Lime Down
Solar Park

Environmental Statement

Volume 3, Appendix 15-2: BESS Fire Emissions Modelling (Clean)

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Schedule of Changes

Revision	Section Reference	Description of Changes	Reason for Revision
2	Table 9, Table 10 and Table 11	Updated Maximum Hourly Mean Concentration values presented in Tables 9, 10 and 11 as a result of Applicant due diligence.	Updated for Deadline 2 as a result of Applicant due diligence.

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Appendix 15-2: BESS Fire Emissions Modelling

1.1 Introduction

1.1.1 The Battery Energy Storage System (BESS) has the potential to cause air quality impacts in the rare result of a fire incident. Concentrations of carbon monoxide (CO), formaldehyde, hydrogen chloride (HCl), hydrogen cyanide (HCN), hydrogen fluoride (HF), ammonia (NH_3), nitrogen dioxide (NO_2) and particulates from a potential BESS fire have been modelled using an air quality dispersion model to determine the likely effects on human health.

1.1.2 A high-level visibility assessment has also been undertaken using the modelled particulates results to determine the effect of BESS fire emissions on visibility on the local road and rail network to inform the **Outline Battery Safety Management Plan (BSMP) [EN010168/APP/7.21].**

1.1.3 The following sections outline the methodology used in the assessment and the modelling results.

1.2 Assessment Methodology

Relevant Guidance and Standards

1.2.1 **ES Volume 1, Chapter 15: Air Quality [EN010168/APP/6.1]** provides an overview of the legislation and planning policy against which the Scheme has been considered for air quality.

1.2.2 The assessment has been undertaken with due consideration of the Environment Agency's (EAs) 'Air emissions risk assessment for your Environmental Permit' guidance (Ref 15-1), which provides advice on assessing releases to air. Whilst this guidance is used for dispersion modelling for environmental permitting purposes, it includes useful general guidance on undertaking detailed modelling of emissions to air.

1.2.3 Given a potential BESS fire would be a relatively short-term incident, it is considered appropriate to compare predicted concentrations against Acute Exposure Guidance Levels (AEGLs), which have higher threshold concentrations than the national air quality objectives and are relevant to short term releases. AEGLs are expressed as concentrations of a substance above which it is predicted that the general population could experience, including susceptible individuals:

- Level 1 - Notable discomfort, irritation, or certain asymptomatic non-sensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure;

- Level 2 - Irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape; and
- Level 3 - Life-threatening health effects or death (Ref 15-2).

1.2.4 The occurrence of adverse health effects is not likely to occur in the general public at concentrations below the AEGLs. AEGLs have a range of exposure periods ranging from 10 minutes to 8 hours and the AEGLs applicable to this assessment are presented in **Table 1**. AEGLs are expressed in units of parts per million (ppm) but have been converted into units of microgram per cubic meter (µg/m^3) to allow direct comparison against predicted concentrations (as background concentrations and model outputs are provided in µg/m^3).

1.2.5 It should be noted that there are also AEGLs for 10 minute and 30 minute exposure periods, however, the dispersion model uses hourly meteorological data, therefore the shortest time period that concentrations can be predicted over is one hour. Depending on the pollutant, the 10 minute and 30 minute AEGL has an equivalent or higher threshold concentration than the corresponding 1 hour AEGL, and so comparison of hourly model outputs against 1 hour AEGL values is considered more worst-case than comparison against 10 minute and 30 minute AEGLs.

1.2.6 There is no AEGL for particulates. As such, the Health and Safety Executive (HSE) Workplace Exposure Limit (WEL) (Ref 15-3) has been used, which is 4 mg/m^3 for respirable dust. Whilst this is over an 8 hour reference period, it is considered appropriate for use in the assessment in lieu of any other limits. In the absence of an AEGL 1 threshold for CO, CO concentrations have also been compared against the World Health Organisation (WHO) 1-hour CO guideline value of 35,000 µg/m^3 (Ref 15-4), which is a lower threshold concentration than AEGL 2 and 3. The WHO air quality guidelines are a set of evidence-based recommendations of limit values for specific air pollutants developed to help countries achieve air quality that protects public health.

1.2.7 The impact of the smoke plume on visibility has been calculated based on the mass concentration of particulate matter, using the following equation developed in the Principles of Smoke Management (Ref 15-5):

$$S = K / \alpha_m m_p$$

Where:

S = visibility through smoke (m).

K = proportionality constant; value of 3 has been used in the assessment which is applicable to the observation of a non-light emitting object in smoke.

α_m = specific extinction coefficient (m^2/g); value of 7.6 m^2/g has been used in the assessment based on flaming combustion of wood and plastics (as opposed to smouldering which has lower α_m value).

m_p= mass concentration of particulate matter (g/m^3); value has been calculated using the modelled PM_{10} concentration associated with the BESS fire.

1.2.8 It should be noted that the visibility through smoke equation above is based on certain assumptions and therefore has inherent limitations, for example the extinction coefficient will depend on the particle size distribution and optical properties of the particulates. The output of the visibility calculations should therefore be treated with caution and used as a guide only.

Study Area

1.2.9 There is no guidance that exists on the assessment of emissions from BESS fires. For the purposes of this assessment, a Study Area of 1km from the BESS Area (at Lime Down D) has been used, based on professional experience of assessing emissions from similar schemes, and based on air quality assessments undertaken for fires at similar BESS sites such as Green Hill Solar Farm (Ref 15-6). The BESS fire emissions Study Area is presented in **ES Volume 2, Figure 15-5: BESS Fire Emissions Study Area, Receptors and Modelled BESS Locations [EN010168/APP/6.2]**.

Modelling Parameters

Input Data

1.2.10 Dispersion modelling was undertaken using ADMS-6 (v6.0.2.1), which is developed by Cambridge Environmental Research Consultants Ltd and is accepted for the air quality assessment of industrial source type releases within the UK by the Environment Agency, Defra and local authorities. ADMS-6 is a short-range dispersion modelling software package that simulates a wide range of buoyant and passive releases to atmosphere. It is a new generation model utilising boundary layer height and Monin-Obukhov length (height at which turbulence is generated more by buoyancy than by wind shear) to describe the atmospheric boundary layer and a skewed Gaussian concentrations distribution to calculate dispersion under convective conditions.

