the biogas upgrading system to the natural grid. This underscores the across all operational areas of the biogas plant (GAOHSA, 2008; Marjolaine, 2020). Fig. 3 identifies the main hazards associated with the seven primary components from our dataset, highlighting where these hazards are mostly occurring. In addition, Natech, being a natural disaster that cannot be controlled, will be eliminated from our analysis

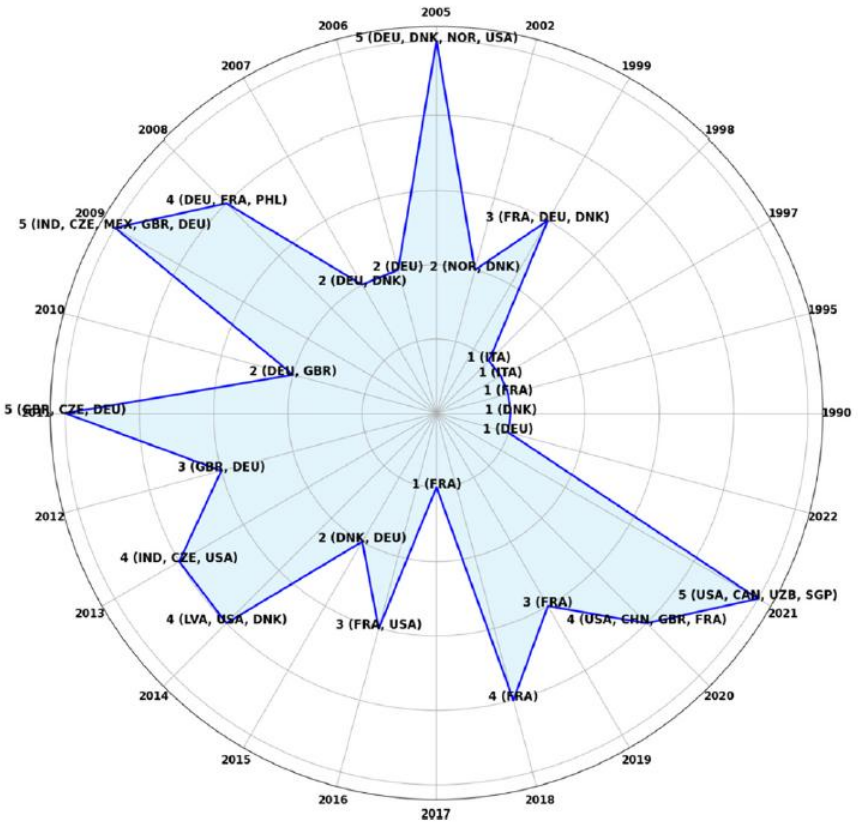


Fig. 4. Yearly distribution of biogas plant accidents. Keycode: Denmark - DNK, France - FRA, Italy - ITA, Germany - DEU, Norway - NOR, USA - USA, Philippines - PHL, India - IND, Czech Republic - CZE, Mexico - MEX, United Kingdom - GBR, Latvia - LVA, China - CHN, and Canada – CAN.

