4. Hazard to Life Assessment

4.1 Introduction

In accordance with Clause 3.4.4 of the EIA Study Brief (ESB-226/2011) [1], a hazard assessment (HA) shall be conducted to evaluate the biogas risk to existing, committed and planned off-site population due to operation of the Project.

The HA will be carried out on the proposed Organic Waste Treatment Facility Phase 2 (OWTF 2) at Sha Ling, North District that is proposed to receive and process 300 tonnes per day of source separated food waste generated from the commercial and industrial (C&I) sectors. The location of the proposed site is shown in **Figure 2.1** and the preliminary site layout is shown in **Figure 4.1**. **Table 4.1** shows the implementation programme of OWTF 2.

Table 4.1 Implementation Programme of OWTF 2

Key Stage of the Project	Indicative Milestones
Commencement of Feasibility and EIA Studies	2011
Commencement of Tendering for DBO Contract	2014
Commencement of Construction of the Project	2015
Commencement of the Operation of the Project	2017

Mott MacDonald has commissioned BMT as specialist sub-Consultant for Quantitative Risk Assessment.

4.2 Scope and Objectives

According to the technical requirements specified in Section 3.4.4 of the EIA Study Brief [1], the HA has been carried out following the criteria for evaluating hazard to life as stated in Annexes 4 and 22 of the Environmental Impact Assessment Ordinance Technical Memorandum (EIAO TM) [2] (Hong Kong Risk Guidelines).

The objectives of the HA corresponding to section 3.4.4 of the EIA Study Brief [1] are:

(i) Identify hazardous scenarios associated with the generation, transfer, storage and use of biogas due to operation of the Project and then determine a set of relevant scenarios to be included in a Quantitative Risk Assessment (QRA);
(ii) Execute a QRA of the set of hazardous scenarios determined in (i), expressing population risks in both individual and societal terms;
(iii) Compare individual and societal risks with the criteria for evaluating hazard to life stipulated in Annex 4 of the TM; and
(iv) Identify and assess practicable and cost-effective risk mitigation measures.

4.3 Risk Legislation, Standards and Guidelines

4.3.1 Risk Criteria

The estimated risk levels of hazardous sources has been compared with the risk guidelines stipulated in the Environmental Impact Assessment Ordinance Technical Memorandum (EIAO TM) Annex 4 [1] to determine the acceptability. As set out in the EIAO TM Annex 4, the risk guidelines comprise the two following components:

- Individual Risk Guideline: The maximum level of off-site risk should not exceed 1 in 100,000 per year (i.e. $1x10^{-5}$ per year);

- Societal Risk Guideline: The societal risk guideline is expressed in terms of lines plotting the frequency (F) of N or more fatalities in the off-site population from hazardous scenarios at the facility of concern. This can be presented graphically as in **Figure 4.2.** There are 3 areas representing differing levels of risk as described below:

  (i) Acceptable - where risks are so low that no action is necessary;
  (ii) Unacceptable - where risks are so high that they should be reduced regardless of the cost or else the hazardous activity should not proceed;
  (iii) ALARP (As Low As Reasonably Practicable) - where the risks associated with the hazardous activity should be reduced to a level "as low as reasonably practicable", in which the priority of measures is established on the basis of practicality and cost to implement versus risk reduction achieved.

4.4 Hazard Assessment Methodology

4.4.1 Assessment Scenario

Description of the methodology and information required for the assessment are detailed in the following sub-sections. **Figure 4.3** shows the methodology of the HA which consists of the following tasks:

- **Data/ Information Collection**: collect relevant data / information which is necessary for the hazard assessment;
- **Hazard Identification**: identify hazardous scenarios associated with the operations of the OWTF 2 by reviewing historical accident database, such as Major Hazard Incident Data Service (MHIDAS) and relevant similar studies and then determine a set of relevant scenarios to be included in the HA;
- **Frequency Assessment**: estimate the frequencies of the identified hazardous scenarios by reviewing historical accident data, previous studies or using Fault Tree Analysis (FTA) of the identified hazardous scenarios.
- **Consequence Analysis**: conduct source term modelling and effect modelling for the identified hazardous scenarios.
- **Risk Assessment**: evaluate the risks associated with the identified hazardous scenarios. The evaluated risks are compared with the Criteria for Evaluating Hazard to Life stipulated in Annex 4 of the EIAO TM to determine their acceptability.
- **Risk Mitigation and Recommendations**: identify and assess practicable and cost-effective risk mitigation measures as necessary. Risks of the mitigated case are reassessed to determine the level of risk reduction as required.

The hazard assessment covers the following two scenarios:

- *Year 2017 scenario* - OWTF 2 is expected to be in operation by 2017. The QRA study assesses the risk impact to the projected population in year 2017 due to generation, transfer, storage and usage of biogas in OWTF 2.
- *Year 2017 scenario with proposed developments* - There are uncertainties on the population intake (e.g. future Kong Nga Po Comprehensive Development Area and Sandy Ridge Crematorium and Columbarium Facilities) during the operational phase of the OWTF 2. To evaluate the impact of OWTF 2 to the proposed developments, population intake of the proposed developments has been assessed.

The Hazard Assessment study for OWTF 1 under Agreement No. CE 7/2008 (EP), "Organic Waste Treatment Facilities, Phase I" [7] (hereafter refer to as "OWTF 1 HA Study") has been reviewed and taken as a reference for the Project.

Hazardous scenarios have been identified by reviewing hazardous scenarios developed for similar installations. Hazardous scenarios and frequency adopted in the hazard assessment are confirmed independently using review of historical incidents.

4.4.2 Data/ Information Collection

The following data/ information were collected:

- Population data around the OWTF 2 site (e.g. San Uk Ling Holding Centre, Sandy Ridge Village);
- Traffic population (e.g. Man Kam To Road);
- Surrounding Topography ;
- Meteorological data near the OWTF 2 site (including atmospheric stability class, wind speed and wind direction); and
- The preliminary design of generation, transfer, storage and use of biogas at OWTF 2 site.

4.4.2.1 Population data around the Project site

The Project site is located at Sha Ling in the North District, within the Frontier Closed Area (FCA). Information from various sources, such as Census and Statistics Department (C&SD), Transport Department (TD), Civil Engineering and Development Department (CEDD), Hong Kong Police Force (HKPF) and Planning Department (PlanD) have been obtained for population estimation wherever applicable, as shown in **Table 4.2**. The Consultant conducted a site survey on 15 March 2012 for a better estimation of population. The site survey includes village house counts in residential areas surroundingf the Project site.

Table 4.2 Population and Traffic Data Sources

Sources	Details
Census and Statistics Department	2011 Population Census [3]
Planning Department	1. Projections of Population Distribution, 2010-2019 [4] 2. Proposed Residential Development in Kong Nga Po and Hung Lung Hang [5] 3. Man Kam To Development Corridor [5]
Civil Engineering and Development Department	1. Kong Nga Po Development
Hong Kong Police Force	1. San Uk Ling Holding Centre 2. Rifle Range 3. Police Dog Unit and Force Search Unit Training School 4. Hong Kong Police Force Border District Headquarters
Transport Department	Annual Traffic Census 2011 - Annual average daily traffic (AADT) [6]
Others	Consultant conducts a site survey to collect population data from surrounding villages

A presence factor is considered for different types of buildings to account for occupancies during different times of the day. Referencing the HA for "Organic Waste Treatment Facilities (OWTF), Phase I (EIA-176/2009)" [7], Kai Tak Development EIA (Chapter 11) [8] and other EIAs approved EIAO, it is noted that Kai Tak Development EIA gives a more comprehensive analysis on temporal changes in population, in terms of "Residential Dwellings", "Industrial Buildings" and "Commercial Buildings" population groups. Therefore, the presence factor for various population groups applied in this study is adopted from Kai Tak Development EIA [8]. For open space areas (e.g. Cemetery), population has been estimated based on relevant studies (e.g. Land Use Planning for the Closed Area-Feasibility Study) or site observation.

OWTF 2 will have an environmental educational centre inside the site office building. Tentatively during day time on weekdays, there will be at maximum 40 visitors visiting this centre.

In order to reflect the temporal distribution of population with time, 4 "time periods" were used in the Kai Tak Development EIA, namely, Weekday (Day), Weekday (Night), Weekend (Day) and Weekday (Night). However, the definitions of "Day" and "Night" are not explicitly given in the Report. In the HA for PHIs of the Harbour Area Treatment Scheme (HATS) Stage 2A EIA (Para. 14A.23) [9], daytime is defined as 07:00 to 19:00 and night-time from 19:00 to 07:00. This split is considered in line with Kai Tak Development EIA [8] and adopted in this Project.

The assumption of temporal variation in different population categories are summarised in **Table 4.3**.

Table 4.3 Temporal Changes in Population for Various Categories

Time Period	Residential Dwellings	Industrial/ Commercial Buildings	Open Space/ Recreational
Weekday (Day) (Mon-Fri 07:00-19:00)	50%	100%	100%
Weekday (Night) (Mon-Fri 19:00-07:00)	100%	10%	10%
Weekend (Day) (Sat-Sun 07:00-19:00)	70%	40%	100%
Weekend (Night) (Sat-Sun 19:00-07:00)	100%	5%	10%

Indoor populations are distinguished from the outdoor population. Typical indoor/ outdoor ratios that are applied for various population categories are listed in **Table 4.4** [7][8].