Table 1 AEGLs for the Modelled Pollutants (Ref 15-2)

Pollutant	1 Hour			4 Hour			8 Hour		
	Level 1 (ppm)	Level 2 (ppm)	Level 3 (ppm)	Level 1 (ppm)	Level 2 (ppm)	Level 3 (ppm)	Level 1 (ppm)	Level 2 (ppm)	Level 3 (ppm)
CO	NR*	83	330	NR	33	150	NR	27	130
Formaldehyde	0.9	14	56	0.9	14	35	0.9	14	35
HCl	1.8	22	100	1.8	11	26	1.8	11	26
HCN	2	7.1	15	1.3	3.5	8.6	1	2.5	6.6
HF	1	24	44	1	12	22	1	12	22
NH_3	30	160	1,100	30	110	550	30	110	390
NO_2	0.5	12	20	0.5	8.2	14	0.5	6.7	11
Pollutant	**1 Hour**			**4 Hour**			**8 Hour**		
	Level 1 (µg/m^3)	Level 2 (µg/m^3)	Level 3 (µg/m^3)	Level 1 (µg/m^3)	Level 2 (µg/m^3)	Level 3 (µg/m^3)	Level 1 (µg/m^3)	Level 2 (µg/m^3)	Level 3 (µg/m^3)
CO	NR	95,085	378,049	NR	37,805	171,840	NR	30,931	148,928
Formaldehyde	1105	17,195	68,780	1105	17,195	42,988	1105	17,195	42,988
HCl	2684	32,807	149,121	2684	16,403	38,771	2684	16,403	38,771
HCN	2211	7849	16,583	1437	3869	9507	1106	2764	7296
HF	818	19,642	36,010	818	9821	18,005	818	9821	18,005
NH_3	20,896	111,444	766,176	20,896	76,618	383,088	20,896	76,618	271,644
NO_2	941	22,582	37,636	941	15,431	26,345	941	12,608	20,700

*NR = Not recommended due to insufficient data

1.2.11 The model utilises hourly meteorological data to define conditions for plume rise, transport and diffusion of pollutants. It estimates the concentration for each source and receptor combination for each hour of input meteorology and calculates user-selected long-term and short-term averages.

1.2.12 The BESS Area would be situated in Lime Down D (Field D1) as shown in **ES Volume 2, Figure 3-3: Indicative 400 kV Substation and BESS Layout [EN010168/APP/6.2]**. **ES Volume 1, Chapter 3: The Scheme [EN010168/APP/6.1]** provides a description of the BESS Area, and in summary this is anticipated to include up to 270 BESS Containers. The precise number of BESS Containers will depend upon the level of power capacity of energy storage that the Scheme will require.

1.2.13 The final layout of the BESS Area will be determined during detailed design. For the purpose of this assessment, worst case BESS fire locations (i.e. locations within the BESS Area closest to sensitive receptors) have been modelled as depicted in **ES Volume 2, Figure 15-5: BESS Fire Emissions Study Area, Receptors and Modelled BESS Locations [EN010168/APP/6.2].** The arrangement of the BESS has not been finalised, therefore the maximum extent of the BESS area has been used as a worst case.

1.2.14 Each of the six BESS fire locations have been modelled as an area source so that plume rise was factored into the model (the model does not allow for plume rise for volume sources). The area source dimensions have been based on the dimensions of one BESS container (6058mm wide and 2591mm long).

1.2.15 Emissions data for BESS fires are limited. At the recommendation of the Applicant's Battery Safety and Testing Consultant, emissions data have been derived from the GridSolv Quantum Cube Bespoke Unit Testing Summary Report, prepared by Fire & Risk Alliance LLC for Wartsila North America, Inc. (Ref 15-7). The test fire was conducted using Large Format Prismatic (LFP) lithium iron phosphate battery modules; each module comprised 52 cells and each rack comprised eight modules. Emissions from a test fire were measured using a probe approximately 3.35m above ground level. The maximum recorded concentrations are presented in **Table 2**. It should be noted that the report presents concentrations for other gases (such as carbon dioxide and methane), however, only gases considered the most harmful to human health have been considered in this assessment.

Table 2 Maximum Gas Concentrations Measured above the Initiating Unit

Pollutant	Maximum Concentration (ppm)
CO	330
Formaldehyde	56
HCl	100
HCN	15
HF	44
NH_3	1,100
Nitric Oxide (NO)	20

1.2.16 Emissions data were not available in the report for particulates. As such, at the recommendation of the Applicant's Battery Safety and Testing Consultant, particulate emissions data was taken from the Axminster Energy Hub Plume Assessment Study prepared by DNV for Clearstone Energy (Ref 15-8). The assessment assumed that a battery unit fire is equivalent to a diesel fire for production of Particulate Matter and used a concentration of $0.25g/m^3$. The height at which the concentration was measured was not reported, therefore the same height as that reported in the Quantum Cube Bespoke Unit Testing Summary Report (Ref 15-7) has been assumed (3.35m).

1.2.17 The Quantum Cube Bespoke Unit Testing Summary Report (Ref 15-7) did not report a maximum temperature at the sampling point. As such, the maximum recorded temperature from the roof of another test fire was utilised, at the recommendation of the Scheme's Battery Safety and Testing Consultant. The Sungrow BESS PowerTitan 2.0 Large Scale Burn Test Report prepared by DNV for Sungrow Power Supply Co., Ltd. (Ref 15-9) reported a maximum roof temperature of 914^{o}C. In lieu of any other suitable data, this was used for the temperature. Roof temperatures can reach 1300^{o}C during a fire; it is therefore considered that using a temperature of 914^{o}C is a conservative estimate as a higher temperature would be expected to increase the buoyancy and aid dispersion.

