FICHTNER
Consulting Engineers Limited

Runcorn CC Facility - EP Application

Viridor Runcorn CCS Ltd

Dispersion Modelling Assessment

ENGINEERING + CONSULTING

Document approval

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Management Summary

Fichtner Consulting Engineers Ltd ("Fichtner") has been engaged by Viridor Runcorn CCS Limited to undertake a Dispersion Modelling Assessment to support the application for an Environmental Permit (EP) for a carbon capture (CC) facility to serve the Runcorn Energy Recovery Facility (ERF). The ERF comprises four incineration lines. Viridor is proposing to install a CC facility with a single line to extract carbon dioxide (CO_2) from the emissions produced by each line of the ERF. Full details of the CC facility for can be found in the Supporting Information document.

Dispersion Modelling of Emissions

Dispersion modelling of emissions has been undertaken using ADMS 6. The ADMS dispersion model is routinely used for air quality assessments to the satisfaction of the Environment Agency (EA). The model uses weather data from the local area to predict the spread and movement of the exhaust gases from the stack for each hour over a five-year period. The model takes account of wind speed, wind direction, temperature, humidity and the amount of cloud cover, as all of these factors influence the dispersion of emissions. The model also takes account of the effects of buildings and terrain on the movement of air.

Dispersion modelling has been carried out for the following scenarios:

1. Permitted Facility – the ERF operating as per the conditions of the existing EP; and
2. Proposed Facility – the emissions from each line of the ERF being ducted to the CC facility.

To set up the model, it has been assumed that the ERF operates for the whole year and releases emissions at the emission limits set out in the existing EP continuously, and these are either emitted from the main stack of the ERF or pass through to the CC facility before emitting to atmosphere. The CC process alters the flue gas composition. The difference in the flue gas composition (temperature, moisture content and volume) as a result of the CC process has been accounted for. However, for modelling purposes it is assumed that the CC facility does not offer any additional abatement of emissions which is extremely conservative given that the CC facility includes a wash system which is likely to significantly reduce emissions of many of the pollutants released, including acid gases, particulates and ammonia.

Dispersion modelling has also been carried out to determine the impact of venting of CO_2.

The model has been used to predict the ground level concentration of pollutants on a long-term and short-term basis across a grid of points. In addition, concentrations have been predicted at the identified sensitive receptors.

Approach and Assessment of Impact on Air Quality – Protection of Human Health

The air quality impact on human health has been assessed using a standard approach based on guidance provided by the EA. Using this approach, in relation to the Air Quality Assessment Levels (AQALs) set for the protection of human health the following can be concluded from the assessment.

1. Emissions from the operation of the CC facility will not cause a breach of any AQAL.
2. There is predicted to be an increase in the impacts as a result of the operation of the CC facility, but the overall impact of the Installation is not significant. This includes for the additional products released from the CC facility such as amines, nitrosamines and nitramines.

3. There is no risk of exceeding an AQAL for any metal either on a long or short term basis.

Approach and Assessment of Impact on Air Quality – Protection of Ecosystems

One European designated receptor (the Mersey Estuary) and five local nature sites have been identified for inclusion in the assessment. The impact of air quality on ecology has been assessed using a standard approach based on guidance provided by the EA. Using this approach the following can be concluded from the assessment.

1. At the Mersey Estuary, the peak impact on oxides of nitrogen, ammonia and nitrogen deposition due to the operation of the CC facility are predicted to exceed 1% of the Critical Level and Critical Load and in the case of ammonia and nitrogen deposition the baseline exceeds the Critical Level and Critical Load.
2. At all local ecological sites, the contribution from the Installation can be screened out 'insignificant' as it is less than the Critical Levels and Critical Loads.
3. These impacts assume that the CC facility does not offer any additional abatement of emissions and the emissions from the ERF and the emissions assuming operating at the ELVs are passed through the CC facility before emitting to atmosphere. The reduction in impacts would reduce emissions from the CC facility to a level where it is unlikely that a significant impact would occur at the Mersey Estuary.

Carbon dioxide venting

The CC facility include a CO_2 vent which would be used in the event that CO_2 does not meet the pipeline specifications and cannot be exported. The CO_2 stack is proposed to be the same height as the stacks on top of the absorber columns. The dispersion model has been run assuming the continuous operation of the CO_2 vent. This considered the impact at ground level and at elevated working areas. This analysis has shown that no significant effects are predicted as a result of CO_2 venting.

Summary and conclusions

In summary, the assessment has shown that the air quality impact of the Installation would not have a significant impact on local air quality, the general population or the local community. As such there should be no air quality constraint in granting an EP for the CC facility.

Contents

1 Introduction

1.1 Background

Fichtner Consulting Engineers Ltd ("Fichtner") has been engaged by Viridor Runcorn CCS Limited (Viridor) to undertake a Dispersion Modelling Assessment to support the application for a Environmental Permit (EP) for a carbon capture facility to serve the Runcorn Energy Recovery Facility (ERF). The location of the Facility is shown in Figure 1.

The ERF comprises four incineration lines. Viridor is proposing to install a carbon capture (CC) facility with a single line to extract carbon dioxide (CO_2) from the emissions produced by each line of the ERF. Full details of the proposed changes being applied for can be found in the Supporting Information document.

This assessment has considered the following scenarios:

- the "Permitted Facility" – the impact of the ERF operating at the maximum permitted emission limit values (ELVs); and
- the "Proposed Facility" – the impact of the ERF including the CC Facility assuming operation of the ERF at the ELVs.
- The difference in impact has been quantified to determine the impact of this variation application.

The existing EP for the Facility (EPR/XP3005LB) implements the requirements of the Waste Incineration Best Available Techniques (BAT) Reference Document (the WI BREF) and as such for certain substances has two sets of ELVs which need to be complied with; one up to 2 December 2023, and a more stringent ELV post this date. The changes proposed as part of this EP variation will only take place after 2 December 2023 and as such the ELVs for the Permitted Facility have been taken as those relevant after 2 December 2023.

When considering the impact on human health, the predicted atmospheric concentrations have been compared to the Air Quality Assessment Levels (AQALs) for the protection of human health. It is noted that for dioxins the AQAL is a Tolerable Daily Intake (TDI) which considers the combination of the intake from inhalation and ingestion. As such it is not possible to demonstrate compliance with the assessment level with just reference to the air concentration. A separate Dioxin Pathway Intake Assessment has been undertaken to assess the pathway intake of these pollutants and impacts compared to the TDI. This is provided as a separate technical report and is included as Appendix D.2 of the EP application.

When considering the impact on ecosystems the predicted atmospheric concentrations have been compared to the Critical Levels for the protection of ecosystems. Deposition of emissions over a prolonged period can have nutrification and acidification impacts. An assessment of the long-term deposition of pollutants has been undertaken and the results compared to the habitat specific Critical Loads.

This assessment also includes consideration of the impact of the Facility during abnormal operations of the ERF as defined within the Industrial Emissions Directive (IED) (Directive 2010/75/EU) for the combustion of waste.

1.2 Structure of the report

This report has the following structure.

- National and international air quality legislation and guidance are considered in section 2.
- The residential properties and ecological receptors which are sensitive to changes in air quality associated with the Facility and identified in section 3.
- The background levels of ambient air quality are described in section 4.
- The inputs used for the dispersion model are contained in section 5.
- Details of the sensitivity analysis carried out is presented in section 6.
- A discussion of the validity of the model and uncertainty is presented in section 7.
- The assessment methodology and results of the assessment of the impact of emissions on human health is presented in section 8.
- The assessment methodology and results of the assessment of the impact of emissions at ecological sites is presented in section 9.
- An assessment of the impact of venting of CO_2 on air quality is contained in section 10.
- An overview of potential effect on the abnormal operations as defined within the IED are set out in section 11.
- The conclusions of the assessment are set out in section 12.
- The Appendices include illustrative figures, detailed results tables and further information on the modelling of amine emissions from the CC facility.

2 Legislation Framework and Policy

2.1 Air quality assessment levels

In the UK, Ambient Air Directive (AAD) Limit Values, Targets, and air quality standards and objectives for major pollutants are described in The Air Quality Strategy (AQS). In addition, the Environment Agency (EA) include Environmental Assessment Levels (EALs) for other pollutants in the environmental management guidance 'Air Emissions Risk Assessment for your Environmental Permit'[1] ("Air Emissions Guidance"), which are also considered. The long-term and short-term EALs from these documents have been used when the AQS does not contain relevant objectives. Standards and objectives for the protection of sensitive ecosystems and habitats are also contained within the Air Emissions Guidance and the Air Pollution Information System (APIS).

AAD Target and Limit Values, AQS Objectives, and EALs are set at levels well below those at which significant adverse health effects have been observed in the general population and in particularly sensitive groups. For the remainder of this report these are collectively referred to as AQALs. Table 1 to Table 4 summarise the air quality objectives and guidelines used in this assessment.

Table 1: Air Quality Assessment Levels (AQALs)

Pollutant	**AQAL (µg/m³)**	**Averaging Period**	**Frequency of Exceedances**	**Source**
Nitrogen dioxide (NO_2)	200	1 hour	18 times per year (99.79th percentile)	AAD Limit Value
	40	Annual	-	AAD Limit Value
Sulphur dioxide (SO_2)	266	15 minutes	35 times per year (99.9th percentile)	AQS Objective
	350	1 hour	24 times per year (99.73rd percentile)	AAD Limit Value
	125	24 hours	3 times per year (99.18th percentile)	AAD Limit Value
Particulate matter (PM_{10})	50	24 hours	35 times per year (90.41st percentile)	AQS Objective
	40	Annual	-	AQS Objective
Particulate matter ($PM_{2.5}$)	10	Annual	-	Environmental Targets (fine particulate matter) (England) regulations 2023

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[1] https://www.gov.uk/guidance/air-emissions-risk-assessment-for-your-environmental-permit#environmental-standards-for-air-emissions

Pollutant	AQAL (µg/m³)	Averaging Period	Frequency of Exceedances	Source
Carbon monoxide (CO)	10,000	8 hours, running	-	AAD Limit Value
	30,000	1 hour	-	Air Emissions Guidance
Hydrogen chloride (HCl)	750	1 hour		Air Emissions Guidance
Hydrogen fluoride (HF)	160	1 hour	-	Air Emissions Guidance
	16	Annual	-	Air Emissions Guidance
Ammonia (NH_3)	2,500	1 hour	-	Air Emissions Guidance
	180	Annual	-	Air Emissions Guidance
Benzene (C_6H_6)	5	Annual	-	Air Emissions Guidance
	30	24 hours	-	Air Emissions Guidance
Polychlorinated biphenyls (PCBs)	6	1-hour	-	Air Emissions Guidance
	0.2	Annual	-	Air Emissions Guidance
Polycyclic Aromatic Hydrocarbons (PAHs)	0.00025	Annual	-	AQS Objective
Formaldehyde (CH_2O)	100	30-minute	-	Air Emissions Guidance
	5	Annual	-	Air Emissions Guidance
Monoethanolamine (MEA)	400	1-hour	-	Air Emissions Guidance
	100	24 hour	-	Air Emissions Guidance
Total nitrosamines (as NDMA(1))	0.0002	Annual		Air Emissions Guidance
Carbon dioxide (CO_2)	5,000 ppm	8-hour	-	EH40/2005 Workplace exposure limits
	15,000 ppm	15-minute	-	

Notes:

(1) NDMA is N-nitrosodimethylamine

In the first instance the total impact of all amines has been compared to the EAL published by the EA for MEA. However, as outlined in Section 5.3 the CC facility will also release small amounts of dimethylamine (DMA) and diethanolamine (DEA). The EA has not currently published EALs for these substances. Therefore, EAL have been derived using the EA approach as set out within Appendix F. In summary the following EALs are proposed for DMA and DEA:

Table 2: EALs for Additional Amines

Amine	24-hour (µg/m^3)	1-hour (µg/m^3)
DEA	0.2	None recommended
DMA	3.3	None recommended