Table 4.4 Indoor/ Outdoor Ratios for Different Population Categories

Population Category	Indoor (Outdoor) Ratio
Residential	0.90 (0.10)
Industrial/ Commercial	0.90 (0.10)
Road	0 (1)
Open Space	0.00 (1.00)

4.4.2.2 Traffic Population

Traffic data was obtained from the Traffic Impact Assessment (TIA) for the OWTF 2, TIA of Land Use Planning for the Closed Area-Feasibility Study [5] and Annual Traffic Census of Transport Department [6]. Traffic data was used to calculate traffic distribution during day-time and night-time. The traffic population was predicted based on the following equation:

*Traffic Population = (No. of persons / vehicle) * (No. of vehicles / hr) * Road Length / Speed*

The representative speed for calculating the traffic population is the speed limit of the roads (i.e. 50 km/h for roads and 80 km/h for expressways).

Annual average daily traffic (AADT) data from “The Annual Traffic Census 2011” of TD [6] is also referred, traffic flow parameter, vehicle classification and average occupancy of vehicles from nearest Core Station 5003 - Fanling Highway (From So Kwun Po Interchange to Wo Hop Shek Interchange) is outlined in **Table 4.5** and **Table 4.6**.

Table 4.5 Time Modes for Temporal Variation of Road Population

Description	Time (hr)
AADT R12/24 (07:00-19:00, Daytime)	12
AADT Others (19:00-07:00, Night-time)	12

Based on AADT, **Table 4.6** shows 16-hour average occupancy of different classes of vehicle [6].

Table 4.6 16-hour Average Occupancy of Different Classes of Vehicle [6]

Time (16-hour average)	Class of Vehicle									
	Motor Cycle	Private Car	Taxi	Private Light Bus	Private Light Bus	Goods vehicles		Non Franchised Bus	Franchised Bus	
						Light	Medium & Heavy		Single-Decked	Double-decked
Proportion of vehicles (%)	1.3	46.9	4.9	0.9	0	23.8	19.5	2.4	0.1	0.2
Occupancy	1.1	1.4	1.9	2.4	0	1.4	1.2	13.5	1	1.4

Note: The sum for proportion of vehicles in % may not equal 100% due to figure rounding.

Traffic population is assumed to be 100% outdoor [8]. Average occupancy of 1.68 persons per vehicle is calculated by taking into account the traffic mix and according to traffic census data for occupancy of various vehicle classes. Ratio of 12 hour flow (Day-time: 0700 - 1900) to 24 hour flow is 71.45%, which means Ratio of 12 hour flow (Night-time: 1900 - 0700) to 24 hour flow is 28.55%. [6]

Population density is obtained by multiplying the instantaneous number of vehicles calculated from the Annual Average Daily Traffic (AADT) figure (in vehicles per day) with the average occupancy of each vehicle.

Taking Station 5465 for Man Kam To Road (ATC 2011) [6] as an example:

- AADT 15,920 vehicles per day, speed limit 50 km/hr
- Average vehicles per hour = 15,920 vehicles per day x 71.45% / 12 (day time) = 948 vehicles per hour
- Instantaneous no. of vehicles = 948 vehicles per hr/ 50 km per hr = 19 vehicles per km
- Traffic population density = 1.68 people/vehicle × 19 vehicle/km = 31.9 people/km
- Current traffic population (day time) = road length x traffic population density = 2.1 km × 31.9 people per km = 67 people.

Table 4.7 and Table 4.8 show the current population (2012) and future traffic population (2017) around the Project site. Figure 4.4a, Figure 4.4b and Figure 4.4c show the location of the population around the Project site.

Table 4.7 Current Residential and Employment Population (2012) and Future Population (2017) around OWTF 2 Project Site

ID	Description	Land Use	Current Population (2012)	Future Population (2017)	Indoor	Outdoor	Weekday (Day)	Weekday (Night)	Weekend (Day)	Weekend (Night)	Approximate Shortest Distance to the Project Site (m)[(1)]	Source of reference
1	Police Dog Unit and Force Search Unit Training School	G/IC	70+ 60 (60 visitors on Thursday)	74+ 60 (60 visitors on Thursday)	0.9	0.1	100%	10%	40%	5%	390	(a)
2	San Uk Ling Holding Centre	G/IC	35	35	0.9	0.1	100%	10%	40%	5%	150	(b), (c)
3	San Uk Ling Firing Range	G/IC	Nil	Nil	0	1	100%	10%	100%	10%	300	(b), (d)
4	Hong Kong Police Force Border District Headquarters	G/IC	200	200	0.9	0.1	100%	10%	40%	5%	570	(b)
5	Cement Plant	Industrial	20	20	0	1	100%	10%	40%	5%	280	(e)
6	Area 1	Residential	276	353[(2)]	0.9	0.1	50%	100%	70%	100%	60	(e)
7	Area 2	Residential	54	69[(2)]	0.9	0.1	50%	100%	70%	100%	60	(e)
8	Area 3	Residential	72	92[(2)]	0.9	0.1	50%	100%	70%	100%	150	(e)
9	Area 4	Residential	60	77[(2)]	0.9	0.1	50%	100%	70%	100%	45	(e)
10	Area 5	Residential	72	92[(2)]	0.9	0.1	50%	100%	70%	100%	20	(e)
11	Area 6	Residential	60	77[(2)]	0.9	0.1	50%	100%	70%	100%	115	(e)
12	Area 7	Residential	192	246[(2)]	0.9	0.1	50%	100%	70%	100%	140	(e)
13	Area 8	Residential	408	521[(2)]	0.9	0.1	50%	100%	70%	100%	160	(e)
14	Area 9	Residential	102	131[(2)]	0.9	0.1	50%	100%	70%	100%	150	(e)
15	Area 10	Residential	114	146[2)]	0.9	0.1	50%	100%	70%	100%	230	(e)
16	Area 11	Residential	240	307[(2)]	0.9	0.1	50%	100%	70%	100%	380	(e)
17	Area 12	Residential	150	192[(2)]	0.9	0.1	50%	100%	70%	100%	480	(e)

ID	Description	Land Use	Current Population (2012)	Future Population (2017)	Indoor	Outdoor	Weekday (Day)	Weekday (Night)	Weekend (Day)	Weekend (Night)	Approximate Shortest Distance to the Project Site (m)(1)	Source of reference
18	Kong Nga Po Comprehensive Development Area Residential Population	Residential	N/A	3600(3)	0.9	0.1	50%	100%	70%	100%	190	(d), (f), (g)
19	Hung Lung Hang Residential Population	Residential	N/A	1960(4)	0.9	0.1	50%	100%	70%	100%	500	(d)
20	Man Kam To Development Corridor	Industrial/ Commercial	N/A	2720(4)	0.9	0.1	100%	10%	40%	5%	0	(d), (f)
21	Sandy Ridge Crematorium and Columbarium (C&C) Facilities	Other Use (Cemetery)	N/A	1900(5)	0	1	100%	10%	100%	10%	260	(d), (f), (g)
22	Visitors to OWTF Phase 2 Facility	Industrial/ Commercial	N/A	40(6)	0.9	0.1	100%	0	0	0	0	(g)

Note:
(1) Estimated from HK GeoInfo Map, powered by HKSARG Geospatial Information Hub (GIH) of the Lands Department (http://www.map.gov.hk) [31]
(2) According to “Projections of Population Distribution 2010-2019” [4], the average annual population growth rate for TPU 6.4.1 (at which OWTF 2 locates) is 4%. The annual population growth rate is taken conservatively as 5%.
(3) The population is referred to Sec 2.7 Interfacing Projects. This is the expected population in year 2020. The population adopted in the HA in year 2017 is on the conservative side.
(4) The implementation of Hung Lung Hang Residential Area and Man Kam To Development Corridor proposals will depend on private initiatives and the implementation program is subject to private development application. The population adopted in the HA in year 2017 is on the conservative side.
(5) This is the expected population in year 2026. The population will be adopted in the HA in year 2017 is on the conservative side.
Maximum 40 visitors are estimated based on the working paper. Visits will only be arranged during daytime on week days. On-site staff is not included.
Data Source:
(a) Population data provided by Police Dog Unit.
(b) Population data provided by Hong Kong Police Force
(c) Population data provided by Immigration Department
(d) Land Use Planning for the Closed Area-Feasibility Study [5]
(e) Population number is estimated based on site survey and HK GeoInfo Map [31]. The average household size is assumed to be 3 which is the average household size in Hong Kong according to 2011 Census [3]
(f) Population data provided by Planning Department
(g) Population data provided by Civil Engineering and Development Department
(h) Working paper of feasibility study, Development of Organic Waste Treatment Facilities Phase 2

Table 4.8 Current Traffic Population (2012) and Future Traffic Population (2017) around OWTF 2 Project Site

ID	Description	Landuse	Current Population (2012)		Future Population (2017)		Indoor	Outdoor	Source
			Daytime	Night-time	Daytime	Night-time			
R1	Man Kam To Road (2.1 km)	Road	67	27	290 (8)	116 (8)	0	1	(i), (j), (k)
R2	Kong Nga Po Road (2.3 km)	Road	56 (7)	24 (7)	84 (8)	34 (8)	0	1	(j), (k)
R3	Sha Ling Road (6) (1.6 km)	Road	6	3	29	12	0	1	(i)

Note:

(6) Traffic on Sha Ling Road (ID: R3) is assumed to be 10% of Man Kam To Road (ID: R1) for conservatism, e.g. daytime 67 / 2.1km x 1.6km x 10% = 5.10, roundup to 6.

(7) 2016 Traffic data from TIA of Land Use Planning for the Closed Area - Feasibility Study (Future) [5] is applied to 2012 on conservative side.

(8) 2021 Traffic data from TIA of Land Use Planning for the Closed Area - Feasibility Study (Future) [5] is applied to 2017 on conservative side.