1.2.18 When modelling a fire in ADMS, the height of the release should be the height of the flames. Maximum flame heights of around 4m were reported in the Sungrow BESS PowerTitan 2.0 Large Scale Burn Test Report (Ref 15-9). However, this exceeds the height of the sampling point, therefore the height of the release was assumed to be 3.35m (height of the sampling point). This is considered a conservative estimate as a higher release height would generally result in increased dispersion.

1.2.19 The plume rise is primarily buoyancy-driven rather than being mechanically expelled like a stack, as such a nominal value of 1m/s has been used for the velocity to activate the plume rise module (which would not activate if the velocity was 0m/s).

Meteorological Data and Surface Characteristics

1.2.20 Meteorological data recorded at Fairford weather station was used for the air quality modelling as this was the closest, most appropriate station with good data capture for the desired time period. Fairford weather station is located approximately 28km north east of the BESS Area, at RAF Fairford and is predominantly surrounded by open agricultural land. In accordance with the EA guidance (Ref 15-1), models have been run using five years of meteorological data, from 2020 to 2024 inclusive. The meteorological data was obtained from Air Pollution Services which provided hourly meteorological data for each year.

1.2.21 A surface roughness of 0.3m and minimum Monin-Obukhov length of 10m was used to represent the predominantly agricultural/rural surroundings of the Scheme. These parameters, which are determined by land use, influence wind patterns and atmospheric turbulence affect pollution dispersion. These values were selected as they were judged to be most representative of the predominant land use dispersion characteristics across the Study Area.

Building and Terrain Inputs

1.2.22 The dispersion of pollutants released from elevated sources can be influenced by the presence of buildings close to the emission point. The main effect of a building is to entrain pollutants into the cavity region in the immediate leeward side of the building, bringing them rapidly down to ground level. This means that pollutant concentrations near the building would be increased but also decreased further away.

1.2.23 Buildings taller than 40% of the stack height and at a distance within 5 L from the stack (where L is the lesser of the building height and the maximum projected width) should be included in the model (Ref 15-10). The only buildings located in the vicinity of the BESS Area would be the control rooms associated with the 400 kV substation, which is located in Field D22 of Lime Down D (refer to **ES Volume 2: Figure 3-1 Indicative Site Layout Plan [EN010168/APP/6.2]**). These buildings are expected to be 4.8m high, and the substation area is located more than 30m away from the BESS area at its closest point. There are therefore no buildings that are considered likely to influence dispersion and that have been included in the model.

1.2.24 Terrain data has been incorporated into the model using 50m x 50m resolution terrain data from the Ordnance Survey (OS) OS Terrain 50 dataset. The terrain file covers the Scheme and its surroundings.

1.2.25 The data presented in **Table 2** are measured concentrations at a point 3.35m above ground level. Emission rates of 1g/m^2/s were used in the model, together with the parameters discussed above (summarised in **Table 3**).

Table 3 Parameters used to Derive Emission Rates for use in the Assessment

<table>
<tr><th colspan="2">Parameter</th><th>Model Inputs</th></tr>
<tr><td colspan="2">Area source geometry</td><td>6058mm wide and 2591mm long</td></tr>
<tr><td colspan="2">Release height</td><td>3.35m</td></tr>
<tr><td colspan="2">Velocity</td><td>1m/s</td></tr>
<tr><td colspan="2">Temperature</td><td>914°C</td></tr>
<tr><td rowspan="8">Emission Rate</td><td>CO</td><td rowspan="8">1 g/m^2/s</td></tr>
<tr><td>Formaldehyde</td></tr>
<tr><td>HCl</td></tr>
<tr><td>HCN</td></tr>
<tr><td>HF</td></tr>
<tr><td>NH_3</td></tr>
<tr><td>NO</td></tr>
<tr><td>PM_{10}</td></tr>
</table>

1.2.26 The resulting concentrations were then compared with the measured concentrations to derive pollutant specific ratios. These ratios were applied to the preliminary emission rates (1g/m^2/s) to derive the emission rates that were used in the assessment. A test model was then set up using the derived emission rates to ensure that the predicted concentrations at the sampling point matched the measured concentrations. The derived emission rates used in the model are presented in **Table 4.**

Table 4 Derived Emission Rates used in the Assessment

Pollutant	Emission Rate (g/m^2/s)
CO	6.34
Formaldehyde	0.17
HCl	0.31
HCN	0.11
HF	0.86
NH_3	0.03

NO	0.13
PM_{10}	0.45

Receptors

1.2.27 Human receptors have been identified in the vicinity of the Scheme using Google Earth imagery and OS mapping. Worst case receptors have been selected at locations closest to the BESS Area where the public could be exposed to emissions from a potential BESS fire. These include residential properties and public footpaths. The receptor locations are presented in **Table 5** and in **ES Volume 2, Figure 15-5: BESS Fire Emissions Study Area, Receptors and Modelled BESS Locations [EN010168/APP/6.2]**.

Table 5 Receptor Locations

Receptor	X (m)	Y (m)	Z (m)	Distance to BESS Area (m)
R1	389081.0	182383.4	1.5	734.4
R2	388438.3	184161.0	1.5	853.9
R3	388639.9	184304.4	1.5	968.7
R4	388525.6	184203.1	1.5	877.2
R5	388828.0	184246.4	1.5	926.3
R6	389552.0	183012.4	1.5	706.6
R7	389614.9	182994.6	1.5	771.4
R8	389448.2	182324.0	1.5	978.6
R9	389598.3	182497.4	1.5	966.4
R10	389546.1	182961.9	1.5	709.6
R11	387756.5	183299.5	1.5	745.2
R12	388951.4	182398.8	1.5	682.1
PROW1	389080.8	183587.4	1.5	484.3
PROW2	389281.5	183318.5	1.5	476.3
PROW3	389187.4	183462.6	1.5	482.9
PROW4	388425.1	182797.2	1.5	355.6
PROW5	388258.3	182924.4	1.5	384.5
PROW6	388086.7	183004.2	1.5	486.1
PROW7	389053.9	182467.4	1.5	646.4
PROW8	388494.2	182437.0	1.5	678.6

1.2.28 Worst case locations on roads in the vicinity of the BESS Area were selected for the visibility assessment, as detailed in **Table 6** below.