Table 3: Air Quality Assessment Levels for Metals

Pollutant	AQAL (ng/m^3)	Averaging Period	Source
Arsenic (As)	-	1 hour	-
	6	Annual	Air Emissions Guidance
Antimony (Sb)	150,000	1 hour	Air Emissions Guidance
	5,000	Annual	Air Emissions Guidance
Cadmium (Cd)	30	24 hour	Air Emissions Guidance
	5	Annual	AAD Target Value
Chromium (III) (Cr)	2,000	24 hour	Air Emissions Guidance
	-	Annual	-
Chromium (VI) (Cr (VI))	-	1 hour	-
	0.25	Annual	Air Emissions Guidance
Cobalt (Co)	-	1 hour	-
	-	Annual	-
Copper (Cu)	50	24 hour	Air Emissions Guidance
	-	Annual	-
Lead (Pb)	-	1 hour	-
	250	Annual	AQS Target
Manganese (Mn)	1,500,000	1 hour	Air Emissions Guidance
	150	Annual	Air Emissions Guidance
Mercury (Hg)	600	1 hour	Air Emissions Guidance
	60	24 hour	Air Emissions Guidance
	-	Annual	-
Nickel (Ni)	700	1 hour	Air Emissions Guidance
	20	Annual	AAD Limit
Vanadium (V)	1,000	24 hours	Air Emissions Guidance
	-	Annual	-

Table 4: Critical Levels for the Protection of Vegetation and Ecosystems

Pollutant	**Concentration ($\mu g/m^3$)**	**Measured as**	**Source**
Nitrogen oxides NOx) (as NO_2)	75/200*	Daily mean	APIS
	30	Annual mean	AAD Critical Level
Sulphur dioxide (SO_2)	10	Annual mean where lichens and bryophytes are an important part of the ecosystem's integrity	Air Emissions Guidance / APIS
	20	Annual mean for all higher plants	AAD Critical Level
Hydrogen fluoride (HF)	5	Daily mean	Air Emissions Guidance / APIS
	0.5	Weekly mean	Air Emissions Guidance / APIS
Ammonia (NH_3)	1	where lichens and bryophytes are an important part of the ecosystem's integrity	APIS
	3	Annual mean for all higher plants	APIS

Notes:

**only for detailed assessments where the ozone is below the AOT40 Critical Level and sulphur dioxide is below the lower Critical Level of 10 µg/m^3.*

The *AOT40 for ozone is 3,000 ppb.h (6,000 µg/m^3.h) calculated from accumulated hourly ozone concentrations – AOT40 means the sum of the difference between each hourly daytime (08:00 to 20:00 Central European Time, CET) ozone concentration greater than 80 µg/m^3 (40 ppb) and 80 µg/m^3, for the period between 01 May and 31 July.*

In addition to the Critical Levels set out in Table 4, APIS provides habitat specific Critical Loads for nitrogen and acid deposition. Full details of the habitat specific Critical Loads can be found in Appendix B.

There is no AQAL for dioxins and dioxin-like PCBs. As there are other intake pathways besides inhalation for these substances, a separate assessment has been undertaken in which the total intake via inhalation and ingestion has been compared to the Tolerable Daily Intake (TDI). This assessment is presented in the Dioxin Pathway Intake Assessment submitted with this application to vary the EP.

2.2 Areas of relevant exposure

The AQALs apply only at areas of exposure relevant to the assessment level. The following table extracted from Local Authority Air Quality Technical Guidance (2022) (LAQM.TG(22)) explains where the AQALs apply.

Table 5: Guidance on Where AQALs Apply

Averaging period	**AQALs should apply at:**	**AQALs should generally not apply at:**
Annual mean	All locations where members of the public might be regularly exposed. Building façades of residential properties, schools, hospitals, care homes etc.	Building façades of offices or other places of work where members of the public do not have regular access. Hotels, unless people live there as their permanent residence. Gardens of residential properties. Kerbside sites (as opposed to locations at the building façade), or any other location where public exposure is expected to be short-term.
24-hour mean and 8-hour mean	All locations where the annual mean AQAL would apply, together with hotels. Gardens of residential properties.	Kerbside sites (as opposed to locations at the building façade), or any other location where public exposure is expected to be short-term.
1-hour mean	All locations where the annual mean and 24 and 8-hour mean AQALs apply. Kerbside sites (for example, pavements of busy shopping streets). Those parts of car parks, bus stations and railway stations etc. which are not fully enclosed, where members of the public might reasonably be expected to spend one hour or more. Any outdoor locations where members of the public might reasonably be expected to spend one hour or longer.	Kerbside sites where the public would not be expected to have regular access.
15-minute mean	All locations where members of the public might reasonably be exposed for a period of 15-minutes or longer.	

Source: Box 1.1 LAQM.TG(22)

2.3 Industrial pollution regulation

Atmospheric emissions from industrial processes are controlled in England through the Environmental Permitting (England and Wales) Regulations 2016 (and subsequent amendments). The Facility currently has an EP to operate. The EP includes conditions to ensure that the environmental impact of the operations is minimised. This includes conditions to prevent fugitive emissions of dust and odour beyond the boundary of the permitted activity, and limits on emissions to air.

The Industrial Emissions Directive (IED) (Directive 2010/75/EU), was adopted on 07 January 2013, and is the key European Directive which covers almost all regulation of industrial processes in the European Union (EU). Within the IED, the requirements of the relevant sector BREF (Best Available Techniques Reference documents) become binding as BAT (Best Available Techniques) guidance, as follows.

- Article 15, paragraph 2, of the IED requires that ELVs are based on best available techniques, referred to as BAT.
- Article 13 of the IED, requires that 'the Commission' develops BAT guidance documents (referred to as BREFs).
- Article 21, paragraph 3, of the IED, requires that when updated BAT conclusions are published, the Competent Authority (in Scotland this is SEPA) has up to four years to revise permits for facilities covered by that activity to comply with the requirements of the sector specific BREF.

The EA explain that ‘BAT’ means the available techniques which are the best for preventing or minimising emissions and impacts on the environment where ‘techniques’ include both the technology used and the way the installation is designed, built, maintained, operated and decommissioned.

The current Waste Incineration BREF was published by the European Integrated Pollution Prevention and Control (IPPC) Bureau in December 2019. The existing EP has been varied to comply with the requirements of the Waste Incineration BREF.

2.4 Local air quality management

In accordance with Section 82 of the Environment Act 1995 (Part IV), local authorities are required to periodically review and assess air quality within their area of jurisdiction, under the system of Local Air Quality Management (LAQM). This review and assessment of air quality involves assessing present and likely future ambient pollutant concentrations against AQALs. If it is predicted that levels at the façade of buildings where members of the public are regularly present (normally residential properties) are likely to be exceeded, then the local authority is required to declare an Air Quality Management Area (AQMA). For each AQMA, the local authority is required to produce an Air Quality Action Plan (AQAP), the objective of which is to reduce pollutant levels in pursuit of the relevant AQALs.

3 Sensitive Receptors

3.1 Human sensitive receptors

The general approach to the assessment is to evaluate the highest predicted process contribution to ground level concentrations. In addition, the predicted process contribution at a number of sensitive receptors has been evaluated. These sensitive receptors are displayed in Figure 2 of Appendix A and listed in Table 6.

These receptors are a representative sample of the residential properties, schools, hospitals, and care homes within approximately 2 km of the Facility. It is not possible to include every occupied area and as such the assessment also considers the point of maximum impact and by interpretation of plot files.

Table 6: Human Sensitive Receptors

ID	Receptor name	Location		Distance from the absorber stack (km)
		X (m)	Y (m)	
R1	Clarks Terrace (east)	349728	381481	0.29
R2	Sandy Lane 5 (Est of A557)	350263	381406	0.59
R3	Westfield Primary School	350502	382335	0.91
R4	Heathside Nursery	350859	381076	1.27
R5	St Clement's Catholic Primary School	351222	381971	1.44
R6	Holmdale Nursing Home	350800	380580	1.55
R7	Weston Primary School	351131	380652	1.74
R8	Pewithall Primary School	351653	381282	1.92
R9	Hales Gate Road	348145	383335	2.28
R10	Cavendish High Academy	352088	380485	2.63
R11	Church Road (Hale)	347225	381689	2.57

3.2 Ecological sensitive receptors

A study was undertaken to identify the following sites of ecological importance in accordance with the EA’s Air Emissions Guidance criteria:

- Special Protection Areas (SPAs), Special Areas of Conservation (SACs), Ramsar sites, or Sites of Special Scientific Interest (SSSIs) within 10 km of the Facility; and
- National Nature Reserves (NNR), Local Nature Reserves (LNRs), Local Wildlife Sites and ancient woodlands within 2 km of the Facility.

The sensitive ecological receptors identified are presented by distance from absorber column stack in Table 7 and are displayed in Figure 3 of Appendix A.

Table 7: Ecological Sensitive Receptors

ID	Name	Location		Distance from absorber stack at closest point (km)
		X (m)	Y (m)	
European and UK designated sites				
E1	Mersey Estuary SPA/ Ramsar/ SSSI	Point of maximum impact within designated site		0.5
Local sites				
E2	Pickering's Pasture LNR/ LWS	349300	383800	1.6
E3	Runcorn Hill LNR/ LWS	350800	381600	1.0
E4	Frodsham and Helsby and Ince Marshes LWS	350170	379740	2.0
E5	Upper Mersey Estuary Intertidal Areas and Mudflats LWS	348600	381500	1.2
E6	Upper Mersey Estuary LWS	351600	383300	1.9

The Mersey Estuary extends across a wide area. When undertaking the assessment the maximum impact within the designated site has been considered.

A review of the citation for each site has been undertaken to determine if lichens are an important part of the ecosystem's integrity for the purposes of determining the relevant Critical Level for the habitat. None of the supporting information reviewed for the sites identified include any reference to lichens and bryophytes. As such, the higher Critical Levels detailed in Table 4 have been applied.

Reference should be made to Appendix B for full details of the habitats present at each site and the habitat-specific Critical Loads.

4 Baseline Air Quality

The Facility is located in Weston Point, a predominantly industrial area approximately 2 km south-west of Runcorn town centre, within the administrative area of Halton Borough Council (HBC). The location of the Facility is shown on Figure 1 of Appendix A.

Within this section a review of the existing air quality has been carried out with reference to local monitoring data. Where local monitoring data is not available reference has been made to national datasets from a similar setting.

4.1 Air quality management areas

Under Section 82 of the Environment Act 1995 (Part IV), local authorities are required to undertake an ongoing exercise to review air quality within their area of jurisdiction. Two AQMAs have been declared within HBC's administrative area. Widnes No1 and Widnes No2 were both declared on 01 March 2011 due to exceedances of nitrogen dioxide in Widnes, approximately 4 km north of the Facility. The locations of both HBC AQMAs are shown in Figure 2 of Appendix A. Due to the distance from the Facility it is anticipated that there will be no significant impacts on these AQMAs. The impact within the AQMAs will be considered as part of this assessment.

4.2 National modelling – mapped background data

In order to assist local authorities with their responsibilities under LAQM, the Department for Environment Food and Rural Affairs (Defra) provides modelled background concentrations of pollutants throughout the UK on a 1 km by 1 km grid. This model is based on known pollution sources and background measurements and is used by local authorities in lieu of suitable monitoring data. In addition, mapped atmospheric concentrations of ammonia are available from Centre for Ecology and Hydrology (CEH). Concentrations will vary over the modelling domain area. Therefore, the maximum mapped background concentration data within 5 km of the absorber stack have been downloaded along with the concentrations for the grid squares containing the Site. A summary is presented in Table 8.

Table 8: Mapped Background Data

Pollutant	**Annual mean concentration (µg/m³)**		**Dataset**
	At Site	**Max within 5 km of absorber stack**	
Nitrogen dioxide	13.2	19.9	Defra 2018
Sulphur dioxide	2.7	5.2	APIS mid-year 3 year average 2019 to 2021
Particulate matter (as PM_{10})	11.2	15.5	Defra 2018
Particulate matter (as $PM_{2.5}$)	7.7	11.5	Defra 2018
Carbon monoxide	359	414	Defra 2001
Benzene	0.73	1.09	Defra 2001
Ammonia	2.7	4.7	APIS mid-year 3 year average 2019 to 2021

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4.3 AURN monitoring data

The UK Automatic Urban and Rural Network (AURN) is a country-wide network of air quality monitoring stations operated on behalf of the Defra. This includes automatic monitoring of oxides of nitrogen, nitrogen dioxide, sulphur dioxide, ozone, carbon monoxide and particulates. Monitoring locations are broadly categorised into ‘roadside’ and ‘background’ type sites. Concentrations at roadside sites are dominated by local traffic emissions and are only representative of air quality for the immediate area of the analyser, whereas background sites are located away from any large local source and are intended to be representative of background concentrations over several square kilometres. As such, consideration has been given to background monitoring within 10 km of the site and roadside monitoring within 3 km of the site.