Data Source:

(i) AADT 2011 [6]

(j) TIA of Land Use Planning for the Closed Area - Feasibility Study (Future) [5]

(k) TIA of Development of Organic Waste Treatment Facilities 2 - Feasibility Study

4.4.2.3 Surrounding Topography

OWTF 2 is located about 30m above the Principal Datum (mPD). From this point the land slopes gently down towards Man Kam To Road. From site survey and desktop study it has been determined that the most populated areas around OWTF 2 are located around Man Kam To Road and most of the residential premises are low-rise village houses. During assessment the effect of topography was taken into account by using a surface roughness length parameter of 50 cm. This setting can reflect the numerous bushes and obstacles presents around the Project site area [10].

4.4.2.4 Meteorological Data

Meteorological data is required for consequence modelling and risk calculation. Consequence modelling (i.e. dispersion modelling) requires wind speed and stability class to determine the degree of turbulent mixing potential whereas risk calculation requires frequencies of occurrence for each combination of wind speed and stability class. The meteorological data from the Ta Kwu Ling Weather Station in 2010 was adopted in this HA. The data are transformed into a set of weather classes in accordance with the TNO purple book [11] for daytime and night-time, and can be expressed in a combination of wind speed and Pasquill stability classes. Pasquill stability classes (A to F) represent the atmospheric turbulence with class A being the most turbulent class while class F is the least turbulent class [12]. The six most dominant sets of wind speed-stability class combination for both daytime and night-time were identified and the occurrence probability of each weather class is summarised in **Table 4.9** and **Table 4.10**. The average ambient temperature adopted in the analysis is 23°C and relative humidity is 78%.

Table 4.9 Daytime Weather Conditions (Ta Kwu Ling Weather Station 2010)

Wind Direction	2.5B	1D	4D	7D	2.5E	1F	Total
0	8.71	1.45	2.25	0.14	0.9	1.97	15.42
30	2.49	0.83	0.66	0.17	0.21	0.81	5.17
60	2.94	0.47	0.07	0	0.12	1.02	4.62
90	21.48	2.8	3.51	0	1.19	2.23	31.21
120	6.34	1.59	3.25	0.05	1.57	2.18	14.98
150	1.92	0.71	0.17	0	0.19	1.12	4.11
180	2.14	0.66	0.21	0	0.07	1.07	4.15
210	5.63	0.9	0.28	0	0.21	0.66	7.68
240	3.04	0.36	0.17	0	0.05	0.55	4.17
270	1.38	0.28	0	0	0	0.4	2.06
300	1.28	0.19	0.02	0	0.02	0.38	1.89
330	2.47	0.59	0.19	0	0.17	1.09	4.51
Total	59.82	10.83	10.78	0.36	4.7	13.48	100

Table 4.10 Night-time Weather Conditions (Ta Kwu Ling Weather Station 2010)

Wind Direction	2.5B	1D	4D	7D	2.5E	1F	Total
0	0	0	3.08	0.07	1.67	5.76	10.58
30	0	0	1.3	0.12	1.03	2.81	5.26
60	0	0	0.02	0	0.3	3.77	4.09
90	0	0	4.09	0.05	6.6	11.72	22.46
120	0	0	4.8	0.07	6.62	14.18	25.67
150	0	0	0.12	0	0.54	7.73	8.39
180	0	0	0.1	0	0.47	6.2	6.77
210	0	0	0.17	0	0.89	5.39	6.45
240	0	0	0.1	0	0.15	2.95	3.2
270	0	0	0	0	0	1.45	1.45
300	0	0	0.02	0	0.1	2.09	2.21
330	0	0	0.07	0	0.42	2.95	3.44
Total	0	0	13.87	0.31	18.79	67	100

The percentage frequencies are plotted in the form of a wind rose in **Figure 4.5**.

4.4.2.5 Preliminary Design of Generation, Transfer, Storage and Use of Biogas at OWTF 2

The Project is intended to be delivered under a Design Build Operate (DBO) contract arrangement. Therefore, more detailed design information will be provided by the appointed Contractor following tender award. For the purposes of the Feasibility Study, investigations and tendering, a preliminary design has been produced and has been used as the basis of this assessment. Future design development carried out by the appointed Contractor must observe all relevant legislation and guidance, and shall not exceed the risk levels agreed with the regulator under the approved environmental permit unless agreed by the authorities.

Proven biological treatment technologies have been adopted to recover reusable materials and energy, such as compost and biogas from source-separated organic waste. Biogas may be used for onsite heat and power production or for direct injection in the gas network. The preliminary site layout is shown in **Figure 4.1. Figure 4.6** and **Figure 4.7** show the proposed treatment process and mass balance diagram from the Preliminary Design.

An indicative summary of the treatment process is as follows:

The incoming organic waste will pass through a pre-treatment stage which will separate out unsuitable materials and reduce organic material to a homogenous size. Pre-treated material will then be directed to anaerobic digesters. It is proposed to have three vertical cylindrical shaped digesters with each size 5,572 m^3, which can be concrete, steel or glass enamel tanks. Biogas will be generated continuously from digesters with production rate of around 33,285 Nm^3/day.

There will be pressure relief valves installed on the digesters and gasholder protecting against overpressure and under-pressure (50 mbarg/-2 mbarg) and on the gas storage (38 mbarg). Over flow pipes will be provided on the digesters and gasholder for protection against overfilling.

The digesters will also produce solid waste material, which will be dewatered for composting. Wastewater from the dewatered compost will pass through a wastewater treatment plant.

Biogas composition is dependent on the composition of the food waste and the final design of the adopted system. From the preliminary design information, the composition of biogas from Anaerobic Digestion (AD) process are extracted and shown in **Table 4.11** below.

Table 4.11 Composition of Biogas from Anaerobic Digestion (AD) Process

Composition & Parameters		Biogas from AD
Methane	(%)	62 (55~70)
Carbon Dioxide	(%)	38 (30~45)
Density	(Kg/Nm^3)	1.2
Lower Caloric Value	(MJ/Nm^3)	23

The produced biogas will pass through a purification process which consists of a chemical absorption unit and a purification unit. The process will remove the hydrogen sulphide and carbon dioxide from the biogas. According to the Biogas Utilisation Paper [32], the potential uses of the purified biogas are as follows:

1. **Generation of heat and electricity by Combined Heat and Power (CHP) system:** The biogas will be treated and then used to generate electricity and heat through co-generation equipment. The heat and electricity generated will be used onsite. Any surplus electricity will be supplied to the power grid; or

2. **Purification of biogas and connection to a gas pipeline:** The biogas will be treated to remove impurities. Sulphur will be removed by absorption and moisture, siloxanes, carbon dioxide and other impurities will be condensed out by refrigeration. Then, the purified biogas can be connected to an existing synthetic natural gas pipeline, which runs from NENT landfill to Tai Po Gas Production Plant. Direct injection would be achieved via a 5.5km (approx.) pipeline aligned along the Kong Nga Po road to the south-west. The external pipeline will be developed, owned and maintained by the gas utility company up to the appropriate connection point within the OWTF 2 site boundary.

Either one of the above options may be adopted for OWTF 2. The final biogas utilisation option will be confirmed at later stage of the Project. Both cases are considered in the assessment as a conservative approach.

4.5 Hazard Identification

Potential hazardous scenarios associated with generation, transfer, storage and use of biogas in OWTF 2 have been identified. Historical incidents and relevant studies of similar facilities were reviewed to identify possible hazardous scenarios. In addition, the OWTF 1 HA Study [7] has been reviewed to ensure all the relevant hazardous scenarios are incorporated into this Study.

4.5.1 Review of Historical Incident Database

Review of Major Hazard Incident Data Services (MHIDAS) database, eMARS, FACTS, ARIA as well as internet searches was conducted, to further investigate the possible hazards from organic waste treatment facilities involving generation, transfer, storage and use of biogas or methane, anaerobic digesters or facilities of similar nature.

A total of 11 records were identified and grouped into different incident scenarios for further analysis. Details of incident data retrieved from these databases are shown in **Appendix 4.1**.

Table 4.12 summarises the incidents records related to biogas and methane.

Table 4.12 Summary of Biogas or Methane Incidents

Hazardous Scenario	No. of Cases	Country
Methane Storage Tank Failure	3	Turkey, India, Australia
Methane Pipeline Failure	2	UK, USA
Anaerobic Digestion Plant Failure	6	Italy, France, Germany, India

Related biogas or methane release scenarios have been examined. The recorded hazardous scenarios are associated with leakages from piping, valves and storage vessels and operator error.

4.5.2 Review of Relevant Studies

Relevant studies were reviewed in order to identify potential biogas impacts from explosion and flammability. Failure events and the respective hazardous scenarios associated with the biogas facilities have been identified in the approved HK EIA report "Organic Waste Treatment Facilities (OWTF), Phase 1 (EIA-176/2009)" [7] and "Development of a Biodiesel Plant at Tseung Kwan O Industrial Estate (TKOIE) (EIA-156/2008)" [13].

The OWTF 1 HA Study [7] evaluated the risk to construction workers and operational staff of the OWTF 1 due to the transport, storage and use of chlorine associated with the operations at Siu Ho Wan Water Treatment Works (SHWWTW). Chlorine is a poisonous, greenish-yellow gas described as having a choking odour. A set of hazardous scenarios associated with the transport, storage and use of chlorine at SHWWTW was included in the QRA for OWTF 1 [7], which also included the scenarios associated with the impact from biogas storage of OWTF Phase I on the chlorine store of SHWWTW. The hazardous scenarios of biogas identified in OWTF 1[7] were reviewed and adopted in this QRA study where applicable.

The Risk Assessment of the Biodiesel Plant at Tseung Kwan O Industrial Estate [13] assessed risk to life of the general public, including the workers of nearby plants, from the proposed facility during the operational phase of the biodiesel plant. Biogas is generated from an internal circulation (IC) reactor in the water treatment plant. Biogas is temporarily stored in a biogas buffer tank. Biogas consists mostly of methane and its properties are very similar to Natural Gas (NG). While it is non-toxic, in high concentrations it could lead to asphyxiation. A loss of containment can lead to jet fire (if stored/ transferred under sufficient pressure) or to an explosion if the gas accumulates in a confined space. [13] The possible biogas hazards identified in the biodiesel plant study were included in this Study where applicable.