Table 6 Visibility Assessment Locations

Receptor	X (m)	Y (m)	Z (m)	Distance to BESS Area (m)
RAIL1	388586.2	183059.4	1.5	50.3
RAIL2	388803.4	183021.2	1.5	45.6
RAIL3	388690.7	183041.1	1.5	47.7
RAIL4	388915.0	183001.8	1.5	120.7
RAIL5	388470.3	183078.9	1.5	122.7
ROAD1	388324.3	183065.9	1.5	253.9
ROAD2	388500.8	182936.4	1.5	197.1
ROAD3	388423.9	183000.8	1.5	203.8
ROAD4	388212.0	183073.4	1.5	343.2
ROAD5	388564.3	182872.5	1.5	237.9
ROAD6	389515.6	183393.6	1.5	720.5
ROAD7	389405.4	183766.7	1.5	846.9
ROAD8	389475.2	183583.3	1.5	781.0

Model Outputs

1.2.29 The model has been used to predict the maximum one hour mean pollutant concentration that would occur at each receptor, based on five years of meteorological data. The maximum one hour mean concentrations have been compared against the 1 hour, 4 hour and 8 hour AEGLs shown in **Table 1.** This approach is considered to be worst-case, as it assumes that a potential fire incident occurs at the same time that the meteorological conditions are poorest for pollution dispersion. Furthermore, the approach assumes that the maximum one hour mean concentration would be sustained for the duration of the 4 hour and 8 hour AEGL exposure periods.

Background Concentrations

NO_2 and PM_{10}

1.2.30 Defra predicted annual mean background maps provided in 1km x 1km grid squares (Ref 15-11) have been used to determine background pollutant concentrations for NO_2 and PM_{10} for each receptor location. Base year concentrations (2025) have been used as a worst case as concentrations are predicted to reduce in future years.

CO

1.2.31 Defra Pollution Climate Mapping predicted annual mean background maps provided in 1km x 1km grid squares (Ref 15-11) have been used to determine background pollutant concentrations for CO for each receptor location. The latest year available from the maps is 2010, which has been used for the assessment.

NH_3

1.2.32 The Air Pollution Information System (APIS) annual mean background maps provided in 1km x 1km grid squares (Ref 15-12) have been used to determine background pollutant concentrations for NH_3 for each receptor location. The concentrations represent a three-year average for the period 2020 to 2022.

Formaldehyde

1.2.33 As described by the UK Health Security Agency (Ref 15-13), concentrations of Formaldehyde in ambient air are generally below 10 $\mu g/m^3$; but may reach 20 $\mu g/m^3$ in urban or industrial areas. Given the rural land use surrounding the Scheme, an annual mean background concentration of 10 $\mu g/m^3$ has been used at all receptors in the assessment.

HF

1.2.34 Very little data exists on concentrations of HF in UK ambient air, but concentrations are expected to be extremely low. An annual mean HF concentration of between 0.06 and 0.23 $\mu g/m^3$ was monitored at a UK HF production site between 1991 and 1994 (Ref 15-14). In the absence of any other data, a background HF concentration of 0.23 $\mu g/m^3$ has been used for all receptors in the assessment, which is expected to be worst-case given the nature of the measurements.

HCl

1.2.35 The latest annual mean background HCl concentration measured from Rothamsted has been used, which corresponds with the year 2015 (Ref 15-11). Rothamsted is part of the UKEAP: Acid Gas and Aerosol Network and is the nearest site with data to the Scheme. An annual mean HCl concentration of 0.28 $\mu g/m^3$ was measured at this site in 2015 which has been used at all receptors.

HCN

1.2.36 No information is available on background concentrations of HCN, but the concentrations are expected to be negligible and have been assumed to be zero in the assessment.

Short Term Background Concentrations

1.2.37 In accordance with the EA guidance (Ref 15-1), it has been assumed that the short-term background concentration of a substance is twice its long-term concentration. As such, annual mean background concentrations were doubled to approximate the short term background concentrations corresponding with the AEGL exposure periods shown in **Table 1**. The background concentrations used in the assessment are presented in **Table 7**. These background concentrations were added to the model outputs to calculate the total concentration for comparison against the AEGLs.

Table 7 Estimated Short Term Background Concentrations

Receptor	Short Term Background Concentration (µg/m³)							
	CO	Formaldehyde	HCl	HCN	HF	NH_3	NO_2	PM_{10}
R1	205.4	10.0	0.28	0.0	0.23	1.9	4.1	12.4
R2	203.7	10.0	0.28	0.0	0.23	1.8	4.3	11.8
R3	203.7	10.0	0.28	0.0	0.23	1.8	4.0	11.0
R4	203.7	10.0	0.28	0.0	0.23	1.8	4.0	11.0
R5	203.7	10.0	0.28	0.0	0.23	1.8	4.0	11.0
R6	203.9	10.0	0.28	0.0	0.23	1.9	4.0	11.0
R7	205.4	10.0	0.28	0.0	0.23	1.9	4.1	12.0
R8	205.4	10.0	0.28	0.0	0.23	1.9	4.3	11.8
R9	205.4	10.0	0.28	0.0	0.23	1.9	4.3	11.8
R10	205.4	10.0	0.28	0.0	0.23	1.9	4.3	11.8
R11	203.8	10.0	0.28	0.0	0.23	1.8	4.3	11.8
R12	203.9	10.0	0.28	0.0	0.23	1.8	4.1	12.2
PROW1	203.9	10.0	0.28	0.0	0.23	1.9	4.1	12.4
PROW2	203.9	10.0	0.28	0.0	0.23	1.9	4.1	12.0
PROW3	203.9	10.0	0.28	0.0	0.23	1.9	4.1	12.0
PROW4	203.9	10.0	0.28	0.0	0.23	1.8	4.1	12.0
PROW5	203.9	10.0	0.28	0.0	0.23	1.8	4.1	12.4
PROW6	203.8	10.0	0.28	0.0	0.23	1.8	4.1	12.4
PROW7	205.4	10.0	0.28	0.0	0.23	1.9	4.1	11.8
PROW8	203.9	10.0	0.28	0.0	0.23	1.8	4.3	11.8
ROAD1*	-	-	-	-	-	-	-	11.8
ROAD2*	-	-	-	-	-	-	-	12.4
ROAD3*	-	-	-	-	-	-	-	11.8