The closest AURN monitoring stations to the Facility are in Widnes and Liverpool Speke. The Widnes station (Milton Road) is a roadside site located approximately 4 km to the north. Therefore, data from this analyser is not representative of concentrations in the vicinity of the site and data from this site has not been considered further in this analysis.

The Liverpool Speke site located approximately 6 km to the west is classified as an ‘Urban Industrial’ site. A review of this site shows that although it is classified as ‘Urban Industrial’, there is only light industry in the area and the site it is not located close to any significant road or heavy industrial pollutant sources. Therefore, the Liverpool Speke site can be considered a representative background site. Background sites are positioned that they are not influenced significantly by any single source or street but rather by the integrate contribution from all sources upwind of the station and are considered broadly representative for several square kilometres.

Monitoring data from the Liverpool Speke AURN has been obtained from the most the UK-air website and is presented in the following table.

Table 9: Liverpool Speke AURN Monitoring

Pollutant	**Concentration (µg/m³)**						
	AQAL	**Mapped Bg 2018**	**2018**	**2019**	**2020**	**2021**	**2022**
Annual mean concentrations							
Nitrogen dioxide	40	20	18	19	12	16	15
Sulphur dioxide	N/A	3(1)	2	2	2	3	2
Particulate matter (PM_{10})	40	13	14	17	15	11	15
Particulate matter ($PM_{2.5}$)	20	9	9	9	7	6	9
Percentiles							
Nitrogen dioxide							
99.79%ile of hourly means	200	-	73	87	69	73	81
Sulphur dioxide							
99.18%ile of daily means	125	-	11	5	7	9	7
99.73%ile of hourly means	350	-	27	18	18	30	24
99.9%ile of 15-minute means	266	-	46	38	26	63	39
Particulate matter (as PM_{10})							
90.41%ile of daily means	50	-	23	28	27	16	23

Pollutant	**Concentration (µg/m^3)**						
	AQAL	**Mapped Bg 2018**	**2018**	**2019**	**2020**	**2021**	**2022**
Note: *(1) Background sulphur dioxide concentration taken from APIS mid-year 3 year average 2019 to 2021*							

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As shown, monitored pollutant concentrations are well below the relevant AQALs. There is little difference between the mapped backgrounds and the monitored concentrations, so it can be concluded that the mapped background concentration is representative of concentrations in the vicinity of the monitoring site. In addition, there have been no exceedences of the short term AQALs.

4.4 LAQM monitoring data

In addition to the national AURN, local authorities undertake monitoring of a range of pollutants as part of the LAQM review process. A review of the monitoring undertaken by HBC has shown that they operate two continuous analysers, both of which are classified as ‘roadside’. One roadside monitor is located in each of the AQMAs in Widnes detailed in 4.1. As these monitoring locations are more than 4 km from the Facility the monitored concentrations are not representative of general baseline conditions in the vicinity of the site. Therefore, the continuous monitoring data from these sites has not been considered further.

In addition to the continuous analysers, HBC undertakes diffusion tube monitoring of nitrogen dioxide as part of the LAQM process. HBC operates one urban background diffusion tube, located approximately 1.5 km from the Site, and ten roadside or kerbside sites, of which one is located within 3 km of the site. Monitoring data from these sites is presented in Table 10.

Table 10: Diffusion Tube Nitrogen Dioxide Monitoring

Diffusion Tube	**Location**		**NO$_2$ annual mean concentration (µg/m^3)**			
	X	**Y**	**2018 Mapped bg**	**2019**	**2020**	**2021**
Lee Street (2) – urban bg	350896	380810	13.6	26.5	23.3	24.7
Cronton Lane (3) - roadside	351379	381458	14.1	-	22.8	26.5

Source: Halton Borough Council Annual Status Report 2022

Monitored concentrations at the roadside site are higher than the mapped background, representative of local traffic emissions. The monitored concentrations at the urban background site are much higher than the mapped background. A review of the location of this site shows that it is located adjacent to a relatively minor road (Heath Road South), so may also be influenced by local traffic emissions.

Giving consideration to all mapped background and monitoring data, it is considered appropriate to use the higher of either the mapped background concentrations within 5 km of the site, or the maximum monitored at a background location. The exception is for nitrogen dioxide, for which the concentrations monitored at the urban background site are much higher than the mapped background, potentially due to local road traffic emissions, and may not be representative of background concentrations over a wider area. A summary of baseline concentrations is provided in Table 15.

4.5 Other national monitoring networks data

Neither the Defra mapped background dataset, AURN, or LAQM include monitoring of other pollutants released from the Facility such as hydrogen chloride, hydrogen fluoride, or VOCs. As such reference has been made to national modelling to determine a suitable background concentration for these pollutants.

4.5.1 Hydrogen chloride

Hydrogen chloride was measured until the end of 2015 on behalf of Defra as part of the UK Eutrophying and Acidifying Atmospheric Pollutants (UKEAP) project. This consolidates the previous Acid Deposition Monitoring Network (ADMN), and National Ammonia Monitoring Network (NAMN). Monitoring of hydrogen chloride ceased at the end of 2015 and none of the historic sites were located within 10 km of the Site. Prior to the cessation of the monitoring concentrations were fairly constant.

The maximum annual average monitored within the UK between 2011 and 2015 was 0.71 µg/m^3. In lieu of any recent representative monitoring this has been used as the background concentration for this assessment as a conservative estimate.

4.5.2 Hydrogen fluoride

Baseline concentrations of hydrogen fluoride are neither measured locally nor nationally, since these are not generally of concern in terms of local air quality. However, the EPAQS report ‘Guidelines for halogens and hydrogen halides in ambient air for protecting human health against acute irritancy effects’ contains some estimates of baseline levels, reporting that measured concentrations have been in the range of 0.036 µg/m^3 to 2.35 µg/m^3.

In lieu of any local monitoring, the maximum measured baseline hydrogen fluoride concentration has been used as the background concentration for the purpose of this assessment as a conservative estimate.

4.5.3 Ammonia

Ammonia is also measured as part of the UKEAP project at rural background locations. There are no UKEAP monitoring locations within 10 km of the site. The nearest monitoring site is at Bickerton Hill, approximately 30 km to the south. In lieu of any local UKEAP monitoring, the maximum mapped background value from APIS within 5 km of the site (4.7 µg/m^3) has been used for the purpose of this assessment when considering the impact with reference to the AQALs for the protection of human health, and the site-specific background concentration from each designated ecological site from APIS has been used when evaluating the impact at ecological receptors, if needed.

4.5.4 Volatile Organic Compounds

As part of the Automatic and Non-Automatic Hydrocarbon Network, benzene concentrations are measured at sites co-located with the AURN across the UK. The closest monitoring site to the site is Liverpool Speke, a non-automatic monitoring site 7.9 km to the north. The measured concentration of benzene is broadly similar to the mapped background dataset. As such the maximum mapped background concentration within 5 km of the Facility has been used. This value is 1.09 µg/m^3.

4.5.5 Metals

In addition to the local monitoring, metals are measured as part of the Rural Metals and UK Urban/Industrial Networks (previously the Lead, Multi-Element and Industrial Metals Networks). A site was located at Runcorn Weston Point, an urban industrial site 0.7 km to the south-east. However, this site closed in March 2019. Monitoring from this site from 2015 onwards is presented in the Table 11.

Table 11: Annual Mean Metals Concentrations – Runcorn Weston Point

Substance	**Annual mean concentration (ng/m^3)**						**Max (as % of AQAL)**
	AQAL	**2015**	**2016**	**2017**	**2018**	**2019(1)**	
Arsenic	6	0.56	0.68	0.62	0.68	0.83	13.8%
Cadmium	5	0.09	0.12	0.09	0.09	0.12	2.4%
Chromium	-	1.50	1.10	1.60	1.70	1.50	-
Cobalt	200	0.19	0.14	0.19	0.39	0.10	-
Copper	-	5.30	6.00	5.50	5.09	4.70	-
Lead	250	5.09	5.90	4.90	4.70	7.00	2.8%
Manganese	150	2.80	3.30	3.20	3.20	3.30	2.2%
Mercury(2)	-	19	15	19	16	-	-
Nickel	20	1.50	1.10	1.10	0.83	0.78	7.5%
Vanadium	-	1.00	0.96	1.10	0.97	1.00	-

Notes:

(1) No data after 14 March 2019.

(2) No data after 31 Dec 2018.

Source: © Crown 2023 copyright Defra via uk-air.defra.gov.uk, licenced under the Open Government Licence (OGL).

In addition to the suite of metals monitored at Runcorn there would be releases of thallium, mercury and antimony from the Facility. With reference to these pollutants:

- Thallium is not routinely monitored as part of the metals network.
- Monitoring of antimony across the UK ceased at the end of 2013. The maximum monitored at any background site in 2013 was 1.30 ng/m^3 at Detling, which is well below the AQAL.

Due to the close proximity of the Weston Point monitoring location, these monitored concentrations are considered appropriate for use as the baseline concentrations of metals in this assessment. For antimony, which was not recorded at Weston Point after 2013, the value recorded at Detling in 2013 has been used as a conservative value.

4.5.6 Dioxins, furans and polychlorinated biphenyl (PCBs)

Dioxins, furans and PBCs are monitored on a quarterly basis at a number of urban and rural stations in the UK as part of the Toxic Organic Micro Pollutants (TOMPs) network. There are no national monitoring locations within 10 km of the site. The closest site is located in Manchester.

A summary of dioxin and furan and PCB concentrations from all monitoring sites across the UK is presented in Table 12 and Table 13. Monitoring data for dioxins and furans is only available up to the end of 2016 from the UK-Air website. For PCBs, data is only available up to the end of 2018 from the UK-Air website.

Table 12: Dioxin and Furans Monitoring

Site	Annual mean concentration (fgTEQ/m³)				
	2012	2013	2014	2015	2016
Auchencorth Moss	0.13	0.86	0.01	0.01	0.13
Hazelrigg	8.75	2.02	2.61	5.27	4.59
High Muffles	4.32	0.6	1.07	0.54	2.73
London Nobel House	15.42	3.47	2.89	4.34	21.27
Manchester Law Courts	32.99	10.19	16.52	5.94	12.23
Weybourne	9.3	2.34	1.61	1.42	16.32

Source: © Crown 2023 copyright Defra via uk-air.defra.gov.uk, licenced under the Open Government Licence (OGL).

Table 13:TOMPS – PCB Monitoring

Site	Annual mean concentration (pg/m³)				
	2014	2015	2016	2017	2018
Auchencorth Moss	23.23	24.27	25.32	19.09	12.31
Hazelrigg	25.84	41.68	52.58	33.15	22.22
High Muffles	26.11	33.43	37.76	31.63	8.86
London Nobel House	107.49	121.39	110.46	121.87	46.63
Manchester Law Courts	128.93	97.99	92.6	97.27	40.10
Weybourne	17.00	20.95	38.61	32.26	11.23

Source: © Crown 2023 copyright Defra via uk-air.defra.gov.uk, licenced under the Open Government Licence (OGL).

This analysis shows that the concentrations vary significantly between sites and years. The maximum monitored concentration from the past 5 years of available monitoring data has been used as the background concentration within this assessment. These values are 32.99 fg/TEQ/m³ for dioxins and furans and 128.93 pg/m³ for PCBs.

4.5.7 Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic Aromatic Hydrocarbons (PAHs) are monitored at a number of stations in the UK as part of the PAH network. For the purpose of this assessment, benzo(a)pyrene is considered as this is the only PAH which an AQAL has been set. The closest monitoring station to the Facility is at Liverpool Speke.

Due to the mixture of rural, residential and industrial nature of the land around the Facility, the monitored concentrations at Liverpool Speke are likely to be reasonably representative. However, the monitoring site is across the large expanse of the Mersey estuary from the Facility. In order to be conservative, the assessment has considered monitored data from urban background sites, shown in Table 14.

Table 14: Benzo(a)pyrene

Site	AQAL (ng/m³)	Annual mean concentration (ng/m³)				
		2018	2019	2020	2021	2022
Min	0.25	0.06	0.06	0.04	0.05	0.08
Max		0.25	**0.50**	0.24	0.22	**0.29**

Site	AQAL (ng/m^3)	Annual mean concentration (ng/m^3)				
		2018	2019	2020	2021	2022
Average		0.16	0.21	0.15	0.16	0.20
Liverpool Speke		0.10	0.14	0.06	0.08	0.18

Source: © Crown 2023 copyright Defra via uk-air.defra.gov.uk, licenced under the Open Government Licence (OGL).