4.5.3 Biogas Properties

Biogas is a colourless flammable hydrocarbon gas at atmospheric conditions. Generally, biogas has a methane content of 55% to 70% by volume. The physical and chemical characteristics of biogas are modelled as a composition of 70-mol% methane and 30-mol% carbon dioxide [7] as a conservative approach (flammability increases with increase of methane content). Properties of biogas are very similar to those of Natural Gas (NG), which is presented in **Table 4.13.**

Biogas can be further purified in the later processing stages. Carbon dioxide party removed increases the methane content to at least 80% by volume. 100% methane is used to model the purification unit as a conservative approach.

Table 4.13 Properties of Biogas (Natural Gas)

Property	Values
Flammability	Extremely Flammable
Auto-Ignition Temperature	580°C
Flash Points	-188°C
Melting Point	-182.5°C
Boiling Point	-161.4°C
Flammable Limits	5% (Lower) – 15% (Upper)
Vapour Density	0.59-0.72 (air = 1)

4.5.4 Spontaneous Failures

Gasholder Failure

The Preliminary Design recommends the use of a dry membrane fixed tank gasholder with steel containment for evening out variations in biogas production from the digesters. This type of gas holder typically consists of an external steel containment which forms the outer shape of the tank, as well as an internal membrane (a "dry bag") which makes up the actual gas space. A non-return valve is installed at the inlet pipe to prevent gas from back-flow. Gas is discharged through the outlet pipe by suction blower. There are pressure relief valves on the gas holder for protection against the exceedence of designed gas storage pressure (38 mbarg), and over flow pipes on the gas holder for protection against overfilling. There will be emergency shut-off valves at the inlet and outlet pipes of the gas holder. In case of gas holder failure, the emergency shut-off valves can close the inlet and outlet pipes and the release of biogas to the atmosphere can be minimised.

A gas holder of dry bag type is different from column guided water-sealed gas holders, which do not have a gas holder crown. Therefore, tilting of tank top or blown seal failure will not occur in the operation of the gas holder. However, release of biogas could be from various parts of the gas holder or associated piping and devices. Possible hazardous outcomes include fireball, jet fire, flash fire and Vapour Cloud Explosion (VCE) [7].

The size of the gas storage, for evening out the variation in the gas production, is equal to 1 hour gas production. Assuming an hourly production rate of 1,387Nm^3 per hour, the required gas storage capability will therefore be around 1,400 Nm^3, with a design for 2 x 800m^3 gas holders. The storage amount of the biogas will be around 1,920 kg. The maximum storage quantity is less than 15 tonnes. The quantity does not exceed the lower threshold quantity for existing Potentially Hazardous Installations (PHIs) for flammable gas and town gas installations in Hong Kong. Therefore, the proposed waste treatment facilities are not classified as a PHI.

Digester and Sulphur Absorption Vessel Failure

The preliminary design of the OWTF 2 incorporates three digester tanks with a combined volume of 15,858m^3. The digesters consist of concrete, steel or glass enamel holding tanks, with either gas or top mounted mixing systems. Approximately 300tpd of organic waste slurry will enter the digestion tanks along with additional water to reduce the Dissolved Solid (DS) content from an estimated 22% to 10%. The estimated average residence time within the digesters is assumed to be 21 days. Providing space for mixing and gas production gives a volume requirement of approximately 15,000 m^3 (biogas volume is about 858 m^3) in total of the three digesters. Therefore, a biogas volume of 286 m^3 will be assumed in each digester. Heating is required for heating of biomass during feeding of the digesters and for heat loss compensation from the digesters. The required heating will be provided via heat recovered from the CHP unit, or from a boiler. Pressure relief valves will be installed on the digester for protection against overpressure and under pressure (50 mbarg/ -2 mbarg) and over flow pipes on the gas holder protecting against overfilling.

Two 5m^3 sulphur absorption vessels are provided downstream of the gasholders for the absorption of hydrogen sulphide in the biogas. The absorption vessels are made of steel and filled with absorbents, (Zinc oxide or Iron oxide). An explosion proof blower will be used to extract the biogas from gasholder to the sulphur absorption vessels at 400 mbarg. The absorbents are neither flammable nor explosive so the major hazard will be from the release of biogas.

Failure of the digesters or the sulphur absorption vessels can be caused by undetected corrosion, fatigue, material or construction defect. Release of biogas could be from various parts of the process vessels as well as associated piping and devices. Possible hazardous outcomes include fireball, jet fire, flash fire and VCE.

Aboveground Inlet or Outlet Piping Failure

Piping will be used to connect process vessels to the gasholder, compressor, and further purification unit and gas grid connection point. Failure along the on-site piping may be caused by undetected corrosion, fatigue, material or construction defect, or associated with flange gasket / valve leakage resulting in continuous gas release to the atmosphere. Failures of gaskets and valve leak only tend to give relatively small scale leakage and will not contribute to any off-site risk. Nevertheless, gasket and valve leak failure will be considered and be absorbed into pipework failure in the study. [8] For above ground piping, possible hazardous outcomes include jet fire, flash fire and VCE. For underground piping, possible hazardous outcomes include flash fire and VCE.

An above ground pipeline of 300 mm diameter will be installed. The length of the aboveground pipeline is estimated to be 100 m long by referring to the equipment layout in the Project Site. A length of 200 m for the above ground pipeline has been adopted in the study to represent a conservative approach.

Purification Unit Failure

A purification unit is used to condense carbon dioxide from the biogas, leaving a majority of methane which is used for heat and power generation or gas utilisation downstream. The major modes of failure in the purification unit are similar to those of the above ground piping failures described in earlier paragraphs.

Since the purification unit mainly consists of a pipeline, a 100 mm diameter pipeline at 20 barg with 100 m length has been adopted in the study to represent a conservative approach.

4.5.5 External Hazards

External hazards that are outside the control of the operating personnel could still pose a threat to the OWTF 2. Such hazards are termed as ‘external hazards’ because they are independent of the operations on-site but can lead to major hazard scenarios. This section discusses the credibility of loss of containment due to the external hazards with respect to Hong Kong’s geographical location.

Aircraft Crash

The OWTF 2 site is located about 32 km from the Hong Kong International Airport. The frequency of aircraft crash has been estimated using the HSE methodology, which is in line with approved “Kai Tak Development” EIA report [8] [17]. Details of frequency analysis are given in **Section 4.6.2**.

Helicopter Crash

Historical incidents show that helicopter accidents during take-off and landings are confined to a small area around the helipad, extending up to 200m from the centre of the helipad [13] [17]. 93% of accidents occur within 100m of the helipad. The remaining 7% occur between 100 and 200m of the helipad.

Since the distance to nearest helicopter landing pad (namely Man Kam To Helicopter Landing Pad) is about 1,000 m away from the Project site [31], as shown in **Figure 4.12**, only the background crash rate for helicopters is considered in this report. Details of frequency analysis are given in **Section 4.6.2**.

Vehicle Impact

Only authorised vehicles will be permitted to enter the OWTF 2 site, and speed will be restricted for vehicle movements around the site. Safety markings and marked crash barriers will be provided to the above ground piping, digesters and the gas holder near the entrance. The accident rate is calculated to be $1.80x10^{-07}$ severe car accident per km per year based on statistical data for Vehicle/ Object Crash accident involving medium and heavy goods vehicles in recent years, which is in line with approved EIA report "Hong Kong Section of Guangzhou - Shenzhen - Hong Kong Express Rail Link" [23]. Details of frequency analysis are given in **Section 4.6.2**.

Earthquake

Hong Kong is situated on the southern coast of mainland China facing the South East China Sea. Hong Kong is not located within the seismic belt and according to Hong Kong Observatory, earthquakes occurring in the circum-Pacific seismic belt, which passes through Taiwan and Philippines, are too far away to affect Hong Kong significantly [14]. Although there has not been any reported case of destructive earthquake in Hong Kong, loss of containment incident due to earthquake was considered credible in this study. The probability of earthquake occurrence at Modified Mercalli Intensity Scale VII and higher in Hong Kong is low comparing to other regions, and is estimated to be 1.0×10^{-5} per year [15]. The failure probability of the equipment in an earthquake (both leak and rupture) is assumed to be 0.01. Details of frequency analysis are given in **Section 4.6.2**.

Landslides

The elevation of the Project site is about 30mPD and there is a registered slope (feature 3NW-C/C30) that lies at about 48mPD. According to Geotechnical Engineering Office's Slope Information System, the slope gradient is of 25° and is mainly made up of decomposed volcanic materials. In addition, there is a flat area (elevation of about 37mPD) in front of the slope feature toe which should act as a buffer zone limiting the hazard to the tanks/ facilities from major landslides in the area. Besides, the above ground piping, digesters and gas holders will be installed on foundations that can withstand the impact of landslide. Hence, landslides causing release of biogas are not considered further in this assessment. Details of the natural terrain study are given as below.

The Enhanced Natural Terrain Landslide Inventory and the Large Landslide Inventory have been used and the information obtained is shown in **Figure 4.13**. No landslides or slope failure are recorded to have occurred within the site or on the natural terrain which remains around the Site. A number of relict landslides have been recorded immediately to the south of the Site, but this natural terrain was removed by the site formation works carried out between 1982 and 1991. Thus, landslides causing release of biogas are not considered further in this assessment. These landslides, together with other landslides on similar natural terrain in the area, are usually located on the upper parts of the slopes, at the heads of ephemeral first-order drainage lines.