Receptor	Short Term Background Concentration (µg/m³)							
	CO	Formaldehyde	HCl	HCN	HF	NH_3	NO_2	PM_{10}
ROAD4*	-	-	-	-	-	-	-	11.8
ROAD5*	-	-	-	-	-	-	-	12.4
ROAD6*	-	-	-	-	-	-	-	12.0
ROAD7*	-	-	-	-	-	-	-	12.0
ROAD8*	-	-	-	-	-	-	-	12.0
RAIL1*	-	-	-	-	-	-	-	11.8
RAIL2*	-	-	-	-	-	-	-	11.8
RAIL3*	-	-	-	-	-	-	-	11.8
RAIL4*	-	-	-	-	-	-	-	11.8
RAIL5*	-	-	-	-	-	-	-	11.8

*Receptors only considered in visibility assessment, therefore only PM_{10} background required.

Unit Conversion

1.2.38 AEGL concentrations are expressed in units of ppm, whereas ADMS-6 outputs are provided in units of µg/m³ and background concentrations are also typically provided in µg/m³. To convert the AEGLs into µg/m³ for comparison against the modelled concentrations, the following equation was used:

AEGL (µg/m³) = molecular weight x AEGL (ppb) ÷ 24.45

1.2.39 The molecular weights for each pollutant used in the assessment are as follows:

- CO - 28.01;
- Formaldehyde - 30.03;
- HCL - 36.46;
- HCN - 27.03;
- HF - 20.01;
- NH3 - 17.03; and
- NO - 30.01.

1.3 Results

Human Health

1.3.1 The modelled concentrations presented in **Table 8** are the maximum one hour mean concentrations modelled over five years using worst case parameters for the BESS fire. The final column of the table indicates which BESS fire location resulted in the maximum pollutant concentrations at each receptor. The results indicate that the highest concentration was predicted at receptor PROW4 and resulted from a fire at the BESS 3 location. PROW4 is a receptor point corresponding with a public right of way, 356m to the south-west of BESS 3.

1.3.2 The results in **Table 8** present the concentrations resulting from a BESS fire only. Background concentrations have been added to the modelled fire concentrations, and the resulting total concentrations are presented in **Table 9**. As indicated in **Table 9**, the predicted maximum one-hour mean PM_{10} concentrations were all well below the 8 hour WEL (4000µg/m^3) and the predicted maximum one-hour mean CO concentrations were well below the 1 hour WHO guideline value (35,000µg/m^3). All other maximum one-hour mean concentrations were well below AEGL level 1 (notable discomfort, irritation, or certain asymptomatic non-sensory effects) for 1 hour, 4 hour and 8 hour exposure periods.

1.3.3 It should be noted that emissions data was available for NO rather than NO_2. However, there are no AEGLs available for NO and it states that “AEGL values for nitrogen dioxide should be used for emergency planning” rather than NO (Ref 15-2). As such, for the purposes of this assessment, it has been assumed that modelled NO concentrations are NO_2.

Table 8 Maximum Modelled One-Hour Mean Concentrations

Receptor	Maximum Hourly Mean Concentration (µg/m^3)								BESS Location where Maximum Concentration was Modelled
	CO	Formaldehyde	HCl	HCN	HF	NH_3	NO_2	PM_{10}	
R1	590.0	16.1	28.8	10.1	79.3	2.8	12.3	42.1	BESS 5
R2	530.8	14.5	25.9	9.1	71.3	2.5	11.1	37.8	BESS 4
R3	500.2	13.6	24.4	8.6	67.2	2.4	10.4	35.7	BESS 2
R4	540.9	14.8	26.4	9.3	72.7	2.6	11.3	38.6	BESS 1
R5	492.5	13.4	24.0	8.5	66.2	2.3	10.3	35.1	BESS 2
R6	585.7	16.0	28.5	10.1	78.7	2.8	12.2	41.8	BESS 6
R7	539.4	14.7	26.3	9.3	72.5	2.5	11.2	38.5	BESS 6
R8	500.6	13.7	24.4	8.6	67.3	2.4	10.4	35.7	BESS 5
R9	486.2	13.3	23.7	8.4	65.3	2.3	10.1	34.7	BESS 6
R10	579.3	15.8	28.2	10.0	77.9	2.7	12.1	41.3	BESS 5
R11	524.1	14.3	25.5	9.0	70.4	2.5	10.9	37.4	BESS 1
R12	615.5	16.8	30.0	10.6	82.7	2.9	12.8	43.9	BESS 5
PROW1	899.6	24.5	43.8	15.5	120.9	4.2	18.7	64.1	BESS 4
PROW2	841.7	23.0	41.0	14.5	113.1	4.0	17.5	60.0	BESS 6
PROW3	883.4	24.1	43.1	15.2	118.7	4.2	18.4	63.0	BESS 4
PROW4	1311.4	35.8	63.9	22.5	176.2	6.2	27.3	93.5	BESS 3