As shown, the maximum at any urban background site exceeds the AQAL. Based on monitoring data from Speke, this is likely to be over-conservative. The maximum monitored concentration from Liverpool Speke (0.18 ng/m^3) has been used as the background concentration within this assessment.

4.5.8 Aldehydes

Baseline concentrations of aldehydes are neither measured locally nor nationally, since these are not generally of concern in terms of local air quality. Formaldehyde is the aldehyde with the most stringent AQAL. The Defra report 'Non-methane Volatile Organic Compounds in the UK'[2] presents the results of some monitoring studies, reporting a maximum measured formaldehyde concentration in the UK of 2.37 $\mu g/m^3$.

In lieu of any local monitoring, the maximum measured baseline formaldehyde concentration has been used for the purpose of this assessment as a conservative estimate.

4.5.9 Amines, nitrosamines and nitramines

The concentrations of amines and amine degradation products (i.e. nitrosamines and nitramines) in ambient air, and their consequent impacts on human health, are active areas of research. Inhalation of these compounds is only one potential pathway, with other known sources including dietary exposure, drinking water, and some pharmaceuticals. Nitrosamines have been detected in food and drink, particularly those with high concentrations of nitrites such as processed meat, cheese, alcoholic beverages and processed vegetables. However, this assessment is concerned only with exposure via inhalation, and has therefore only considered ambient air concentrations. The solvent to be used in the CC facility, MEA, does not form a stable nitrosamine. However, it has the potential to degrade into substances that do form stable nitrosamines; therefore it is appropriate to consider baseline concentrations of amines, nitrosamines and nitramines.

The EA's Air Quality Modelling and Assessment Unit (AQMAU) produced a report in 2021[3] which details their recommendations for the assessment of emissions from amine-based CCS systems. With regard to baseline concentrations, the report states:

> *"we found no ambient air measurements of amines, nitrosamines or nitramines in the UK."*

Nitrosamines, which are the compounds with the greatest potential human health effects, have short atmospheric lifetimes on the order of hours before undergoing photolysis. As such, only local sources would contribute significantly to baseline concentrations. There are no known industrial sources of amines to the atmosphere in the local area.

No existing local sources of point source emissions of amines have been identified. Therefore, in the first instance it has been assumed that ambient air concentrations of these pollutants in the

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[2] Defra Air Quality Expert Group, Non-methane Volatile Organic Compounds in the UK, 2020

[3] AQMAU (Environment Agency), Recommendations for the assessment and regulation of impacts to air quality from amine-based post-combustion carbon capture plants, November 2021

vicinity of the Site are below the limit of detection (LOD) of any currently available monitoring techniques and have been assumed to be zero.

4.6 Summary of background concentration used in assessment

In summary, there is some local monitoring of nitrogen dioxide, sulphur dioxide, particulate matter, benzene, metals, dioxins and PAHs. The analysis has shown that the monitored concentrations at the closest background sites is similar to the Defra and APIS mapped background concentrations. This suggests that the mapped background model is performing well in the local area and can be used as a source of baseline concentrations at background locations.

The concentrations of road traffic pollutants (in particular nitrogen dioxide, and to a lesser degree particulate matter) vary spatially across the modelling domain. As such for these pollutants additional consideration will be given to determine the baseline concentration for these pollutants taking into account the local monitoring data and other sources of data regarding local concentrations, such as Defra's ambient air quality mapping.

For other pollutants, in the first instance it will be assumed that baseline concentrations are as per those set out in the following table. These are based on a mixture of monitoring at modelled data sets. Where the contribution from the Proposed Facility cannot be screened out as 'insignificant' (see Section 8.1 for methodology), the choice of baseline concentration will be given additional consideration, taking into account the local monitoring and the contribution from other local sources, and noting that any local monitoring data includes a contribution from the Existing Facility.

Table 15: Summary of Baseline Concentrations

Pollutant	Annual mean concentration	Units	Justification
Nitrogen dioxide	19.9	µg/m³	Maximum mapped background concentration within 5 km of the Site (2018 Defra dataset)
Sulphur dioxide	5.2	µg/m³	Maximum mapped background concentration within 5 km of the Site (APIS 2019 – 2021 mid year)
Particulate matter (as PM_{10})	15.5	µg/m³	Maximum mapped background concentration within 5 km of the Site (2018 Defra dataset)
Particulate matter (as $PM_{2.5}$)	11.5	µg/m³	Maximum mapped background concentration within 5 km of the Site (2018 Defra dataset)
Carbon monoxide	414	µg/m³	Maximum mapped background concentration within 5 km of the Site (2001 Defra dataset)
Hydrogen chloride	0.71	µg/m³	Maximum monitored concentration across the UK 2011 to 2015
Hydrogen fluoride	2.35	µg/m³	Maximum measured concentration from EPAQS report
Ammonia	4.7	µg/m³	Maximum mapped background concentration within 5 km of the Site (APIS 2019 – 2021 mid year)

Pollutant	Annual mean concentration	Units	Justification
Benzene	1.09	µg/m³	Maximum mapped background concentration within 5 km of the Site (2001 Defra dataset)
Mercury	19	ng/m³	Maximum monitored annual mean concentration from Runcorn Weston Point from 2015-2019
Antimony	1.30	ng/m³	Maximum monitored across UK in most recent year of monitoring data (2013)
Arsenic	0.83	ng/m³	Maximum monitored annual mean concentration from Runcorn Weston Point from 2015-2019 Chromium VI assumed to be 20% of total chromium in line with EA guidance.
Cadmium	0.12	ng/m³	
Chromium	1.70	ng/m³	
Chromium VI	0.34	ng/m³	
Cobalt	0.39	ng/m³	
Copper	6.00	ng/m³	
Lead	7.00	ng/m³	
Manganese	3.30	ng/m³	
Mercury	19.0	ng/m³	
Nickel	1.50	ng/m³	
Vanadium	1.10	ng/m³	
Dioxins and furans	32.99	fg/m³	Maximum UK monitored concentration between 2012 and 2016
Polychlorinated biphenyl (PCBs)	128.93	pg/m³	Maximum UK monitored concentration between 2014 and 2018
Benzo(a)pyrene (PAHs)	0.18	ng/m³	Maximum monitored concentration from Speke between 2017 and 2022
Formaldehyde	2.37	µg/m³	Maximum measured concentration from Defra report
Amines	0	-	No monitoring available. Assumed to be below the LOD of current monitoring techniques and effectively zero.
Nitramines	0	-	
Nitrosamines	0	-	

4.7 Baseline conditions at ecological sites

The Air Pollution Information System (APIS) database sets out the baseline concentrations on a grid across the UK. Atmospheric concentrations of oxides of nitrogen, ammonia, acid and nitrogen deposition are provided on a 1 km x 1 km grid. A large quantity of data is available but is only considered relevant where the impact of emissions cannot be screened out as ‘insignificant’ without reference to baseline conditions (as per the methodology detailed in section 9.1. The site-specific baseline concentrations relevant to the assessment are detailed in section 9.4 and appendices 0 - D.

5 Modelling Methodology

5.1 Selection of model

Detailed dispersion modelling was undertaking using the model ADMS 6, developed and supplied by Cambridge Environmental Research Consultants (CERC) This is a new generation dispersion model, which characterises the atmospheric boundary layer in terms of the atmospheric stability and the boundary layer height. In addition, the model uses a skewed Gaussian distribution for dispersion under convective conditions, to take into account the skewed nature of turbulence. The model also includes modules to take account of the effect of buildings and complex terrain.

ADMS is routinely used for modelling of emissions for environmental permitting purposes to the satisfaction of the EA. An analysis of the variation in model outputs has been undertaken and the maximum predicted concentration for each pollutant and averaging period has been used to determine the significance of any potential impacts.

5.2 Source and emissions data – ERF – i.e. the Permitted Facility

The source and emissions input data utilised within the modelling for the ERF are presented in Table 17 to Table 18. These are presented per line and are based on operational data obtained from the continuous emissions monitoring system (CEMS), representative of normal operation. These inputs have been used to determine the impact for the Permitted Facility.

Table 16: Stack Data - ERF

Item	Unit	Value
Height	m	105
Effective internal diameter (all lines combined)	m	4.40
Number of lines	-	4
Stack location	m, m	349850, 381783

Table 17: Flue Gas Conditions – ERF

Item	Unit	ERF – all lines combined
Temperature	°C	160
Exit moisture content	% v/v	16.90%
	kg/kg	0.122
Exit oxygen content	% v/v dry	9.70%
Reference oxygen content	% v/v dry	11.00%
Volume at reference conditions (273.15K, dry, ref O_2)	Nm^3/h	841,031
	Nm^3/s	233.62
Volume at actual conditions	Am^3/h	1,451,483
	Am^3/s	403.19
Flue gas exit velocity	m/s	26.52

Table 18: Stack Emissions Data – ERF All Lines Combined

Pollutant	**Daily or periodic**		**Half-hourly**	
	ELV (mg/Nm³, unless stated)	**Release rate (g/s, unless stated)**	**ELV (mg/Nm³, unless stated)**	**Release rate (g/s, unless stated)**
Oxides of nitrogen (as NO_2)	180	42.052	400	93.448
Sulphur dioxide	40	9.345	200	46.724
Carbon monoxide(1)	50	11.681	150(1)	35.043
Total dust (PM)(2)	5	1.168	30	7.009
Hydrogen chloride	8	1.869	60	14.017
Volatile organic compounds (as TOC)	10	2.336	20	4.672
Hydrogen fluoride	1	0.234	-	-
Ammonia	15	3.506	-	-
Cadmium and thallium	0.02	4.672 mg/s	-	-
Mercury	0.02	4.672 mg/s	-	-
Other metals(3)	0.3	70.09 mg/s	-	-
Benzo(a)pyrene (PAHs)(4)	0.2 µg/Nm³	46.72 µg/s	-	-
Dioxins and furans(5)	0.06 ng/Nm³	14.02 ng/s	-	-
PCBs(6)	5 µg/Nm³	1.17 mg/s	-	-

Notes:

All emissions are expressed at reference conditions of dry gas, 11% oxygen, 273.15K.

(1) Averaging period for carbon monoxide is 95% of all 10-minute averages in any 24-hour period.

(2) As a worst-case it has been assumed that the entire dust emissions consist of either PM_{10} or $PM_{2.5}$ for comparison with the relevant AQALs.

(3) Other metals consist of antimony (Sb), arsenic (As), lead (Pb), chromium (Cr), cobalt (Co), copper (Cu), manganese (Mn), nickel (Ni) and vanadium (V).

(4) 0.2 µg/m³ is the maximum recorded at a UK plant (2019 Waste Incineration BREF, Figure 8.121). This is assumed to be the emission concentration for the ERF.

(5) The EP includes a limit of 0.06 ng I-TEQ/Nm³ as an average over a minimum of 6 hours, and a limit of 0.08 ng I-TEQ/Nm³ as a long-term average over a minimum of 2 weeks. The long-term average sampling is only required if it cannot be demonstrated that emissions are low and stable. It has been assumed that the long-term average monitoring will not be required and an emission limit of 0.06 ng I-TEQ/Nm³ is representative of the maximum annual mean emission concentration from the Facility.

(6) Table 3.8 of the 2006 Waste Incineration BREF states that the annual average total PCBs is less than 0.005 mg/Nm³ (dry, 11% oxygen, 273K). In lieu of other available operational data, this has been assumed to be the emission concentration for the ERF.

If the ERF continually operated at the half-hourly limits, the daily limits would be exceeded. The ERF is designed to achieve the daily limits and as such will only operate at the short-term ELVs for short periods on rare occasions.

5.3 Source and emissions data – CC facility

The source and emissions input data utilised within the modelling for the CC facility are presented in Table 19 to Table 21. These have been used to determine the impact for the Proposed Facility. The mass release rate of emissions of pollutants emitted from the ERF is assumed to be unchanged in passing through the CC facility.

As set out in the Supporting Information the design of the CC facility has been optimised to have the greatest temperature of the release without significant loss of the efficiency on the ERF. A detailed stack height analysis has been carried out to determine what height would be needed to have a similar impact to the Permitted Facility. However, due to the significantly different temperature of the release and increased mass of pollutants per volume of air emitted a similar impact cannot be achieved without a stack height of over 130 m. It has been deemed that a stack of up to height approximately 110 m could be constructed without significant complexities to the civils works as such this is deemed to be the maximum stack height for the CC facility. This is the stack height which is being applied for as part of this EP application.