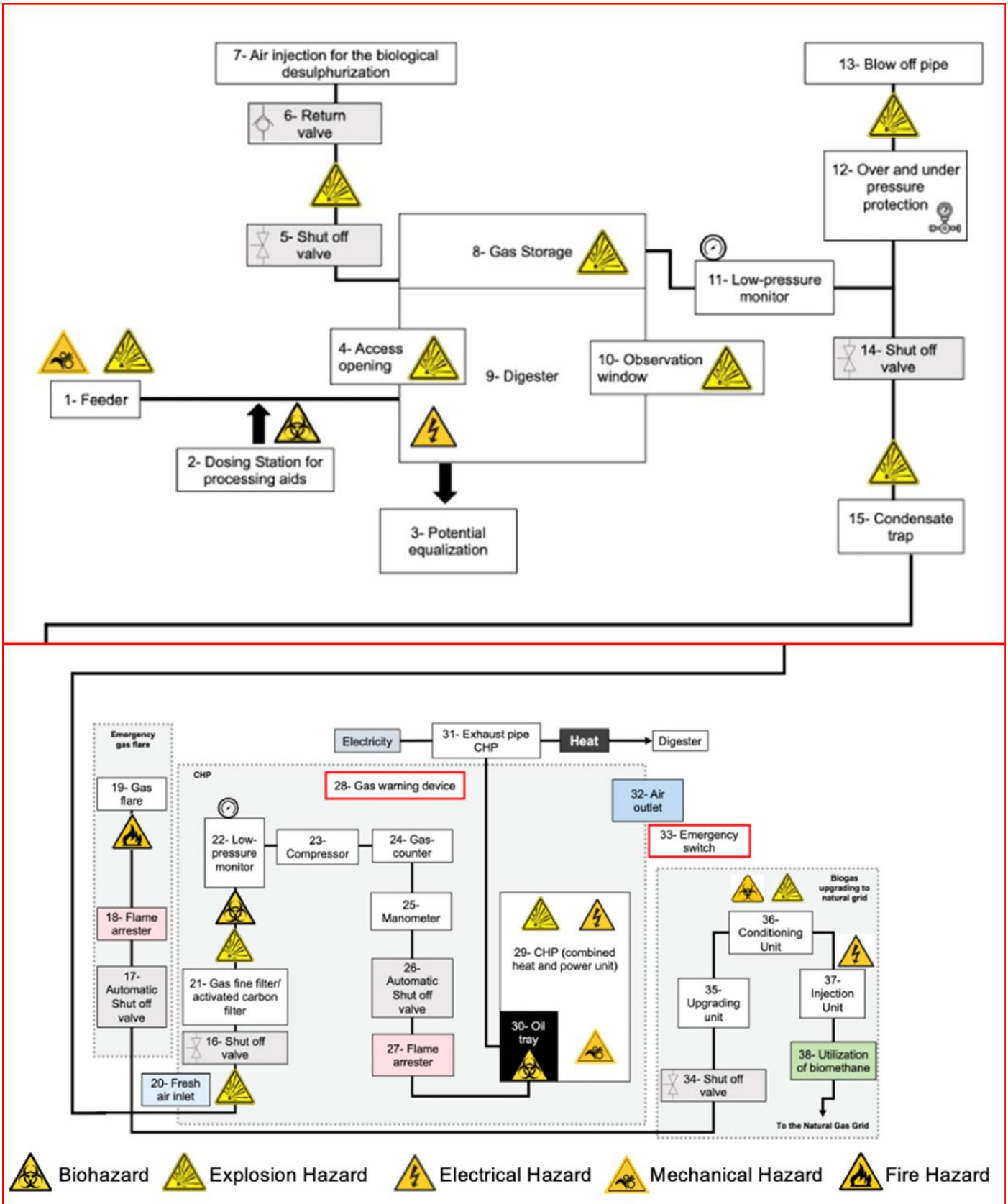


Fig. 2. Possible hazard identification in the typical biogas plant.

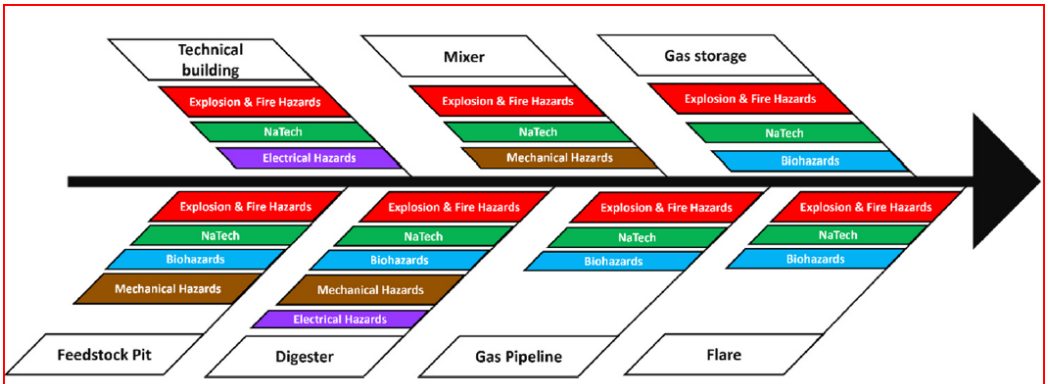


Fig. 3. Fishbone hazards analysis for the seven main biogas components.