<table>
<tr><th rowspan="2">Receptor</th><th colspan="8">Maximum Hourly Mean Concentration (µg/m^3)</th><th rowspan="2">BESS Location where Maximum Concentration was Modelled</th></tr>
<tr><th>CO</th><th>Formaldehyde</th><th>HCl</th><th>HCN</th><th>HF</th><th>NH_3</th><th>NO_2</th><th>PM_{10}</th></tr>
<tr><td>PROW5</td><td>1210.6</td><td>33.0</td><td>59.0</td><td>20.8</td><td>162.7</td><td>5.7</td><td>25.2</td><td>86.3</td><td>BESS 3</td></tr>
<tr><td>PROW6</td><td>905.8</td><td>24.7</td><td>44.1</td><td>15.6</td><td>121.7</td><td>4.3</td><td>18.9</td><td>64.6</td><td>BESS 1</td></tr>
<tr><td>PROW7</td><td>631.4</td><td>17.2</td><td>30.8</td><td>10.9</td><td>84.9</td><td>3.0</td><td>13.1</td><td>45.0</td><td>BESS 5</td></tr>
<tr><td>PROW8</td><td>627.7</td><td>17.1</td><td>30.6</td><td>10.8</td><td>84.3</td><td>3.0</td><td>13.1</td><td>44.7</td><td>BESS 3</td></tr>
<tr><td>Maximum</td><td>1311.4</td><td>35.8</td><td>63.9</td><td>22.5</td><td>176.2</td><td>6.2</td><td>27.3</td><td>93.5</td><td>BESS 3</td></tr>
<tr><td>AEGL 1 (1 hour)</td><td rowspan="3">35,000*</td><td rowspan="3">1105</td><td rowspan="3">2684</td><td>2211</td><td rowspan="3">818</td><td rowspan="3">20,896</td><td rowspan="3">941</td><td rowspan="3">4000**</td><td>-</td></tr>
<tr><td>AEGL 1 (4 hour)</td><td>1437</td><td>-</td></tr>
<tr><td>AEGL 1 (8 hour)</td><td>1106</td><td>-</td></tr>
<tr><td>Maximum as % AEGL 1 (1 hour)</td><td rowspan="3">3.7%*</td><td rowspan="3">3.2%</td><td rowspan="3">2.4%</td><td>1.0%</td><td rowspan="3">21.5%</td><td rowspan="3">0.0%</td><td rowspan="3">2.9%</td><td rowspan="3">2.3%**</td><td>-</td></tr>
<tr><td>Maximum as % AEGL 1 (4 hour)</td><td>1.6%</td><td>-</td></tr>
<tr><td>Maximum as % AEGL 1 (8 hour)</td><td>2.0%</td><td>-</td></tr>
</table>

*No AEGL 1 for CO so WHO 1-hour guideline used.

**No AEGL for PM_{10} so 8-hour HSE WEL used.

Table 9 Maximum Modelled One-Hour Mean Concentration including Backgrounds

Receptor	Maximum Hourly Mean Concentration (µg/m^3)								BESS Location where Maximum Concentration was Modelled
	CO	Formaldehyde	HCl	HCN	HF	NH^3	NO_2	PM_{10}	
R1	1000.8	36.1	29.3	10.1	79.7	6.6	20.9	65.7	BESS 5
R2	938.2	34.5	26.4	9.1	71.8	6.1	19.1	59.9	BESS 4
R3	907.6	33.6	24.9	8.6	67.7	6.0	18.5	57.8	BESS 2
R4	948.4	34.8	26.9	9.3	73.2	6.2	19.3	60.7	BESS 1
R5	899.9	33.4	24.6	8.5	66.6	5.9	18.3	57.2	BESS 2
R6	993.5	36.0	29.1	10.1	79.2	6.5	20.4	65.8	BESS 6
R7	950.2	34.7	26.8	9.3	72.9	6.3	19.8	62.1	BESS 6
R8	911.5	33.7	25.0	8.6	67.7	6.1	19.0	59.3	BESS 5
R9	897.0	33.3	24.3	8.4	65.8	6.1	18.7	58.3	BESS 6
R10	990.2	35.8	28.8	10.0	78.3	6.5	20.6	64.9	BESS 5
R11	931.7	34.3	26.1	9.0	70.9	6.0	19.0	61.8	BESS 1
R12	1023.3	36.8	30.6	10.6	83.2	6.6	21.0	68.7	BESS 5
PROW1	1307.3	44.5	44.4	15.5	121.3	8.0	26.9	88.2	BESS 4
PROW2	1249.5	43.0	41.6	14.5	113.6	7.7	25.7	84.1	BESS 6
PROW3	1291.1	44.1	43.6	15.2	119.2	7.9	26.6	87.1	BESS 4
PROW4	1719.2	55.8	64.5	22.5	176.7	9.8	35.5	118.3	BESS 3

Receptor	Maximum Hourly Mean Concentration (µg/m^3)								BESS Location where Maximum Concentration was Modelled
	CO	Formaldehyde	HCl	HCN	HF	NH^3	NO_2	PM_{10}	
PROW5	1618.4	53.0	59.6	20.8	163.1	9.4	33.4	111.1	BESS 3
PROW6	1313.4	44.7	44.7	15.6	122.2	7.9	27.0	88.2	BESS 1
PROW7	1042.2	37.2	31.3	10.9	85.3	6.8	21.7	68.6	BESS 5
PROW8	1035.4	37.1	31.2	10.8	84.8	6.6	21.3	69.6	BESS 3
Maximum	1719.2	55.8	64.5	22.5	176.7	9.8	35.5	118.8	BESS 3
AEGL 1 (1 hour)				2211					-
AEGL 1 (4 hour)	35000*	1105	2684	1437	818	20896	941	4000**	-
AEGL 1 (8 hour)				1106					-
Maximum as % AEGL 1 (1 hour)				1.0%					-
Maximum as % AEGL 1 (4 hour)	4.9%	5.0%	2.4%	1.6%	21.6%	0.0%	3.8%	3.0%	-
Maximum as % AEGL 1 (8 hour)				2.0%					-

*No AEGL 1 for CO so WHO 1-hour guideline used.

**No AEGL for PM_{10} so 8-hour HSE WEL used.

No background data available for HCN

Visibility

1.3.4 **Table 10** presents the modelled PM_{10} concentrations and corresponding predicted visibility at the modelled points corresponding with the closest sections of road and rail network to the BESS Area.