Table 19: Stack Data – CC facility

Item	Unit	Value
Height	m	110
Internal diameter	m	4.85
Absorber stack location	m, m	349793.0, 381762.5

Table 20: Flue Gas Conditions – CC facility

Item	Unit	Value
Temperature	°C	58.15
Exit moisture content	% v/v	18.65%
	kg/kg	0.138
Exit oxygen content	% v/v dry	10.73%
Reference oxygen content	% v/v dry	11%
Volume at reference conditions (273.15K, dry, ref O_2)	Nm^3/h	690,790
	Nm^3/s	191.9
Volume at actual conditions	Am^3/h	999,019
	Am^3/s	277.5
Flue gas exit velocity	m/s	15

Table 21: Stack Emissions Data – CC facility

Pollutant	Daily or periodic	
	Emission conc. (mg/Nm^3, unless stated)	**Release rate (g/s, unless stated)**
MEA - primary amine$^{(1)}$	10	1.919
Nitrosamines from MEA$^{(2)}$	None emitted	None emitted
Nitramines from MEA$^{(3)}$	0.0953 µg/Nm^3	18.27 ng/s
DEA – secondary amine$^{(1)}$	0.25	0.048
Nitrosamines from DEA$^{(4)}$	0.05 µg/Nm^3	9.59 ng/s
Nitramines from DEA$^{(3)}$	2.4 ng /Nm^3	0.457 ng/s
DMA – secondary amine$^{(1)}$	0.25	0.048
Nitrosamines from DMA$^{(4)}$	0.05 µg/Nm^3	9.59 ng/s
Nitramines from DMA$^{(3)}$	2.4 ng/Nm^3	0.457 ng/s
Aldehydes	5	0.959

Notes:

All emissions are expressed at reference conditions of dry gas, 11% oxygen, 273.15K, for the flue gas flow rate at the absorber stack.

For pollutants with an ELV from the ERF the same g/s release rate has been assumed from the CC facility – refer to Table 18 for the relevant release rates.

(1) MEA based system with the main primary amine being MEA with trace amounts of DEA and DMA. Emissions of DEA and DMA in total assumed to be 5% of the MEA emissions with a 50/50 split of each.

(2) No nitrosamines from MEA emitted.

(3) Total nitramines assumed to be 0.1 µg/Nm^3 apportioned as per the amine concentration – i.e. 95% from MEA, with 2.5% from DEA and DMA.

(4) Total nitrosamines assumed to be 0.1 µg/m^3 apportioned equally between nitrosamines formed from DEA and from DMA.

The emissions concentrations presented in Table 21 for amines, nitrosamines, nitramines and formaldehyde are not intended as proposed ELVs for the CC facility but are included as the likely upper end of long-term average emissions from the CC facility to allow the impact to be quantified. The ELVs to be included in the EP will be confirmed with the EA during the determination of the application to vary the EP.

It has been assumed that the CC facility continually operates at the emissions concentrations presented in Table 21. However, as all four lines of the ERF are unlikely to operate continuously throughout the year, and there will be periods when the CC facility will require maintenance, this is considered to be a very conservative assumption.

5.4 Source and emissions data – hybrid coolers

The CC facility includes a hybrid cooling system. The exit temperature and volume will vary with ambient conditions. However, as a screening exercise the model has been run with the highest anticipated flow rate. The coolers are arranged as an array of 20 units on the hybrid cooler building and 25 units on the compressor house. As part of the screening exercise each bank of units has been modelled as a single point source. The inputs used are presented in Table 22 and Table 23.

Table 22: Stack Data – Hybrid Coolers

Item	Unit	Value
Height	m	20
Effective internal diameter – hybrid cooler zone	m	12.98
Effective internal diameter – compressor house	m	14.51
Stack location – hybrid cooler zone	m, m	349722.0, 381745.6
Stack location – compressor house	m, m	349732.0, 381717.0

Table 23: Flue Gas Conditions – Hybrid Coolers

Item	Unit	Value
Temperature	°C	9
Exit moisture content	% v/v	3.55%
	kg/kg	0.022
Actual flow rate - hybrid cooler zone	m^3/s	800
Actual flow rate - compressor house	m^3/s	1,000
Exit velocity	m/s	6.04

The vendor has confirmed that the coolers will emit small quantities of regulated pollutants as a consequence of the direct contact cooling (DCC) process. These emissions have been included in the dispersion modelling to quantify the potential impacts. The emissions parameters are detailed in Table 24, assuming the maximum flow rate from the hybrid coolers. Any pollutants not listed will have an imperceptible emission concentration.

Table 24: Stack Emissions Data – Hybrid Coolers

Pollutant	Emission conc. ($\mu g/m^3$)	Release rate (mg/s)	
		Hybrid cooler zone	Compressor house
Volatile organic compounds (as TOC)	3.204	2.563	3.204
Ammonia	0.532	0.426	0.532
Cadmium and thallium	0.087	0.0695	0.0868
Mercury	0.087	0.0695	0.0868
Other metals	0.865	0.692	0.865

Note:

All emissions are expressed at actual flow conditions.

The release rate of pollutants from the hybrid coolers is very small. However, the impact of emissions has been assessed as a conservative measure. The results are presented in section Table 48.

5.5 Source and emissions data – CO_2 vent

The CC facility includes a vent for CO_2 full details of when this vent would be operational are set out in the Supporting Information. Any CO_2 venting event would be limited to a short period of time, typically the time taken to depressurise the CC facility (or a section thereof) and release the stored CO_2 inventory. The maximum duration of venting is to be determined during detailed design. However, as a screening exercise the model has been run assuming a constant release. Therefore, the operation of the CO_2 vent during the worst-case conditions for dispersion is captured. The inputs used are presented in Table 25 and Table 26.

Table 25: Stack Data – CO_2 Vent

Item	Unit	CO_2 vent
Height	m	110
Internal diameter	m	1.048
Stack location	m, m	349784, 381762

Table 26: Flue Gas Conditions – CO_2 vent

Item	Unit	CO_2 vent
Temperature	°C	-6°C
Volume at actual conditions	Am^3/h	39,350
Flue gas exit velocity	m/s	22.43
Heat capacity (Cp)	J/°C/kg	853.2
Molar mass	g	44.01
Release rate of CO_2	tph	140.4
	g/s	39,000

The impact of CO_2 venting has been predicted on a grid of receptors at 1.5 m above ground level (representing ground-level exposure) and at receptors including those representing exposure at 1.5 m above the top the ERF building and at the existing and new monitoring platforms on the stacks. The receptor locations and heights are given in Table 27.

Table 27: Discrete Receptor Locations – CO_2 Vent Modelling

ID	Receptor name	Location		
		X (m)	Y (m)	Z (m)
R1	New monitoring platform - ERF	348520	375350	25.5
R2	New monitoring platform – Absorber	345000	376500	75.5
R3	ERF Building 1	346160	375700	43.5
R4	ERF Building 2	348385	376077	43.5
R5	ERF Building 3	348620	376504	43.5

ID	Receptor name	Location		
		X (m)	Y (m)	Z (m)
R6	ERF Building 4	347155	374154	43.5
R7	Existing monitoring platform	345747	374846	50.0

5.6 Other inputs

Modelling has been undertaken over a grid of 10 km x 10 km with grid spacing of 120 m which is less than 1.5 times the stack height. Reference should be made to Figure 4 of Appendix A for a graphical representation of the modelling domain.

Table 28: Modelling Domain

Parameter	Grid
Grid Spacing (m)	120
Grid Start X	344900
Grid Finish X	354900
Grid Start Y	376800
Grid Finish Y	386800

5.6.1 Meteorological data and surface characteristics

The impact of meteorological data has been taken into account by using meteorological data from the Liverpool Airport meteorological recording station for the years 2018 – 2022 sourced from Air Pollution Services (APS) Limited. Liverpool Airport is located approximately 6 km to the west of the Facility. Wind roses for each year of meteorological data can be found in Figure 5 of Appendix A.

The minimum Monin-Obukhov length utilised in ADMS can be selected for both the dispersion site and meteorological site. This is a measure of the minimum stability of the atmosphere and can be adjusted to account for urban heat island effects which prevent the atmosphere in urban areas from ever becoming completely stable. Surface conditions surrounding the Facility are mixed industrial and urban, whilst conditions at Liverpool Airport are grassland with the edge of the Liverpool City conurbation to the north. As such, the minimum Monin-Obukhov length has been set to 30 m at the dispersion site and 30 m at the meteorological site, which is considered appropriate for the setting of each site.

The surface roughness length utilised in ADMS can additionally be selected for both the dispersion site and meteorological site. The surface roughness length varies widely across the modelling domain, from very low values over the estuary to much higher values over built-up areas. To account for the varying surface roughness length, a spatially-varying surface roughness file has been generated. The land-use class for each point in the file has been extracted from the CEH Land Cover database[4] and cross-referenced with the most likely surface roughness length value[5]. Reference should be made to Figure 6 of Appendix A for a visualisation of the surface roughness file used.

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[4] Marston, C.; Rowland, C.S.; O'Neil, A.W.; Morton, R.D. (2022). Land Cover Map 2021 (10m classified pixels, GB). NERC EDS Environmental Information Data Centre

[5] Taken from "Roughness length classification of Corine Land Cover classes", Megajoule Consultants, 2007

Table 29: Terrain and Surface Roughness Extents

Terrain and surface roughness	Grid
Processing resolution	64 x 64
Grid Start X	344300
Grid Finish X	355400
Grid Start Y	376300
Grid Finish Y	387400

Table 30: Surface Roughness Lengths Used for Different Land Use Classes

Land Use Classification	Corine 2018 Land Use Codes	Surface Roughness Length (m)
Broad-leaved forest	311	0.75
Green urban areas	141	0.6
Discontinuous urban fabric Construction sites Industrial or commercial units Sport and leisure facilities Port areas	112 133 121 142 123	0.5
Complex cultivation patterns	243	0.3
Non-irrigated arable land Inland marshes Salt marshes	211 411 421	0.05
Pastures	231	0.03
Airports Mineral extraction sites	124 132	0.005
Intertidal flats	423	0.001
Water*	511	0.0000001
**CLC roughness classification for water is 0, but this is not a valid input for ADMS. The value has been set to 0.0000001m.*		

The surface roughness for the meteorological site has been set to 0.5 m which is appropriate considering the immediate land use surrounding the meteorological recording site.

A summary of the meteorological parameters used in the dispersion modelling is shown in Table 31.

Table 31: Meteorological parameters

Parameter	Dispersion Site Value (m)	Met Site Value (m)
Surface roughness length	Variable	0.5
Minimum Monin-Obukhov length	30	30

5.6.2 Terrain

It is recommended that by CERC, where gradients within 500 m of the modelling domain are greater than 1 in 10, the complex terrain module within ADMS (FLOWSTAR) should be used. A terrain file to cover the output grid of points set out in Table 29 was created using Ordnance Survey Terrain 50 data. Reference should be made to Figure 7 of Appendix A for a visualisation of the terrain file used.

5.6.3 Buildings

The presence of adjacent buildings can significantly affect the dispersion of the atmospheric emissions in various ways:

- Wind blowing around a building distorts the flow and creates zones of turbulence. The increased turbulence can cause greater plume mixing.
- The rise and trajectory of the plume may be depressed slightly by the flow distortion. This downwash leads to higher ground level concentrations closer to the stack than those which would be present without the building.

It is recommended that buildings should be included in the modelling if they are both:

- Within 5L of the stack (where L is the smaller of the building height and maximum projected width of the building); and
- Taller than 40% of the stack.

The ADMS 6 user guide also states that buildings less than one third of the stack height will not have any effect on the dispersion calculations in the model.

A review of the Site layout has been undertaken and the details of the applicable buildings are presented in Table 32. A plan showing which buildings have been included in the model is presented in Figure 8 of Appendix A.

Table 32: Building Details

Buildings	Centre point		Height (m)	Length (m)	Width (m)	Angle (°)
	X (m)	Y (m)				
CC facility						
Absorber tower	349793.0	381762.5	53.0	13.3 (diameter)		-
Hybrid cooler zone*	349722.0	381745.6	20	18.0	46.0	174
Compressor house*	349732.0	381717.0	20	35.0	35.	174
ERF						
Boiler House	349866.1	381690.0	42.0	43.5	102.0	356
Bunker	349868.1	381652.5	38.4	31.1	102.0	356

Note:
** Only included when modelling releases from the hybrid coolers.*

5.6.4 Wind turbines

Wind turbines have the potential to affect the dispersion of emissions if the wind is blowing from the stack towards the turbines, or from the turbines to the stack, causing a wake. This can be accounted for within ADMS by using the wind turbines module. However, wind turbine wakes are generally dissipated within 12-15 rotor diameters, with the wind turbine effects becoming more noticeable when the stack is within a few rotor diameters of the turbine. No wind turbines have been identified which lie within 12-15 rotor diameters of the Facility, so this option has not been used.