No Large Landslides are recorded in the immediate area of the Site. The nearest recorded Large Landslide is located approximately 300 m to the south-west, at an elevation of +75mPD at the head of a drainage line on the other side of the valley adjoining the Site (see **Figure 4.13**). This feature (3NWC063L) is recorded as a 30m x 25m active slide, with a sharp main scarp, hummocky morphology and absent or sparse vegetation.

Four incidents are recorded within the general area (see **Figure 4.13**), but only one of these (MW97/8/17) is in a position at the sloping area around the Site. This incident occurred on 7 August 1997 and comprised a small (0.5 cu m) failure in a soil cut slope. The cause of failure was logged by GEO as "infiltration" and "washout". No previous instability or groundwater seepage was noted. The failure appears to have involved slope C453 which was later (August 1999) improved by Prescriptive Measures.

Guidelines for Natural Terrain Hazard Studies are contained in GEO (2003). "Inclusion" criteria help to identify whether a site requires screening in respect of natural terrain hazards, and are as follows:

(a) the proposed development involves Group 1, 2 or 3 facilities, and

(b) there is "hillside" sloping at more than 15° within 100m horizontally upslope from the site.

With respect to these criteria, the existing and proposed developments at the site fall within Group 2 (a) – built-up area (this definition includes "… incinerator… refuse transfer station… manned substation…". However, criterion (b) is not met as there is no natural terrain overlooking the Site.

Under the guidelines in GEO (2003) there is no requirement for further screening or study of natural terrain hazards. "Natural terrain hazards" are defined as; open hillslope landslides; channelized debris flows; deep-seated slides; rock falls; and boulder falls.

Lightning

Lightning sparks could ignite combustible gas in air. OWTF 2 will be equipped with a lightning protection system that can effectively protect the OWTF 2 equipment from lightning. Lightning protection installations should be installed following IEC 62305, BS EN 62305, AS/NZS 1768, NFPA 780 or equivalent standards. [30] The installations will be protected with lightning conductors to safely earth direct lightning strikes. The double grounding system will be inspected regularly. Therefore, failures due to lightning strikes are to be covered by generic failure frequencies. [13]

External Fire

External fire means the occurrence of fire event which leads to the failure of the equipment inside OWTF 2. The facilities will be equipped with fire alarm and fire suppression system. In addition, stringent procedures are implemented to prohibit smoking or naked flames to be used on-site. However, hill / vegetation fires are relatively common in Hong Kong and could potentially occur near OWTF 2. Details of frequency analysis are given in **Section 4.6.2**.

Typhoon/ Tsunami

Loss of containment due to severe environmental event such as typhoon or tsunami (large scale tidal wave) is not possible. OWTF 2 will be designed to withstand wind load for local typhoon and the location of OWTF 2 means that it is not threatened by tsunami in Hong Kong. Thus, typhoon or tsunami causing a release of biogas is not considered further in this assessment.

4.5.6 Possible Hazardous Scenarios and Hazardous Outcomes

<u>OWTF Phase 1</u>

Referencing OWTF Phase I EIA [7], OWTF Phase I will be operated on a 24-hour basis daily, pre-treated material would be fed into the buffer tanks to start the anaerobic digestion process. From the buffer tanks, the material is pumped to the individual digester where a major portion of the organic material is converted into biogas. In the reference design, five vertical cylindrical digesters are provided, each with a design capacity of approximately 3,000m^3. After digestion, the material from digesters is pumped to a dewatering facility and further treated by tunnel composting. All the post-treatment facilities were located in an enclosed building with air extraction system. In summary, anaerobic digestion (AD) and composting were recommended for OWTF 1.

The biogas is then treated and compressed to approximately 100 mbar and stored in a double membrane gasholder. The design of energy recovery system aims to convert the energy contained in the biogas to electricity and heat by the application of cogeneration units (Cogen Units). A stand-by flare was provided for burning the surplus biogas in emergency or under abnormal circumstances.

The gasholder is a spherical double membrane type and is different from column guided water-sealed gas holders in that it does not have a gas holder crown. Therefore, tilting of tank top or blown seal failure will not occur in the operation of the double membrane gasholder. It is concluded that release of biogas could be from various parts of the gasholder or associated piping and devices.

<u>OWTF Phase 2</u>

For OWTF 2, a combination of anaerobic digestion (AD) and composting is considered appropriate [32]. Three vertical cylindrical shaped digesters each sized at 5,572 m^3 are proposed, which will be constructed in steel or concrete. Biogas will be generated continuously from the digesters. **Figure 4.6** shows the Process Flow Diagram (PFD) of OWTF 2.

Energy will be recovered under normal conditions, with emergency flare under emergency conditions. All biogas generated will either be exported to CHP for power generation, or further purified and exported to the gas utility distribution network. Before utilisation of biogas in either case, sulphur in biogas will be removed by absorption with two vessels of 5m^3 volume.

The preliminary design of OWTF 2 predicts biogas production is about 33,285 Nm^3/d, with a required buffer storage capacity of 1,387 Nm^3 for 1 hour capacity onsite. As the design is still preliminary, a buffer storage capacity of 1,600 m^3 is adopted in this HA study as a conservative approach.

Based on the review of OWTF 1 and available information of OWTF 2, both facilities will be using similar organic waste treatment technology, that is a combination of anaerobic digestion (AD) and composting.

The sulphur absorption vessels are structurally similar to anaerobic digestion vessels. **Table 4.14** identifies the possible hazardous scenarios and hazardous outcomes in OWTF 2, making reference to the OWTF 1 EIA Study [7].

Table 4.14 Possible hazardous scenarios and hazardous outcomes in OWTF 2

Potential Cause	Reference ID in Figure 4.6	Release Type	Hazardous Outcome
Gasholder	16	Rupture	Fireball VCE Flash fire
		Leak	Jet fire VCE Flash fire
Digester	13	Rupture	Fireball VCE Flash fire
		Leak	Jet fire VCE Flash fire
Sulphur absorption vessels	General impurities removal equipment for biogas purification	Rupture	Fireball VCE Flash fire
		Leak	Jet fire VCE Flash fire
Aboveground inlet or outlet piping / purification piping/ pump / non-return valve / flange	General plant item	Rupture / Leak	Jet fire VCE Flash fire
Safety valve *	General plant item	Discharge due to overfilling	Jet fire VCE Flash fire

Note: #Aboveground inlet or outlet piping will be assumed for all piping in this HA study that takes into account failure of piping will lead to direct release to the atmosphere, on conservative approach.
* Safety valve is a valve mechanism which automatically opens when the pressure exceeds pre-set conditions. Safety valve as a safety measure, the design shall take into account discharging any released fluid to a safe location to avoid hazardous outcome. Hence, safety valve causing a release of biogas shall not be considered as potential cause in this assessment.

Possible hazardous outcomes will be assessed using PHAST Professional version 6.53, to determine the risk impact, where the potential risk associated with the operation, layout and facilities threat posed to life and neighbouring property in a hazardous outcome at the Project. Details of consequence analysis are shown in **Section 4.7**.

4.6 Frequency Analysis

Frequencies for each of the identified hazardous scenarios are estimated using the best available failure data or historical accident data in the process and gas industry. The frequencies documented in the relevant sources are reviewed and justified if necessary, to reflect the specific operation and risk reduction practices evident at the organic waste treatment facilities.

When the historic data on failure frequency is not available, failure frequencies of similar installations or events are adopted with suitable modifications based on the process conditions of OWTF 2. For example, the failure frequency of the fixed tank dry membrane type biogas holder is not readily available in literature, the failure frequency of double containment tank (which is available in TNO purple book [11]) having a similar structural arrangement will be used in this HA Study. Modification is made according to the specifications as required.

4.6.1 Spontaneous Failures Frequencies

Gasholder Failure

The Preliminary Design recommends the use of a fixed steel tank dry membrane type gas holder for evening out variations in biogas production at the OWTF 2 site. This type of gas holder typically consists of an external cylindrical steel tank, and an internal membrane, which makes up the actual gas space. According to “Bevi Risk Assessments” published by National Institute of Public Health and the Environment (RIVM), the catastrophic rupture and leak failure leading to release to atmosphere of double containment tank are 1.25 x 10^{-8} per year and 1 x 10^{-4} per year respectively. [34]

Digester / Sulphur Absorption Vessel Failure

The preliminary design of the OWTF 2 incorporates three digester tanks each with a volume of 5,572m^3 and a combined volume of 15,858m^3. Each digester consists of a concrete, steel or glass enamel holding tank, with either gas or top mounted mixing systems. The system also incorporates two sulphur absorption vessels each with a volume of 5 m^3. The catastrophic rupture and leak failure frequencies of digester tank / sulphur absorption vessel are 1 x 10^{-5} per year and 1 x 10^{-4} per year respectively. [11]

Aboveground / Purification Unit Piping Failure

Failure along the onsite piping may be caused by undetected corrosion, fatigue, material or construction defect, or associated with flange gasket / valve leakage resulting in continuous gas release to the atmosphere. For aboveground piping, catastrophic rupture and leak failure frequencies are 1 x 10^{-7} per metre per year (300 mm dia.) and 5 x 10^{-7} per metre per year (30 mm dia.) respectively. [11]. According to the OWTF 2 layout plan as shown in **Figure 2.4**, a length of approximately 150 m is measured between digesters and the gasholder. Nevertheless, a length of 200 m is assumed for the aboveground pipelines for a conservative approach.

A summary of the base event frequencies are shown in **Table 4.15**.