Table 10 Maximum Modelled One-Hour Mean PM_{10} Concentrations including Backgrounds

Receptor	Road/Rail Name	Maximum Hourly PM_{10} Concentration (including Background)	BESS Location where Maximum Concentration was Modelled	Predicted Approximate Visibility (m)
ROAD1	Hill Hayes Lane	161.4	BESS 1	2446
ROAD2	Hill Hayes Lane	228.0	BESS 3	1732
ROAD3	Hill Hayes Lane	223.9	BESS 3	1763
ROAD4	Hill Hayes Lane	120.5	BESS 1	3275
ROAD5	Bradfield Cottages	185.4	BESS 3	2129
ROAD6	Bradfield Cottages	62.8	BESS 6	6289
ROAD7	Bradfield Cottages	60.9	BESS 1	6481
ROAD8	Bradfield Cottages	61.6	BESS 6	6406
RAIL1	Great Western Railway	1109.6	BESS 3	356
RAIL2	Great Western Railway	1190.1	BESS 5	332
RAIL3	Great Western Railway	453.8	BESS 3	870
RAIL4	Great Western Railway	396.0	BESS 6	997
RAIL5	Great Western Railway	363.9	BESS 3	1085

1.3.5 As indicated in **Table 10**, the lowest visibility predicted on local roads occurs at ROAD2, which represents the closest point of Hill Hayes Lane to the BESS Area. The worst-case visibility distance predicted at this location because of smoke from a BESS fire is approximately 1732m, which is considerably further than vehicle stopping distance at the national speed limit for this road (the typical braking distance is 73m for a car travelling at 60mph (Ref 15-15)). The worst-case visibility predicted on the rail track south of the BESS Area is approximately 332m. However, it should be reiterated that these visibility calculations assume that a fire occurs at the closest BESS container to the road/rail line and that this happens to coincide with the worst possible meteorological conditions for pollution dispersion at that road/rail location (worst hour for dispersion across five years of meteorological data). Furthermore, the equation used to determine visibility is based on certain assumptions and therefore has inherent limitations. The output of the visibility calculations should therefore be treated with caution and, as a precaution, the following measures have been included in the **Outline BSMP [EN010168/APP/7.21]**:

- Should there be a BESS fire in close proximity to the road, the site operator is to determine wind direction and seek to close road if deemed necessary; and
- Should there be a BESS fire in close proximity to the rail line, the site operator is to determine wind direction and notify Network Rail if deemed necessary.

1.4 Uncertainty and Sensitivity

1.4.1 Uncertainty in dispersion modelling predictions can be associated with a number of different factors, including:

- Model uncertainty-due to model limitations;
- Data uncertainty-due to errors in input data, including emissions estimates, background estimates and meteorology; and
- Variability-randomness of measurements used.

1.4.2 Potential uncertainties in model results have been minimised as practicable and worst-case inputs used in the absence of definitive information. This encompassed the following:

- Choice of model – ADMS-6 is a commonly used atmospheric dispersion model and results have been verified through a number of studies to ensure predictions are as accurate as possible;

- Meteorological data – Modelling was undertaken using five years of meteorological datasets from the closest observation site to the Scheme. The highest concentrations predicted by the model over these five years were reported at the worst-case human and visibility receptors;
- Receptor locations – The closest human and visibility receptors to the BESS Area were selected as these are expected to experience the greatest impacts from the fire; and
- Variability - All model inputs are as accurate as possible and worst-case conditions have been considered where necessary in order to ensure a robust assessment of potential pollutant concentrations.

1.4.3 It is considered that the use of the stated measures to reduce uncertainty and the use of worst-case assumptions when necessary has resulted in model accuracy of an acceptable level.

1.5 Assessment and Limitations

1.5.1 The following assumptions have been made within this assessment:

- The term 'BESS container' has been used in this report for consistency with the rest of the DCO Application. However, it should be noted that the **Outline Battery Safety Management Plan (BSMP) [EN010168/APP/7.21]** refers to these elements as 'BESS enclosure' to highlight considerations around battery safety and to acknowledge that modern BESS designs often extend beyond the traditional ISO container formats (e.g., 20ft, 40ft, or 53ft);
- Modelling accounts for a steady burn as a result of deflagration of one BESS container. The BESS facility will be designed with multiple layers of protection to mitigate and minimise the probability of a fire or thermal runaway incident as outlined in the **Outline BSMP [EN010168/APP/7.21]**. It is therefore assumed that the fire would be limited to one BESS enclosure;
- It is assumed that one BESS container is 2438mm in height, 6058mm wide and 2591mm long;
- It is assumed that Prismatic LFP batteries would be used. This is considered to be a reasonable worst case for the purposes of the assessment in terms of BESS toxic gas emission potential;
- There are several battery storage technologies available to the Applicant. For the purposes of the Lime Down DCO Application, a generic 5 MWh BESS comprising six battery racks has been assumed. The exact technology and system chemistry type is still to be

determined; however, it will be a lithium-ion battery cell type. As stated previously, there is limited emissions data available for BESS fires. The modelling was based on a test fire which was conducted using LFP lithium iron phosphate battery modules; each module comprised 52 cells whereas a 5 MWh BESS could contain double this number of cells in each battery module (there would be six racks containing 48 modules rather than ten racks containing 80 modules). As such, a sensitivity test has been undertaken to address this uncertainty. It should be noted that, as stated in the **Outline BSMP [EN010168/APP/7.21]**, detailed modelling of a potential BESS fire would be undertaken at the detailed design stage and used to inform the Emergency Response Plan, therefore any changes to the design would be modelled at the detailed design stage;