Biohazard accidents in biogas plants are primarily associated with releasing toxic or harmful gases, such as H_2S, during anaerobic digestion. Exposure to high H_2S concentrations poses serious health risks to workers, including respiratory problems and even fatalities (Sawaya and Menezes, 2024). Studies indicate that biohazard-related incidents account for approximately 10 % of accidents in biogas plants (Rao et al., 2010). A fishbone diagram (Fig. 5) depicts several main causes that might lead to biohazards in biogas plants, such as inadequate handling practice, organic overload, improper use or disposal of PPE, accidental spills, poor air quality, inadequate labeling of hazardous material, and the generation of hazardous byproducts (Angelidaki and Ellegaard, 2003).

Explosion and fire hazards are significant risks in biogas plants due to the flammable nature of biogas, which is primarily composed of methane (Wu et al., 2025). Accidental gas leaks, improper ventilation, or ignition sources can lead to explosive mixtures and fires (Schmitz et al., 2021; Weiland, 2010). Statistics reveal that explosion and fire-related accidents contribute to around 15 % of incidents in biogas plants (Rao et al., 2010). These accidents can cause property damage, injuries, and loss of life. Fig. 5 represents some leading causes, such as open flames, electrostatic discharges, mechanically generated sparks, exothermic reactions, inadequate ventilation, combustible material, and improper use of electrical equipment (Demirel, 2008).

Electrical hazards are present in biogas plants due to using electrical equipment for processes such as pumping, mixing, heating, and power generation. Improper wiring, equipment malfunctions, or inadequate grounding can result in electrical shocks, fires, or equipment damage (Gupta et al., 2004). Research suggests that electrical accidents account for approximately 12 % of incidents in biogas plants (Rao et al., 2010). Some of the notable causes of electrical hazards represented in Fig. 5 include faulty grounding, high voltages, inadequate insulation, overloaded circuits, electric shock from exposed wiring or equipment, short circuits, improper use of extension cords, and electric shocks from wet conditions (Gupta et al., 2004).

Mechanical hazards in biogas plants can arise from operating various equipment, including pumps, valves, compressors, and agitators. Malfunctions, failures, or improper maintenance of these components can lead to injuries, entanglement, or equipment damage (Weiland, 2010). Statistics show that mechanical accidents contribute to around 18 % of incidents in biogas plants (Rao et al., 2010). As indicated in Fig. 5, entanglement, hydraulic overload, temperature stress, inadequate guarding, failure of safety interlocks, inadequate maintenance, malfunctioning pumps or valves, and inadequate training are some of the potential causes of mechanical hazards in biogas plants (Angelidaki and Ellegaard, 2003).

Natech accidents refer to incidents where natural hazards, such as earthquakes, floods, or storms, trigger technological failures or accidents. In biogas plants, natural hazards can compromise the integrity of structures, pipelines, or storage tanks, resulting in leaks, spills, or even collapses (Jensen and Hylland, 2019). Although the specific percentage may vary, it is vital to consider the potential consequences of such events and implement appropriate risk assessment and prevention measures (Weiland, 2010). These accidents can have severe consequences for both human safety and the environment. Potential causes include tornadoes, tsunamis, floods, hurricanes, rupture of biogas storage tanks, aging and deterioration of equipment, and power outages (Angelidaki and Ellegaard, 2003), as shown in Fig. 5.

Other accidents in biogas plants can include falls from heights, chemical spills, or process deviations. Falls from elevated platforms or ladders can cause injuries and account for approximately 8 % of incidents (Rao et al., 2010). Chemical spills can lead to environmental contamination and health risks, contributing to around 7 % of accidents in

biogas plants (Rao et al., 2010). Process deviations, such as improper mixing or temperature control, can affect the efficiency of biogas production and may result in suboptimal plant performance (Gupta et al., 2004).