Table 4.15 Summary of Spontaneous Failures Frequencies

Events	Frequency of Occurrence	
	Rupture	Leak
Gasholder	1.25 E-8 per year	1.00 E-4 per year
Digester/Sulphur Absorption Vessel	1.00 E-5 per year	1.00 E-4 per year
Aboveground Inlet or Outlet Piping	1.00 E-7 per metre per year	5.00 E-7 per metre per year

Events	Frequency of Occurrence	
	Rupture	Leak
Purification Unit Piping	3.00 E-7 per metre per year	2.00 E-6 per metre per year

4.6.2 External Event Frequencies

Aircraft Crash

The OWTF 2 site is located around 32 km from the Hong Kong International Airport. The frequency of aircraft crash is estimated using the HSE methodology, which is in line with approved “Kai Tak Development” EIA report [8] [17].

The model takes into account specific factors such as the target area of the proposed hazard site and its longitudinal (x) and perpendicular (y) distances from the runway threshold. The crash frequency per unit ground area (per km^2) is calculated as:

$$g(x,y) = NRF\,(x,y) \qquad \text{(Equation 1)}$$

Where *N* is the number of runway movements per year and *R* is the probability of an accident per movement (landing or take-off). $F_L(x,y)$ gives the spatial distribution of crashes and is given by:

For aircraft landing,

$$F_L(x,y) = \frac{(x+3.275)}{3.24} e^{\frac{-(x+3.275)}{1.8}} \left[\frac{56.25}{\sqrt{2\pi}} e^{-0.5(125y)^2} + 0.625 e^{-\frac{|y|}{0.4}} + 0.005 e^{-\frac{|y|}{5}} \right] \qquad \text{(Equation 2)}$$

for x >-3.275 km

For aircraft take-off,

$$F_T(x,y) = \frac{(x+0.6)}{1.44} e^{\frac{-(x+0.65)}{1.2}} \left[\frac{46.25}{\sqrt{2\pi}} e^{-0.5(125y)^2} + 0.9635 e^{-4.1|y|} + 0.08 e^{-|y|} \right] \qquad \text{(Equation 3)}$$

for x >-0.6 km

Equations 2 and **3** are valid only for the specified range of *x* values. If *x* lies outside this range, the impact probability is zero. Aircraft Crash Coordinate System is shown in **Figure 4.8**.

NTSB data [18] for fatal accidents in the US involving scheduled airline flights during the period 1986-2010 are given in **Table 4.16**. The 10-year moving average suggests a downward trend with recent years showing a rate of about 1×10^{-7} per flight. However, only 18.7% of accidents are associated with the approach to landing, 14% are associated with take-off and 4.7% are related to the climb phase of the flight [19]. The accident frequency for the approach to landings hence becomes 1.87×10^{-8} per flight and for take-off / climb 1.87×10^{-8} per flight. Arrival and departure flight paths of Hong Kong International Airport are shown in **Figure 4.9** and **Figure 4.10** respectively.

Table 4.16 U.S Scheduled Airline Accident Rate [18]

Year	Accident rate per 1,000,000 flights for accidents involving fatalities	10-year moving average accident rate per 1,000,000 flights
1986	0.14	-
1987	0.41	-
1988	0.27	-
1989	1.1	-
1990	0.77	-
1991	0.53	-
1992	0.53	-
1993	0.13	-
1994	0.51	-
1995	0.12	0.451
1996	0.38	0.475
1997	0.3	0.464
1998	0.09	0.446
1999	0.18	0.354
2000	0.18	0.295
2001	0.19	0.261
2002	0.00	0.208
2003	0.20	0.215
2004	0.09	0.173
2005	0.27	0.188
2006	0.19	0.169
2007	0	0.139
2008	0	0.13
2009	0.1	0.122
2010	0	0.104

The number of flights from 2001 to 2011 is extracted from the Civil Aviation Department [20], and extrapolated to year 2017 by adopting an annual growth rate of 8% for aircraft movements based on Air Traffic Statistics at HKIA [21]. The number of flights at Chek Lap Kok for year 2017 is estimated at 529,707 The number of plane movements is illustrated in **Table 4.17** below:

Table 4.17 Hong Kong International Airport Civil International Air Transport Movements of Aircraft

Year	Landing	Take-off	Total
2001	98,415	98,402	196,817
2002	103,355	103,346	206,701
2003	93,748	93,759	187,507
2004	118,662	118,646	237,308
2005	131,759	131,745	263,504
2006	140,203	140,177	280,380
2007	147,675	147,657	295,332

Year	Landing	Take-off	Total
2008	150,577	150,561	301,138
2009	139,715	139,684	279,399
2010	153,277	153,257	306,534
2011	166,918	166,887	333,805
2017			529,707 (projected)

The number of plane movements has been divided by 8 to take into account that half of movements are take-offs and only a quarter of landings use specific runways (i.e., runway 07R, 07L, 25L, 25R). This effectively assumes that each runway is used equally.

Considering landings on runway 25R for example, the values for x and y are estimated to be 30 and 16 km respectively. *x and y are measured by Geoinfo map and the difference between north and south runway is assumed to be negligible.

Applying Equation 2 gives $F_L = 1.96 \times 10^{-11}$ km^{-2}. Substituting this into Equation 1 gives:

$$g(x,y) = NRF(x,y) = \frac{529707}{8} \times 1.87 \times 10^{-8} \times 1.96 \times 10^{-11} = 2.427 \times 10^{-14} \mathrm{year}^{-1}\mathrm{km}^{-2}$$

Table 4.18 shows the calculated impact frequency due to aircraft crash is 1.17×10^{-15} per year, which is much less than 1.0×10^{-9} per year. The risk of aircraft crash at the OWTF 2 site is therefore not considered further in the analysis.

Table 4.18 Aircraft Crash Frequency onto the OWTF 2 Site

Site	Distance from Runway Threshold (km)				Crash Frequency (/km^2/yr)*					OWTF2 Area (m^2)	Impact Frequency (/yr)
	07L/25R		07R/25L		07L	25R	07R	25L	Total		
	x	y	X	y	Take-off	Landing	Take-off	Landing			
OWTF2	30	16	30	16	1.91E-21	2.43E-14	1.91E-21	2.43E-14	4.86E-14	24156	1.17E-15

Note: Size of the Project Area is referenced from Statutory Planning Portal [22].

Helicopter Crash

Historical incidents show that helicopter accidents during take-off and landings are confined to a small area around the helipad, extending up to 200m from the centre of the helipad [13] [17]. 93% of accidents occur within 100m of the helipad. The remaining 7% occur between 100m and 200m of the helipad.

For most sites, no consideration is given to helicopter crashes associated with helipads when there are no helipads within 200m of the site [19]. Since the distance to nearest helicopter landing pad (namely Man Kam To Helicopter Landing Pad) is about 1,000m away from the Project site [31], as shown in **Figure 4.12**, only the background crash rate for helicopters is considered in this report.

The background crash rate for helicopters is assumed to be 1.00 x 10^{-5}/km^2/year [35], and hence, by accounting for the areas of anaerobic digesters (254.5m^2 x3), gas holders (63.6m^2 x2), aboveground pipeline area (80m^2), sulphur absorption vessels (7m^2 x2) and purification unit area (150m^2) , the background crash frequencies of helicopter for anaerobic digesters, gas holders, aboveground pipeline, sulphur absorption vessels and purification unit are 7.635 x 10^{-9}/year, 1.272 x 10^{-9}/year, 8 x 10^{-10}/year, 1.4 x 10^{-10}/year, and 1.5 x 10^{-09}/year respectively.

Vehicle Impact

The accident rate is calculated to be 1.80 x 10^{-7} severe car accident per km per year based on statistical data for Vehicle/ Object Crash accident involving medium and heavy goods vehicles in recent years.

Making reference to Road Traffic Accident Statistics obtained from HKSARG Transport Department [33], the overall number of accident involvements per million vehicle-kilometres is given in **Table 4.19** for Medium/ Heavy Goods Vehicles (M/HGVs).

Table 4.19 Hong Kong Vehicle Accident Involvements

Serious and Fatal Vehicle involvements	2003	2004	2005	2006	2007	2008	2009	2010	2011	Average
Invol rate: per million veh-km										
M/HGV	0.79	0.89	0.89	0.86	0.82	0.8	0.76	0.83	0.91	0.84
Total involvements										
M/HGV	1108	1197	1180	1155	1081	1045	907	1031	1141	1094
Fatal involvements										
M/HGV	50	31	27	25	21	17	27	16	22	26
Serious injury involvements										
M/HGV	255	291	257	212	188	176	147	163	196	209
Slight injury involvements										
M/HGV	1136	1380	1412	1364	872	1176	1050	1205	1370	1218
Fatal vehicle involvements ratio										
M/HGV	4.5%	2.6%	2.3%	2.2%	1.9%	1.6%	3.0%	1.6%	1.9%	2.4%
Serious injury involvements ratio										
M/HGV	23.0%	24.3%	21.8%	18.4%	17.4%	16.8%	16.2%	15.8%	17.2%	19.0%
High impact accident involvement rate per million vehicle km										
M/HGV	0.04	0.02	0.02	0.02	0.02	0.01	0.02	0.01	0.02	**0.02**
Medium impact accident involvement rate per million vehicle km										
M/HGV	0.18	0.22	0.19	0.16	0.14	0.13	0.12	0.13	0.16	**0.16**

The data generally shows a constant overall accident involvement rate in the past 9 years. The statistics indicate an overall impact accident involvement rate of 0.18 (=0.02 + 0.16) involvements per million vehicle kilometre (pmvkm) for MGV/HGV. Therefore, the vehicle crash frequency is estimated to be 1.8×10^{-7} per vehicle kilometre per year.

Only authorised vehicles will be permitted to enter the OWTF 2 site, and speed will be restricted for vehicle movements. Safety markings and marked crash barriers will be provided to the aboveground piping, digesters gasholders and purification unit, as shown in **Figure 4.1**.[1] Therefore, it is assumed that vehicle impact could only cause leak failure to digesters and gas holders, whereas it could cause both rupture failure and leak failure to aboveground piping [9].