5.7 Plume depletion

Within ADMS when modelling deposition an option is to include plume depletion where the concentration of pollutants in the plume reduce as the pollutants are deposited. This has not been included in the model as a conservative assumption.

5.8 Chemistry

The Facility will release nitric oxide (NO) and nitrogen dioxide (NO_2) which are collectively referred to as oxides of nitrogen (NOx). In the atmosphere, NO will be converted to NO_2 in a reaction with ozone (O_3) which is influenced by solar radiation. Since the AQALs are expressed in terms of NO_2, it is important to be able to assess the conversion rate of NO to NO_2.

Ground level NOx concentrations have been predicted through dispersion modelling. NO_2 concentrations reported in the results section assume 70% conversion from NOx to NO_2 for annual means and a 35% conversion for short term (hourly) concentrations, based upon the worst-case scenario specified in the EA's guidance for dispersion modelling[6] which is appropriate where the primary NO_2 to NOx ratio is less than 10%. Given the short travel time to the areas of maximum concentrations, this approach is considered conservative.

5.8.1 Amine chemistry

Directly-emitted amines have the potential to react in the atmosphere to form amine degradation products – nitramines and nitrosamines. The ADMS 6 amine chemistry module calculates concentrations of amines, nitramines and nitrosamines based on the release rate of pollutants and a number of user-defined parameters. The parameters used in the dispersion modelling of amine releases are detailed in Table 33.

The primary amine emitted by the CC facility would be MEA. However, it has been assumed that trace amounts of both DEA and DMA would also be emitted. Amines can form both nitrosamines and nitramines. However, the nitrosamines formed from primary amines such as MEA are unstable, forming isomers known as imines within a few seconds. Imines are not reactive nor significantly harmful to human health. Therefore, any directly emitted nitrosamines will be formed from another, secondary amine formed from reactions within the absorber tower. The exact type of secondary amine(s) and resultant nitrosamine(s) are not known at this stage. For the purpose of this assessment it has been assumed that the secondary amines emitted are equal concentrations of DMA and DEA, and the directly emitted nitrosamines are consequently equal concentrations of NDMA (formed from DMA) and n-nitrosodiethanolamine (NDELA, formed from DEA).

The amine chemistry module requires the user to input reaction rate parameters for a number of reactions which are detailed in Appendix E. The values used for the main model runs are detailed in Table 33.

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[6] https://www.gov.uk/guidance/environmental-permitting-air-dispersion-modelling-reports

Table 33: Amine Chemistry Module Input Parameters

Parameter	Units	MEA	DMA	DEA
k1 amine/OH reaction rate constant(1)	$ppb^{-1}s^{-1}$	1.900	1.625	2.525
k2 amino radical/O_2 reaction rate constant(1)	$ppb^{-1}s^{-1}$	$3.10x10^{-9}$	$3.10x10^{-9}$	$4.45x10^{-10}$
k3 rate constant for formation of nitrosamine(1)	$ppb^{-1}s^{-1}$	$2.13x10^{-3}$	$2.13x10^{-3}$	$1.78x10^{-2}$
k4a rate constant for formation of nitramine(1)	$ppb^{-1}s^{-1}$	$7.95x10^{-3}$	$7.95x10^{-3}$	$7.95x10^{-3}$
k4 Amino radical/NO_2 reaction rate constant(1)	$ppb^{-1}s^{-1}$	$9.70x10^{-3}$	$9.70x10^{-3}$	$9.70x10^{-3}$
Branching ratio for amine/OH reaction(1)	Unitless	0.08	0.41	0.41
Ratio of J(nitrosamine)to J(NO_2) (1)(2)	Unitless	0.53	0.34	0.34
Constant for OH concentration calculations(3)	Unitless			0.00016
Formation of stable nitrosamines(4)	-	No	Yes	Yes

Notes:

(1) Taken from the Carbon Capture and Storage Association (CCSA) Position Paper 'Carbon Capture Chemistry Parameters, N-Amines Chemistry'[7], except for the values for DEA. Refer to Appendix E for references for the values for DEA.

(2) J refers to the photolysis rate of each molecule.

(3) Calculated using methodology from CERC Amine Chemistry Supplement, estimated from typical concentrations of OH, ozone and jNO_2. Background ozone taken from Liverpool Speke.

(4) The CERC Amine Chemistry Supplement states that the nitrosamine produced by primary amines is unstable and will rapidly isomerise to form an imine. Therefore, primary amines will not form stable nitrosamines.

In addition, the amine chemistry module requires the user to input hourly varying background concentrations of nitric oxide (NO), nitrogen dioxide (NO_2), and ozone (O_3). The most recent five years of background data from Liverpool Speke has been used. Any missing data in a given year has been infilled using the average for that hour from the remaining years of data.

The amine chemistry parameters and other aspects of modelling amine chemistry are subject to uncertainties. A detailed explanation of the ADMS amine chemistry module and analysis of the sensitivity of model results to the choice of amine chemistry parameters is presented in Appendix E.

5.9 Other local point sources of emissions

It is not necessary to consider the Permitted Facility as a point source in the assessment of emissions from the Proposed Facility, as the flue gas will be emitted from either the ERF stacks or the absorber stack, but not both at the same time. Potentially one or more lines of the ERF could emit from the existing stack with the flue gases from the other lines being treated in the CC facility at the same

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[7] C.Hazell-Marshall, C Nielsen, Carbon Capture Chemistry Parameters, N-Amines Chemistry, CCSA, January 2023

time. However, due to the distance between the sources the maximum impacts would not overlap and would not be greater than the maximum impacts presented in this assessment.

A review of local point source emissions has been undertaken and no additional local point sources (with an EP to operate) have been identified which may have an in-combination impact with the Facility.

The Protos Energy Recovery Facility (ERF) is located approximately 5.6 km to the south-west of the Site. At this distance the contribution from the Facility is insignificant, including for amines, nitrosamines and nitramines. A discussion of the potential cumulative impact is presented in section 8.2.4.

5.10 Baseline concentrations

Background concentrations for the assessment have been derived from monitoring and national mapping as summarised in Table 15. For short term averaging periods, the background concentration has been assumed to be twice the long-term ambient concentration following the EA recommendation within the Air Emission Guidance.

The background concentrations set out in Table 15 have been used to define the total PECs. However, where the contribution from the Facility cannot be screened out as 'insignificant', additional consideration has been made of the contribution from other local sources and road sources to determine an appropriate baseline concentration for the specific receptors of concern. This is then combined with the contribution from the Proposed Facility to determine the PEC. As a conservative measure no allowance has been made for the contribution of the operational ERF to locally monitored pollutant concentrations.

6 Sensitivity Analysis

The following section details the sensitivity of the model to certain input parameters. This has considered the impact of emissions of NOx from the CC facility assuming continual operation with the ERF operating at the ELV and this exhaust being ducted to the CC facility. Where the changes to model inputs result in an increase in impacts the results are highlighted orange, and where they result in a decrease in impacts the results are highlighted green.

6.1 Surface roughness

The sensitivity of the results to using varying surface roughness length has been considered by running the model with a variable surface roughness file and a constant surface roughness value across the modelling domain. For all sensitivity analysis the impact of changing model parameters on the maximum annual mean and short-term concentrations of oxides of nitrogen have been considered.

The following parameters have been kept constant:

- CC facility operating at capacity;
- Stack height on top of absorber column – 110 m;
- Grid – 10 km x 10 km at 125 m resolution;
- Buildings – included;
- Terrain file – included at 64 x 64 resolution;
- Meteorological site surface roughness – 0.5 m;
- Dispersion site Monin-Obukhov length – 30 m;
- Meteorological site Monin-Obukhov length – 30 m; and
- Meteorological data used – Liverpool Airport 2022.

The contribution of oxides of nitrogen emissions from the absorber stack at the point of maximum ground level impact and the maximum impacted receptor are presented in Table 34. In addition, the difference between in impact using the variable surface roughness file has been calculated. Where the impact is less than using the variable surface roughness file this is highlighted in green, and where the impact is greater this is highlighted in yellow.

Table 34: Surface Roughness Sensitivity Analysis

Surface roughness (m)	Concentration (µg/m³)			
	Point of maximum impact – ground level		Maximum impacted receptor	
	Annual mean	Max 1-hour mean	Annual mean	Max 1-hour mean
Variable	**1.34**	**64.86**	**1.18**	**44.06**
0.1	1.39	66.10	1.20	47.59
0.3	1.65	72.80	1.54	51.04
0.5	1.87	73.42	1.78	50.98
0.7	2.05	75.80	1.95	53.52

Surface roughness (m)	**Concentration (µg/m³)**			
	Point of maximum impact – ground level		**Maximum impacted receptor**	
	Annual mean	**Max 1-hour mean**	**Annual mean**	**Max 1-hour mean**
As % of variable surface roughness file				
0.1	103%	102%	101%	108%
0.3	123%	112%	130%	116%
0.5	139%	113%	151%	116%
0.7	152%	117%	164%	121%

As shown, increasing surface roughness lengths result in higher annual mean and short-term concentrations. The spatially varying surface roughness file results in similar maximum impacts to a constant surface roughness length of 0.1 m. This is likely due to the proximity of the Mersey Estuary which comprises mudflats and water with corresponding low surface roughness lengths.

Due to the variations in the surface roughness values across the modelling domain it is considered appropriate to use a variable surface roughness file.

6.2 Terrain

The sensitivity of the results to the effect of terrain has been considered by running the model with and without the terrain file.

The following parameters have been kept constant:

- CC facility operating at capacity;
- Stack height on top of absorber column – 110 m;
- Grid – 10 km x 10 km at 125 m resolution;
- Buildings – included;
- Dispersion site surface roughness – variable at 64 x 64 resolution;
- Meteorological site surface roughness – 0.5 m;
- Dispersion site Monin-Obukhov length – 30 m;
- Meteorological site Monin-Obukhov length – 30 m; and
- Meteorological data used – Liverpool Airport 2022.

The contribution of oxides of nitrogen emissions from the absorber stack at the point of maximum ground level impact and the maximum impacted receptor are presented in Table 35.

Table 35: Effect of Terrain

Scenario	**Concentration (µg/m³)**			
	Point of maximum impact		**Maximum impacted receptor**	
	Annual mean	**Max 1-hour mean**	**Annual mean**	**Max 1-hour mean**
Including terrain	**1.34**	**64.86**	**1.18**	**44.06**
Excluding terrain	1.17	60.85	1.07	41.30
As % of including terrain				
Excluding terrain	87%	94%	91%	94%

As shown, the inclusion of terrain effects results in higher impacts. The terrain file has been included as this is the most realistic scenario.

6.3 Building parameters

ADMS 6 has a buildings effects module to account for the impact of buildings when it calculates the air flow and dispersion of pollutants from a source. The model works by combining the inputted individual buildings into a single effective building for each wind direction.

The sensitivity of the results to the effect of buildings has been considered by running the model with and without the buildings presented in Table 32.

The following parameters have been kept constant:

- CC facility operating at capacity;
- Stack height on top of absorber column – 110 m;
- Grid – 10 km x 10 km at 125 m resolution;
- Terrain – included at 64 x 64 resolution;
- Dispersion site surface roughness – variable at 64 x 64 resolution;
- Meteorological site surface roughness – 0.5 m;
- Dispersion site Monin-Obukhov length – 30 m;
- Meteorological site Monin-Obukhov length – 30 m; and
- Meteorological data used – Liverpool Airport 2022.

The contribution of oxides of nitrogen emissions from the absorber stack at the point of maximum ground level impact and the maximum impacted receptor are presented in Table 36.

Table 36: Effect of Buildings

Scenario	Concentration (µg/m³)			
	Point of maximum impact – ground level		Maximum impacted receptor	
	Annual Mean	Max 1-hour mean	Annual Mean	Max 1-hour mean
Including buildings	**1.34**	**64.86**	**1.18**	**44.06**
Excluding buildings	1.26	66.91	1.16	47.37
As % of including buildings				
Excluding buildings	94%	103%	98%	108%

As shown the inclusion of buildings has a small effect on the predicted impacts, with slightly higher annual mean impacts and slightly lower short-term impacts when buildings are included. The effect of buildings has been included in the modelling as this is the most realistic scenario.