- Batteries are sealed by design so do not vent when in normal use and have no free electrolyte;
- The batteries will be controlled by charging management systems that will detect if a cell or battery is not operating correctly;
- There are no large buildings located on site in close proximity to the BESS cabinets that would affect dispersion;
- There is no AEGL for particulates. As such, the Health and Safety Executive (HSE) Workplace Exposure Limit (WEL) (Ref 15-3) has been used which is 4 mg/m^3 for respirable dust. Whilst this is over an 8-hour reference period, it is considered appropriate for use in the assessment in lieu of any other limits;
- AEGLs for 10 minute and 30-minute exposure periods were not included in the assessment, as the dispersion model uses hourly meteorological data, which means that the shortest time period that concentrations can be predicted over is one hour. Depending on the pollutant, the 10 minute and 30 minute AEGL has an equivalent or higher threshold concentration than the corresponding 1 hour AEGL, and so comparison of hourly model outputs against 1 hour AEGL values is considered more worst-case than comparison against 10 minute and 30 minute AEGLs;
- Visibility is affected not only by particulate concentrations, but by a range of factors including smoke composition, particulate size distribution, humidity levels, light conditions etc, therefore the visibility assessment is considered to be high level, as such detailed conclusions should not be drawn from the results;
- Emissions data for BESS fires are limited and have come from a range of sources. Worst case parameters have been used where possible;

- There is limited real world data collated on fires associated with solar schemes. No suitable emissions data was found for particulates. As such, the assessment assumed that a battery unit fire in the BESS is equivalent to a diesel fire for production of PM as recommended by the Applicant's Battery Safety and Testing Consultant and as done for previous assessments such as the Axminster Energy Hub Plume Assessment Study prepared by DNV for Clearstone Energy (Ref 15-8);
- A nominal value of 1m/s has been used for the velocity to activate the plume rise module;
- Due to the limited availability of data on fires associated with solar schemes, emissions data was available for NO rather than NO_2. For the purposes of this assessment, it has been assumed that modelled NO concentrations are NO_2, as a worst case (NO converts to NO_2 in the atmosphere, and NO_2 is considered more harmful in terms of its health effects);
- There were no background concentrations available for HCN. However, it is considered that background concentrations for this pollutant would be negligible; and
- In accordance with the EA guidance (Ref 15-1), it has been assumed that the short-term background concentration of a substance is twice its long-term concentration. As such, annual mean background concentrations were doubled to approximate the 1-hour background concentration.

1.6 Sensitivity Test

1.6.1 As stated in the previous section, there is limited emissions data available for BESS fires. The modelling was based on a test fire which was conducted using LFP lithium iron phosphate battery modules; each module comprised 52 cells whereas a 5 MWh BESS could contain double this number of cells in each battery module (there would be six racks containing 48 modules rather than ten racks containing 80 modules).

1.6.2 As indicated in **Table 9**, the predicted maximum one-hour mean PM_{10} concentrations were all well below the 8 hour WEL (4000 µg/m^3) and the predicted maximum one-hour mean CO concentrations were well below the 1 hour WHO guideline value (35,000 µg/m^3). All other maximum one-hour mean concentrations were well below AEGL level 1 (notable discomfort, irritation, or certain asymptomatic non-sensory effects) for 1 hour, 4 hour and 8 hour exposure periods. Should the emission rates, and therefore the resultant concentrations double, all pollutant concentrations would still be well below the respective safety levels.

1.6.3 The equation to calculate visibility is not linear, therefore the predicted approximate visibility has been re-calculated based on the predicted PM_{10} concentrations being doubled, as presented in **Table 11**.

Table 11 Doubled Maximum Modelled One-Hour Mean PM_{10} Concentrations including Backgrounds

Receptor	Road/Rail Name	Maximum Hourly PM_{10} Doubled Concentration (with Background)	Predicted Approximate Visibility (m)
ROAD1	Hill Hayes Lane	287.4	1373
ROAD2	Hill Hayes Lane	418.7	943
ROAD3	Hill Hayes Lane	412.4	957
ROAD4	Hill Hayes Lane	205.7	1919
ROAD5	Bradfield Cottages	333.5	1184
ROAD6	Bradfield Cottages	89.4	4415
ROAD7	Bradfield Cottages	85.7	4607
ROAD8	Bradfield Cottages	87.1	4531
RAIL1	Great Western Railway	2183.8	181
RAIL2	Great Western Railway	2344.8	168
RAIL3	Great Western Railway	872.2	453
RAIL4	Great Western Railway	756.6	522
RAIL5	Great Western Railway	692.3	570

As indicated in **Table 11**, should the PM_{10} emissions and resultant concentrations double, the lowest visibility distance predicted on local roads is approximately 943m, which is still considerably further than the vehicle stopping distance at the national speed limit for this road (73m for a car travelling at 60mph (Ref 15-15)). The worst-case visibility predicted on the rail track south of the BESS Area is approximately 168m.

1.7 Mitigation

1.7.1 Prior to the commencement of construction of the BESS, Lime Down Solar Park Ltd. (the ‘Applicant’) will be required to prepare a BSMP. This will build upon the mitigation secured in the **Outline BSMP [EN010168/APP/7.21]** submitted as part of this application. As part of preparation of the BSMP, the Applicant will incorporate the latest good practices for battery storage safety, failure detection and prevention, along with the emergency response planning, as guidance continues to develop in the UK and internationally. The following measures relating to air quality have been included:

- Notification of potentially affected residents including advice on the health effects of smoke and ways to reduce exposure (e.g. close windows and stay indoors);
- Notification of potentially affected members of the public to move to a cleaner air location;
- Cancellation of outdoor events and potentially moving affected residents to a cleaner air location;
- Should there be a BESS fire in close proximity to the road, the site operator to determine wind direction and seek to close the road if deemed necessary; and
- Should there be a BESS fire in close proximity to the rail line, the site operator to determine wind direction and notify Network Rail if deemed necessary.

1.8 Conclusion

1.8.1 Based on the factors of distance to the nearest locations of human exposure and the anticipated short-term nature of a fire incident, the assessment concludes that there would be no significant air quality effects as a result of a BESS fire incident. It is also worth noting that an **Outline BSMP** [**EN010168/APP/7.21]** has been produced as part of this application and identifies how the Applicant will use good industry practice to reduce risk to life, property, and the environment in the rare event of a BESS fire.

1.8.2 Notwithstanding, whilst there is low risk of adverse air quality effects at the closest receptors, the Emergency Response Plan produced at the detailed design stage will incorporate all necessary emergency response procedures and actions based upon thermal runaway test data supplied by the BESS system provider.

1.9 References

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