Earthquake

Hong Kong is situated on the southern coast of mainland China and facing the South East China Sea. Hong Kong is not located within the seismic belt and according to Hong Kong Observatory, earthquakes occurring in the circum-Pacific seismic belt, which passes through Taiwan and Philippines, are too far away to affect Hong Kong significantly [14]. Although there has not been any reported case of destructive earthquake tremor in Hong Kong, loss of containment incident due to earthquake was considered credible in this study. The probability of earthquake occurrence at Modified Mercalli Intensity Scale (MMIS) VII and higher in Hong Kong is low comparing to other regions, and is estimated to be 1.0×10^{-5} per year [15]. The failure probability (for both leak and rupture) of the equipment in an earthquake is assumed to be 0.01 [16].

External Fire

Although OWTF 2 is not located in a country park, some of the surrounding terrain and vegetation is similar to that typically found in country parks. According to the statistics from the Agriculture, Fisheries and Conservation Department, the average number of hill fires was 30 per year during the recent five years 2009 – 2013 (range: 16 to 51). Since the total area of country parks in Hong Kong was 43,394 Ha as in 2011 (most recent available figure), the frequency of hill fire in Hong Kong is taken as 6.91×10^{-8} per m^2 per year.

At the thermal radiation intensity of 37.5 kW/m^2, damage to process equipment can happen [24]. From the literature, for a heat flux of 37.5 kW/m^2, the corresponding flame-to-structure distance is 25 m caused by burning in tree canopy producing persistent flames [36]. For a conservative approach, 50 m is adopted in this study to account for uncertainty (e.g. spreading of hill fire). The resulting total area used in the frequency calculation (**Figure 4.11**) is thus the total area of vegetation extending 50 m beyond the process area, which is 16119 m^2.

In OWTF 2, the facilities will be equipped with fire alarm and fire suppression system (including fire alarms, fire detectors, sprinkler extinguishing system and fire pumps) to protect the facilities against external fire. It is considered that damage to gas holders, vessels and piping happens when there is hill fire as well as failure of fire protection system. By taking into account the failure rate of fire protection system of 2.20×10^{-2} per year [24], the overall frequency of damage to gas holders, vessels and piping is 2.45×10^{-5} per year respectively. It is assumed that damage to the process equipment results in rupture failure and leak failure in equal probability. Hence, the catastrophic rupture and leak failure frequencies of gas holder / digester tank / sulphur absorption vessel / aboveground pipeline are 1.23×10^{-5} per year respectively.

1 The location of above ground piping, digesters and gas holders and purification unit and crash barriers are shown according to the best information currently available.

A summary of the base event frequencies are shown in **Table 4.20**.

Table 4.20 Summary of Base Event Frequencies

Events	Frequency of Occurrence
Aircraft Crash	1.17E-15 per year
Helicopter Crash	1.00E-05 per km^2 per year
Vehicle Impact	1.80E-07 per vehicle-km per year
Earthquake	1.00E-05 per year
External Fire	6.91E-08 per m^2 per year

Fault Tree Analysis (FTA) was conducted to evaluate the frequencies of the identified biogas release scenarios. FTA is the use of a combination of simple logic gates, "AND" and "OR" gates, to synthesise a failure model of the biogas facilities. Fault Tree Analysis is shown in **Appendix 4.2**. The assumptions used in FTA are summarised in the following table (**Table 4.21**):

Table 4.21 Assumptions used in FTA

Items	Assumed Value	Justification
probability of rupture failure in helicopter crash	1	On conservative approach
length of access road	0.16km	Measured using the preliminary plot plan (Figure 4.1)
no. vehicle movements per day	80	Conservative assumption based on the traffic assessment report of OWTF2 (60 for waste trucks, 10 for other vehicles and 10 account for uncertainty).
probability running into gasholder / digesters / absorption vessels / pipelines / purification unit	0.5	Following approved EIA report HATS 2A [9], and based on the fact that concerned process vessels are only at one side of the road.
probability damage to gasholder / digesters / absorption vessels / pipelines / purification unit	1	On conservative approach
probability rupture failure in car crash for pipeline / purification unit	0.1	Following approved EIA report HATS 2A [9]
probability leak failure in car crash for pipeline / purification unit	0.9	Following approved EIA report HATS 2A [9]

4.6.3 Ignition and Explosion Probability

The probabilities of ignition and explosion following a release depend on several factors, i.e. presence of an ignition source, material that was released, and the rate and the duration of the release. Possible ignition sources include hot surfaces, static electricity, flame and hot particles from external fire, etc [24]. The ignition probabilities are further split between immediate ignition and delayed ignition in equal proportions [13]. Immediate ignition of biogas could lead to a fireball or jet fire, whereas delayed ignition could cause a flash fire or vapour cloud explosion. **Table 4.22** shows the total ignition probabilities and explosion probabilities adopted from Cox, Lees and Ang [24] according to gas release size.

Table 4.22 Ignition and Explosion Probabilities for Gas Releases

Release Size	Probability of Ignition	Probability of Explosion
Minor (< 1 kg/s)	0.01	0.04
Major (1 – 50 kg/s)	0.07	0.12
Massive (> 50 kg/s)	0.3	0.3

Event Tree Analysis (ETA) was developed to determine the possible hazard event outcomes from the identified hazardous events and to estimate the hazard event frequencies from the initiating release frequency. Event Tree Analysis is shown in **Appendix 4.3**.

4.6.4 Estimating Generic Frequencies

Generic frequency was estimated based on the historical incidents review identified the accidents involving generation, transfer, storage and use of biogas or methane, anaerobic digesters or facilities of similar nature. The generic accident frequency can be estimated through the information of the number of biogas plants works involved, the operating period and the total number of accidents occurred within the operating period. The objective of the generic frequency estimation is to confirm the appropriateness of adopting generic failure frequencies for this HA.

The generic frequencies estimated based on European experience are 1.73×10^{-4} incident per plant-year, whilst the overall failure frequency for OWTF 2 HA is 2.27×10^{-3} (according to FTA shown in **Appendix 4.2**), which is greater than the estimated value from the European historical incidents. Therefore, the frequencies in the OWTF 2 HA Study are considered reasonably conservative. Details of generic frequency estimation are given in **Appendix 4.4**. Failure scenarios are considered in this study, and modelled comparing to the generic failure frequencies. It is assumed that the biogas facilities will be designed and constructed to the appropriate standards so that generic failure frequencies are appropriate. [13]

4.7 Consequence Analysis

The consequence assessment estimates impact of each outcome in the area of concern. The consequence assessment consists of two major parts, namely:

- Source term modelling – to determine the appropriate discharge models to be used for calculation of the release rate, duration and quantity of the release; and
- Effect modelling – to determine dispersion modelling, fire modelling and explosion modelling from the input of source term modelling.

Releases from hazardous sources and their consequences are modelled with the well-established software PHAST Professional version 6.53.

4.7.1 Source Term Modelling

For instantaneous failure, the whole content release of a tank is modelled. In case of continuous release, release parameters such as release rate and exit velocity are calculated by a discharge model according to storage conditions. Release duration is based on capacity of the storage tank.[2] For piping connecting to the reactor network, release duration is determined by the response time to completely isolate the system. For piping connecting to the storage tank, release duration is based on the time to empty the whole tank gas content for anaerobic digesters and the response time to completely isolate the gasholder. Release parameters together with release duration are then fed into the dispersion model to calculate the effect.

Process vessel, piping and storage vessel would be the major release sources. Relief pressure of pressure relief valves and isolation valves are used to estimate storage pressure in failure cases.

4.7.2 Potential Hazardous Outcomes and their Effect Modelling

The following sub-sections briefly describe the types of hazard events arising from a loss of containment scenario at the OWTF 2.

Gas Dispersion

The Unified Dispersion Model (UDM) model is used for the dispersion calculation of biogas for non-immediate ignition scenarios. The model takes into account various transition phases, from dense cloud dispersion to buoyant passive gas dispersion, in both instantaneous and continuous releases.

Fireball

For immediate ignition of an instantaneous gas release, a fireball can be formed. Fireball is more likely for immediate ignition of instantaneous release and heat is evolved by radiation. The principal hazard of fireball arises from thermal radiation. Due to its intensity, its effects are not significantly influenced by weather, wind direction or source of ignition. Sizes, height, shape, duration, heat flux and radiation are determined in the consequence analysis. A 100% fatality is assumed for anyone within the fireball radius.

Jet Fire

When a pressurised flammable gas is released and ignited immediately, a jet fire could occur. The momentum of the release carries the flammable substance forward in a long plume, giving a flammable mixture by entraining air. Combustion in a jet fire occurs in the form of a strong turbulent diffusion flame, which is heavily influenced by the momentum of the release. The major concern regarding jet fire is the heat radiation effect generated from the fire. The thermal effect to adjacent population is quantified in the consequence model.

Flash Fire

Following a hazardous gas release, it could form a flammable gas cloud initially located around the release point. If this cloud does not get ignited immediately, it could move in the downwind direction and be diluted as a result of air entrainment. Flash fire is the consequence of combustion of gas cloud resulting from

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[2] Referencing OWTF Phase I EIA [7], for a 300mm diameter hole size scenario, the whole content of the gasholder releases to the atmosphere is less than 10 minutes. It was assumed that the amount of gas in a VCE is the same as the rupture scenario. For a 30mm equivalent hole size leak scenario, it was assumed the amount of gas in a VCE is equivalent to 10 minute discharge without being noticed.

delayed ignition. The flammable gas cloud can be ignited at its edge and cause a flash fire of the cloud within the Lower Flammable Limit (LFL) and Upper Flammable Limit (UFL) boundaries.