6.4 Grid resolution

The sensitivity of the results to the grid resolution used has been considered by comparing the results with the grid resolution of 125 with a finer grid resolution of 25 m.

The following parameters were kept constant:

- CC facility operating at capacity;
- Stack height on top of absorber column – 110 m;
- Buildings – included;
- Terrain – included at 64 x 64 resolution;
- Dispersion site surface roughness – variable at 64 x 64 resolution;
- Meteorological site surface roughness – 0.5 m;
- Dispersion site Monin-Obukhov length – 30 m;
- Meteorological site Monin-Obukhov length – 30 m; and
- Meteorological data used – Liverpool Airport 2022.

The contribution of oxides of nitrogen emissions from the absorber stack at the point of maximum ground level impact and the maximum impacted receptor are presented in Table 37 for each scenario.

Table 37: Effect of Grid Resolution

Grid resolution used in model (m)	Oxides of nitrogen PC (µg/m³)	
	Annual mean	Max 1-hour mean
125 m	**1.34**	**64.86**
25 m	1.34	65.67
As % of 125 m grid		
% change	100%	101%

As shown, the choice of grid resolution has a negligible effect on the maximum annual mean concentrations and short-term concentrations. The output grid resolution of 125 m is considered sufficiently fine to accurately capture the maximum predicted concentrations. The choice of grid resolution does not affect the impacts at the specific receptor points.

6.5 Operating below the design point

Dispersion modelling has been undertaken using the emission parameters based on the design nominal case for the ERF and these emissions feeding into the CC facility.

The CC facility is designed to operate at a minimum turndown of 30%, which may occur when 2 lines of the ERF are not operational due to planned or unplanned maintenance, and one or both of the other 2 lines are not at full load. Although this scenario is anticipated to be very rare, the sensitivity of the results to the changes in volumetric flow rate, velocity, and pollutant release rate during this scenario have been modelled.

- Stack height on top of absorber column – 110 m;
- Buildings – included;
- Grid – 10 km x 10 km at 125 m resolution;
- Terrain – included at 64 x 64 resolution;
- Dispersion site surface roughness – variable at 64 x 64 resolution;
- Meteorological site surface roughness – 0.5 m;
- Dispersion site Monin-Obukhov length – 30 m;
- Meteorological site Monin-Obukhov length – 30 m; and
- Meteorological data used – Liverpool Airport 2022.

The contribution of oxides of nitrogen emissions from the absorber stack at the point of maximum ground level impact and the maximum impacted receptor are presented in Table 36.

Table 38: Effect of Running at Minimum Turndown

Scenario	**Concentration (µg/m³)**			
	Point of maximum impact – ground level		**Maximum impacted receptor**	
	Annual Mean	**Max 1-hour mean**	**Annual Mean**	**Max 1-hour mean**
Full load	**1.34**	**64.86**	**1.18**	**44.06**
Minimum (30%) load	1.09	37.01	0.74	24.74
As % of full load				
Minimum (30%) load	81%	57%	63%	56%

As shown the turndown scenario results in lower concentrations than the full load scenario, confirming that the reduction in momentum and buoyancy is more than offset by the reduction in pollutant release rate.

7 Model Validation and Uncertainty

In line with the EA's Air Emissions Guidance the level of uncertainty in the predictions is estimated. To do so, the results of the model validation documentation and the sensitivities have been considered, and the conservatism in the modelling has been reviewed.

7.1 Validation of ADMS model

7.1.1 Introduction

Dispersion modelling of process emission from the Facility has been carried out using ADMS (version 6) produced by CERC.

This section of the report describes the model and explains why it is considered appropriate for modelling the impacts of the Facility.

7.1.2 Model description

ADMS is a new generation dispersion model which characterises the atmospheric boundary layer in terms of the atmospheric stability and the boundary layer height. In addition, the model uses a skewed Gaussian distribution for dispersion under convective conditions, to take into account the skewed nature of turbulence. The model also includes modules to take account of the effect of buildings and complex terrain.

Within ADMS, the FLOWSTAR module is used to generate a new flow and turbulence field based on the terrain. This simulates the changes to the movement of air in the horizontal and vertical direction as a result of the terrain features in that the air flow is simulated flowing above and around raised ground. This modified flow field is then used by the model to adjust the plume height and plume spread parameters calculated by the flat terrain model. The ADMS model can also handle cases of strongly stable flow using a separate plume impingement model.

The technical specification document for the complex terrain module[8] explains that *"terrain should have no more than moderate slopes (up to 1:3) although the model is useful even when this criterion is not met (say up to 1:2)"*.

The surroundings of the site are generally flat or gently sloping, with only a few areas where the gradient is greater than 1:10 and no areas where it is greater than 1:3. CERC notes that during very low wind stable conditions in hilly terrain, horizontal gradients in density can cause katabatic (downslope) winds, which may influence the background flow in deep valleys[9]. These effects are not specifically accounted for in ADMS. However, the local area does not include such valleys and as such this limitation of the model is not relevant to this project.

ADMS 6 includes the option to model the effect of coastlines on diurnal air flows. However, it is not possible to include the effect of buildings or complex terrain and variable surface roughness when modelling the effect of the coastline. As shown in section 6 the model results are sensitive to the spatially varying surface roughness, terrain, and building effects. Therefore, it is considered that model results are likely to be more accurate with these effects included and the coastline effect excluded. The exclusion of coastline effects however is a limitation to the modelling methodology.

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[8] CERC, P14/01S/17 Complex Terrain Module, March 2020

[9] CERC, Note 110 Temperature Inversions in ADMS, 20 April 2017

7.1.3 Model validation

CERC validates its models against available measured data obtained from real world situations, field campaigns and wind tunnel experiments. Validation studies are published on the CERC website[10] Not all of the validation studies are for settings similar to the study area (flat and/or gently sloping terrain within an urban conurbation). There are two validation studies that are considered to be in locations similar to the study area. These are detailed in Table 39.

Table 39: Model Validation Studies

Study	**Notes**
Baldwin Power Plant	Characterised as "complex terrain below the stack height". Complex terrain is included in model for the Facility but it does not rise above the stack height within the study area.
Kincaid, Indianapolis and Prairie Grass experiments	Kincaid – flat farmland with lakes Indianapolis – flat land, mixed industrial/commercial/urban. Although the model for the Facility includes terrain effects, these are relatively minor (see section 6.2). Prairie Grass experiment – ground level release, not relevant to Facility study area.

The validation studies include scatter plots, quantile-quantile plots, and a comparison between the observed and modelled maximum and robust highest concentration (Baldwin Power Station only).

- The scatter plots compare predicted and measured concentrations at a particular location at a particular time.
- The quantile-quantile plots compare the distribution of predicted and measured concentrations during the period having abandoned the (x,t) pairing – i.e. comparing the first highest concentration from the monitored with the first highest concentration predicted.
- The highest concentration is subject to extreme variations. Therefore, the robust highest concentration (RHC) is used due to its stability which is based on a tail exponential fit to the upper end of the distribution. The RHC is strongly related to the average and standard deviation.

The most useful visual aid for evaluating model performance is the quantile-quantile plot which shows how the model performs across the full range of modelled and observed concentrations. The quantile-quantile plots for each validation study are shown below.

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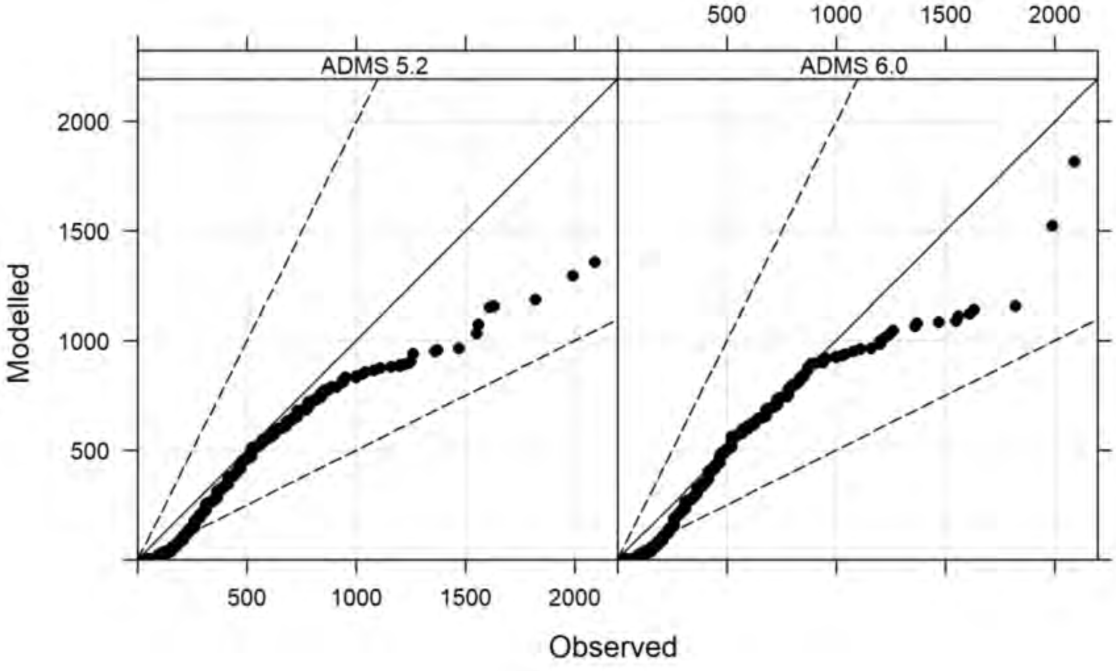
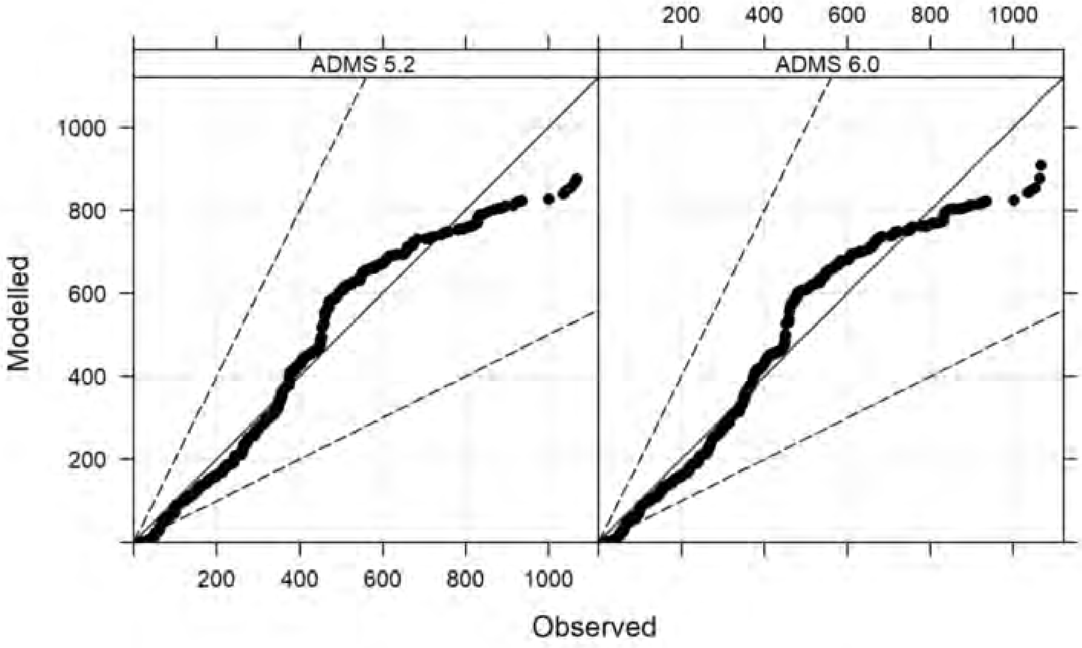
[10] https://www.cerc.co.uk/environmental-software/model-validation.html