Accidents in biogas plants stem from various hazards, including biohazards, explosion and fire risks, electrical and mechanical failures, and natech events. Biohazards, linked to toxic gas releases like H_2S, account for 10 % of incidents, while explosion and fire hazards have a contribution of 15 %, often due to gas leaks. Electrical hazards make up 12 % of accidents from equipment malfunctions, and mechanical failures account for 18 %. Natech events further complicate safety risks, underscoring the need for robust risk assessments and safety measures in biogas facilities.

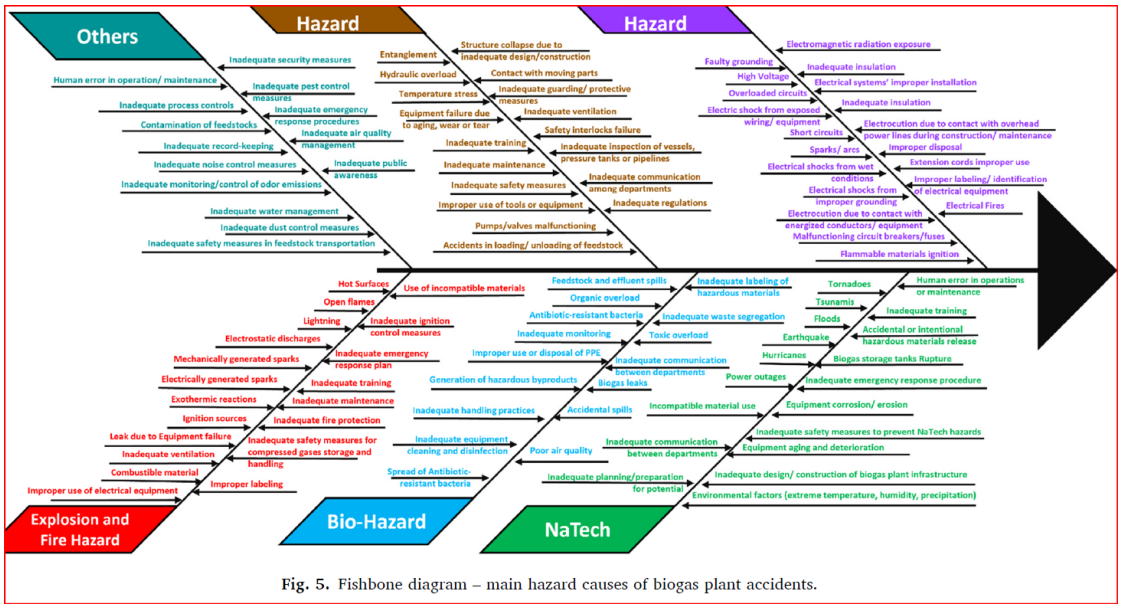


Fig. 5. Fishbone diagram – main hazard causes of biogas plant accidents.

Reference Number 42: Biogas plants – Safe handling of biogas 002:

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Hazard

The main hazard when handling biogas are the combustibility of methane and the explosiveness of methane/air mixtures.
The explosion range of methane lies between 4 % and 17 % by volume in air.
Further hazardous components of biogas are the asphyxiant carbon dioxide and the toxic hydrogen sulfide, which can be lethal even at low concentrations. The density of biogas is influenced by its carbon dioxide content, the atmospheric pressure and temperature. The higher the concentration of carbon dioxide, the higher the density of biogas. If the composition of biogas is unknown, it has to be assumed that biogas can accumulate at the ceiling as well as in basements, pits, shafts and other cavities.

Explosion prevention

In places where biogas plants or parts thereof are installed one must consider the hazard of an explosion. These areas should be classified into Ex-Zones 0, 1 or 2 in accordance with national guidelines.
In places where explosive atmospheres may occur, ignition sources must be avoided, or other protective measures have to be taken to eliminate the risk of ignition. Effective ignition sources include flames, hot surfaces, electrical sparks, static electricity, mechanically created sparks and lightning strikes.