Major hazards from flash fire are thermal radiation and direct flame contact. Since the flash combustion of a gas cloud normally lasts for a short duration, the thermal radiation effect on people near a flash fire is limited. Any persons who are encompassed outdoors by the flash fire could be fatally injured. A fatality rate of 100% is assumed.

Vapour Cloud Explosion

When there is a large amount of pressurised gas rapidly releasing to the atmosphere from a pressurised tank, a vapour cloud could be formed, dispersed and mixed with the surrounding air. If the vapour cloud is passing through a confined/ semi-confined environment and gets ignited, the confinement could limit the degree of expansion of the burning cloud and create an overpressure and explosion. This type of explosion is called a VCE.

Thermal Radiation

Hazardous consequences, such as jet fire, flash fire, etc. is assessed using PHAST's consequence models. Fatality probabilities of various hazardous event outcomes are evaluated at a number of end-point criteria in each type of hazard outcome. The estimation of the fatality/ injury caused by a physical effect such as thermal radiation requires the use of Probit equations, which describe the probability of fatality as a function of some physical effect. The probability of fatality, Pr, due to exposure to heat radiation, i.e. jet fire and fireball is given by the following probit relationship by Eisenberg et al. which provides one of the more conservative estimates [25]:

$$Pr = -14.9 + 2.56 \ln (Q^{4/3} \times t)$$

Where,
Pr is the probit associated with the probability of fatality;
Q is the heat radiation intensity (kW/m^2);
t is the exposure time (s)

4.7.3 Assessment Criteria for Biogas Hazards

Biogas rises and dilutes rapidly due to its buoyancy when it is released to the atmosphere. In case of instantaneous release of biogas, immediate ignition near the release source could lead to fireball. VCE would occur when vapour cloud is trapped between facilities and is ignited. Potential damage from a fireball and a vapour cloud explosion are caused by thermal radiation and overpressure respectively. Assessment criteria for the thermal radiation [24] and overpressure effects [26] are adopted and shown in **Table 4.23** [7].

Table 4.23 Assessment Criteria for Biogas Hazards

Outcome	Effect	Assessment Criteria	Damages
Fire	Thermal radiation intensity	37.5 kW/m^2 / Jet flame / Fireball/ LFL	Process equipment damage
VCE	Overpressure	0.2 bar (about 3 psi)	Damage to heavy machinery

The fatality probability for VCEs is taken from CIA guidelines [27] as shown in **Table 4.24**. The indoors fatality probability is higher because of the increased risk from flying debris such as breaking windows [13].

Table 4.24 End Point Criteria for Vapour Cloud Explosions

Overpressure (psi)	Fatality Probability (outdoors)	Fatality Probability (indoors)
5	0.09	0.55
3	0.02	0.15
1	0.00	0.01

The effective hazardous distances are quantified by DNV's PhastRisk v6.53 Multi-energy model [29] available in the PhastRisk. This model is used to estimate the overpressure effect of vapour cloud explosion. Referencing to the guidance suggested by Kinsella [28] was adopted to determine the confined strength via the determination of the blast strength class. Blast strength category is divided into 12 categories. Blast strength category is a combination of ignition strength, obstruction, existence of parallel plane confinement / unconfinement. "Blast strength category" is used for determining the blast strength class. "Blast strength category" 1 represents high in ignition strength, obstruction and confinement. The lower blast strength category is, the higher the blast strength class. The highest blast strength class 10 is equivalent to detonation of TNT explosive. Thus, high blast strength class implies high initial overpressure. Hazard distance in a VCE increases with the increase in initial overpressure. Blast strength category 3 (equivalent to confined strength between 5 and 7) is estimated based on the following assumptions:

- High Obstruction – 50% volume blockage ratio
- Existence of parallel plane confinement – vertical walls
- Low ignition strength – ignition sources such as spark (mechanical or electrical), flare stack, hot surface

4.7.4 Consequence Distances associated with OWTF 2

Considering the 300mm diameter hole size scenario, the whole content of the gasholder will release to the atmosphere in 3.7 minutes. For the 30mm or less equivalent hole size leak scenario, it is assumed the amount of gas in a VCE is equivalent to 10 minute discharge without being noticed. The consequence distances obtained from PhastRisk modelling for identified release scenarios are shown in **Appendix 4.5**.

For the flash fire events, it shall be noted that flash fire could spread to 146.8m upon purification unit failure, which would only last for a few seconds. Moreover, the perimeter of the fire reduces rapidly when biogas is ignited and consumed in the fire. For the fireball case, the radius of fireball is 29m and the duration is less than 5 seconds upon biogas gasholder rupture. In the worst jet fire event, the maximum jet fire flame length is 94.7m due to full bore rupture of the purification unit.

4.8 Risk Assessment

Risk Summation

Individual risk can be characterised by summation of the results of meteorological data, frequency estimation and consequence analysis, risk levels of the assessed scenarios can be presented by individual risk contours.

Societal risk of the assessed scenarios can be characterised by combining the results of population data, meteorological data, frequency estimation and consequence analysis, in terms of F-N curves.

The above steps are done by using MPACT in the SAFETI software suite v6.53.

Results

In the gasholder rupture event, the fireball duration lasts for about 5 seconds of radius 28.9m according to modelling results. The hazardous distances of flash fire and VCE in the worst case are assessed to be 146.8 m and 80.6 m respectively.

The individual risk (IR) contours associated with the OWTF 2 are shown in **Figure 4.14**. The maximum individual risk remains below $1x10^{-5}$ per year at the site boundary and hence meets the HKRG requirements.

For the societal risk of the 2017 scenario, the potential loss of life (PLL) for the OWTF 2 is 6.42×10^{-6} per year. The PLL value is very low for 2017 scenario, given the low off-site population in the vicinity.

In view of the uncertainties on the population intake (e.g. future Kong Nga Po Comprehensive Development Area, Hung Lung Hang Residential Population, Man Kam To Development Corridor and Sandy Ridge Crematorium and Columbarium Facilities) during the operational phase of the OWTF 2, the impact of OWTF 2 to the proposed developments and their population are also evaluated. The potential loss of life (PLL) for the OWTF 2 with proposed developments is 8.48×10^{-6} per year. It can be observed that the risks are higher comparing to 2017 scenario without proposed developments population intake. This is because the population intakes for all the proposed developments including Kong Nga Po Comprehensive Development Area, Hung Lung Hang Residential Population, Man Kam To Development Corridor and Sandy Ridge Crematorium and Columbarium Facilities are counted in this scenario in 2017 on conservative side.

Figure 4.15 shows the FN Curves for the 2017 scenario and the 2017 scenario with proposed developments. It can be seen that the societal risk for both scenarios are low and within the acceptable region as per HK EIAO Societal Risk Guideline. The risk increases for the case with proposed developments during the operation phase due to increase in surrounding population, but the risks are still low and in the acceptable region.

4.9 Recommendations

Although the risks for both scenarios are within the acceptable region and thus no mitigation measures are necessary, the HA has assumed that the following “Good Practices” and “recommended design measures” for the safe operation of OWTF 2 shall be carried out as far as reasonably practicable.

- The process plant building will be provided with adequate number of gas detectors distributed over the various areas of potential leak sources to provide adequate coverage.
- All electrical equipment inside the building will be classified in accordance with the electrical area classification requirements. No unclassified electrical equipment will be used during operations or maintenance.

- Reference can be made to Codes of Practice and guidance issued in Europe that applies to places where explosive atmospheres may occur (called 'ATEX' requirements). These are covered as part of the European Directive: the Explosive Atmospheres Directive (99/92/EC) and the UK regulations, Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR). Where potentially explosive atmospheres may occur in the workplace, the requirements include, identifying and classifying (zoning) areas where potentially explosive atmospheres may occur; avoiding ignition sources in zoned areas, in particular those from electrical and mechanical equipment; where necessary, identifying the entrances to zoned areas; providing appropriate anti-static clothing for employees; and before they come into operation, verifying the overall explosion protection safety of areas where explosive atmospheres may occur.
- All safety valves design shall take into account discharging any released fluid to a safe location, or stopping misdirection of fluid flows in order to avoid hazardous outcome.
- Safety markings and crash barriers will be provided to the aboveground piping, digesters and the gas holder near the entrance.
- Lightning protection installations will be installed following IEC 62305, BS EN 62305, AS/NZS 1768, NFPA 780 or equivalent standards.
- A 10m high boundary wall with fire resistance will be provided in the vicinity of the digester tanks, gasholders and gas purification equipment to protect the equipment against external fires, and to provide some protection to external areas from the effects of fire/explosion.
- Suitable fire extinguishers will be provided within the site. An External Water Spray System (EWSS) will be installed in appropriate areas, such as around the gasholders, gas purification, desulphurisation units, and digester areas. The facilities will also be equipped with fire and gas detection system and fire suppression system. Stringent procedures are implemented to prohibit smoking or naked flames to be used on-site.
- Fixed crash barriers will be provided in areas where process equipment is adjacent to the internal roadway to protect against vehicle collision. Adequate warning signage and lighting will also be provided and maximum speed limit will also be in place.

Implementation of risk mitigation measures is not required since the risk level is at the acceptable level.

4.10 Conclusion

A QRA for the proposed OWTF 2 was performed on the existing, committed and planned off-site population. Risks associated with the operational phases of the facility are evaluated to be within the acceptable region of the HK EIAO Societal Risk Guideline, for the scenarios with and without population intakes from proposed developments in the vicinity of the Project site.

Good safety practices and recommended design measures for operation of the OWTF 2 that have been assumed within the HA are summarised in **Section 4.9**. Implementation of risk mitigation measures is not required since the risk level is at the acceptable level.

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