Quantile – Quantile Plot – Baldwin Power Station



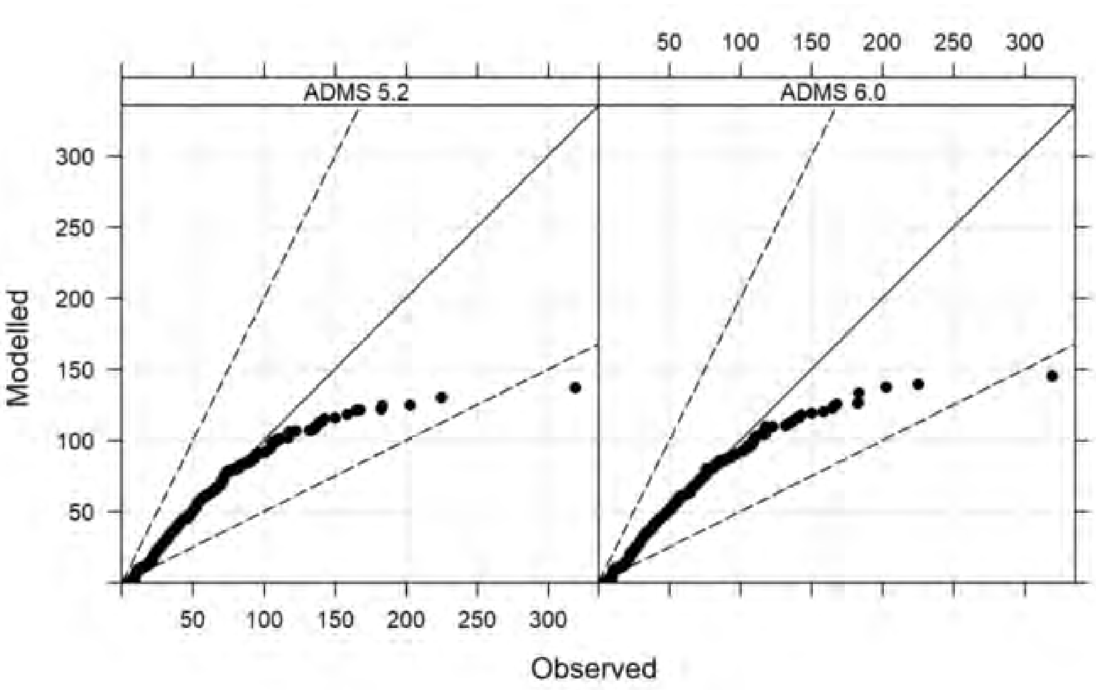
Source: CERC, ADMS 6 Complex Terrain Validation Baldwin Power Plant, April 2023

Quantile – Quantile Plot – Indianapolis



Source: CERC, ADMS 6 Flat Terrain Validation Kincaid, Indianapolis and Prairie Grass, April 2023

Quantile – Quantile Plot – Kincaid



Source: CERC, ADMS 6 Flat Terrain Validation Kincaid, Indianapolis and Prairie Grass, April 2023

These plots show that at the most common (median) concentrations the modelled and observed concentrations are very similar, giving high confidence in annual mean concentrations. However, the maximum concentrations tended to be under-predicted in two out of the three studies (Baldwin and Kincaid), albeit these are based on a very small sample size.

For the Baldwin Power Plant validation is carried out against sulphur dioxide concentrations. In the validation document[11] CERC explain that there are issues with using sulphur dioxide as a tracer which include:

- The limitations of detection are usually of the order of 16 µg/m^3, and concentrations below these are set to one-half of the limit. This leads to considerable inaccuracy when modelled concentrations are low.
- Sulphur dioxide is released from other sources. If estimates of these background concentrations are not available, then the model will underestimate concentrations, particularly long-term averages.

CERC does not report the modelled long-term or annual average concentration against the observed concentration and has only reported the RHC for the Baldwin Power Station study. This is reported for 1 hour, 3 hour and 24 hour averages. The ratio of mean to observed concentrations for the RHC varies from 0.67 to 0.71 across these averaging periods, indicating that the model may be under-estimating the very highest concentrations by up to 33%.

Taking the above into account, it is likely that annual mean concentrations are modelled with a high degree of accuracy. However, the extreme maximum concentrations are less certain, subject to up to 33% uncertainty based on the Baldwin validation study, and potentially over 50% based on the quantile-quantile plot for the Kincaid validation study.

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[11] CERC, ADMS 5 Complex Terrain Validation Baldwin Power Plant, November 2016

7.2 Uncertainty

The validation documentation shows that the levels of uncertainty in the ADMS model with respect to the peak predicted concentrations are typically within 10% of the hourly and daily concentrations, with accuracy over long time frames expected to be at least as high as this.

The sensitivity analysis in section 6 shows that varying terrain parameters leads to changes in the peak results of up to around 13%, which is a similar order to the modelling uncertainty.

Variations in weather data are more complex and feed into the inter-annual variability discussed below.

In order to allow for modelling uncertainty, this assessment includes a number of conservative assumptions. These are explained and quantified in this section.

7.2.1 Interannual variability

The detailed results tables presented in in Appendix C and Appendix D include the breakdown of the peak concentration using each year of meteorological data. The maximum predicted impact over the 5 years of data was then used as the basis of the assessment. Table 40 provides a breakdown of the range of the predicted impacts from the Proposed Facility at the point of maximum impact for each averaging period.

Table 40: Interannual Variability

Averaging time	Impact from Proposed Facility as percentage of maximum	
	Minimum	Average
Annual mean	87%	92%
Max 1-hour	77%	89%
99.79%ile 1-hour	91%	96%
99.73%ile 1-hour	93%	96%
99.9%ile 15-min	81%	89%
Max 24-hour	64%	80%

For the point of maximum impact, the annual average over all five years of weather data is 92% of the highest year, and the minimum is 87% of the highest year. This suggests that using the peak year introduces a conservatism of around 8%. There is similar inter-annual variability for some shorter-term impacts which are reported as percentile values or the maximum hourly value, where an 4-11% conservatism is introduced. For maximum 24 hour concentrations the average is only 80% of the maximum, introducing 20% conservatism. Therefore, the use of the maximum over the 5 years is likely to over-estimate the concentrations that occur in any given year.

7.2.2 Plant availability

The results are based on the assumption that the CC facility would operate for 100% of the time. This is a very conservative assumption. Both the CC facility and the ERF would be offline for periods of maintenance. Routine maintenance would be managed so that the CC facility and ERF are offline at the same time. The CC facility would only be able to operate when the ERF is operational and emissions are suitably stable. The ERF has an availability of 92% and of this the CC facility would be operating for approximately 95%. Therefore, in reality the impact would be significantly lower.

7.2.3 Emission limits

The results are based on the assumption that the ERF will operate at the long term ELVs for 100% of the time. However, the ERF is designed to operate below these with a safety margin. It is assumed that the mass release rate of pollutants from the ERF at the ELVs is released via the CC facility with no allowance for any additional abatement of emissions which would occur within the CC facility.

As detailed in the Supporting Information, the CC facility includes a caustic scrubber and a water wash, which would remove a majority of dust, sulphur dioxide, hydrogen chloride, and hydrogen fluoride. Therefore, actual emissions of these pollutants, and any substances in the particulate phase including metals and dioxins, would be significantly reduced. In addition, a multi-stage wash will be implemented in the absorber tower to reduce emissions of amines and ammonia. Therefore, the impacts predicted for these pollutants from the CC facility are expected to be significantly lower than set out in this assessment.

7.2.4 Short term impacts

For short term impacts it has been assumed that the period when the ERF would need to operate at the half-hourly ELV would occur on all 4 lines concurrently for an entire hour, during the worst-case weather conditions for dispersion and these emissions would transfer through to the CC facility and no further abatement of the pollutants would take place. This is a highly conservative assumption. In order to achieve the daily ELV, the ERF will be operated to achieve the daily ELV for each hour, with only occasional emissions above this and as set out in Section 7.2.3 the CC facility would provide some additional abatement of pollutants.

Furthermore, the half-hourly ELV is that from the IED. The Waste Incineration BAT Conclusions introduce a lower daily limit for oxides of nitrogen and sulphur dioxide which has been transposed into the existing EP. The IED half-hourly limit for oxides of nitrogen is 2 times the IED daily limit, whilst the half-hourly limit for sulphur dioxide is 4 times the daily limit. With the reduced ELVs in the existing EP, the half-hourly limit will be 2.2 times the daily ELV for oxides of nitrogen, and 5 times the daily ELV for sulphur dioxide. Therefore, it is unlikely that peaks in short term emissions would be this high given that a lower daily ELV needs to be achieved.

7.3 Overall effect on results

The conservative assumptions explained above mean that the overall impacts presented in this assessment will be overestimates.

1. Annual mean impacts are overstated by around 10% due to plant availability, by around 8% when inter-annual variability is considered and by at least 10% when allowing for operation below the emission limits. This means that, overall, the annual mean impacts in this assessment have inbuilt conservatism of at least 25-30%.
2. For short term impacts (where these are expressed as percentiles), selecting the worst-case weather conditions across all five years of weather data introduces conservatism of at least 4%, and assuming operation at the short term ELVs introduces conservatism of as much as 50-70%.
3. The validation documentation shows that the level of uncertainty in the model are on average within 10% of the hourly and daily concentrations, with accuracy over long time frames expected to be at least as high as this.
4. The sensitivity analysis presented in section 6 shows that variations in modelling assumptions leads to changes in the peak concentrations of up to 10%.

Therefore, it is considered that the results presented in this assessment are robust as the inbuilt conservatism is of a similar order to the uncertainty in the modelling.

8 Impact on Human Health

8.1 Screening criteria

The Air Emissions Guidance states that to screen out 'insignificant' PCs:

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

As part of this assessment, predicted PCs have been compared to the AQALs detailed in section 2.1.

If the above criteria are achieved, it can be concluded that it is not likely that emissions would lead to significant environmental impacts and the PCs can be screened out.

The long-term 1% PC threshold is based on the judgement that:

- it is unlikely that an emission at this level will make a significant contribution to air quality; and
- the threshold provides a substantial safety margin to protect health and the environment.

The short-term 10% PC threshold is based on the judgement that:

- spatial and temporal conditions mean that short-term PCs are transient and limited in comparison with long-term PCs; and
- the threshold provides a substantial safety margin to protect health and the environment.

For the purpose of this assessment, if the impact can be screened out as 'insignificant' at the point of maximum impact, further assessment is not required. If PCs cannot be screened out, assessment will be undertaken for the following:

- the Predicted Environmental Concentration (PEC, defined as the PC plus the background concentration) at the point of maximum impact; and
- the PC and PEC at areas of public exposure.

If the long-term PEC is below 70% of the AQAL, or the short-term PC is less than 20% of the headroom[12], it can be concluded that "there is little risk of the PEC exceeding the AQAL", and the impact can be considered 'not significant'.

For the assessment of group 3 metals, guidance taken from the EA document 'Guidance on assessing group 3 metals stack emissions from incinerators – V.4 June 2016' ('EA metals guidance') has been used. The EA metals guidance states that where the process contribution for any metal exceeds 1% of the long term or 10% of the short term environmental standard (in this case the AQAL), this is considered to have potential for significant pollution. Where the process contribution exceeds these criteria, the PEC should be compared to the AQAL. The PEC can be screened out if is less than the AQAL. Where the impact is within these parameters it can be concluded that there is no significant risk of exceeding the AQAL.

8.2 Results

Table 41 and Table 42 present the results of the dispersion modelling of process emissions from the Permitted Facility and the Proposed Facility at the point of maximum impact, along with the change in maximum impact. This is a summary of the maximum predicted impact using 5 years of weather data. Detailed results tables for each year of weather data are provided in Appendix C and Appendix

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[12] Calculated as the AQAL minus twice the long-term background concentration.

D for the Permitted Facility and Proposed Facility respectively. Results have been presented at the point of maximum ground level impact of emissions from the Facility.

Results are based on the following:

- Modelling domain size – 10 km x 10 km;
- Buildings – included;
- ERF stack height – 105 m
- Stack height on top of the absorber column – 110 m;
- 5 years of weather data 2018 to 2022 from Liverpool Airport meteorological recording station;
- Operation at the long term ELVs for the entire year;
- Operation at the short term ELVs during the worst-case conditions for dispersion of emissions;
- Worst case conversion of NOx to nitrogen dioxide;
- The entire dust emissions consist of either PM_{10} of $PM_{2.5}$;
- The entire VOC emissions are assumed to consist entirely of benzene;
- Cadmium and thallium are released at the combined emission limit for cadmium and thallium;
- All amines are summed for comparison with the AQAL for MEA;
- All nitrosamines and nitramines are summed for comparison with the AQAL for NDMA;
- There is no additional abatement of emissions through the CC facility.

Process contributions that cannot be screened out as ‘insignificant’ are highlighted. Where the process contribution cannot be screened out as ‘insignificant’, further analysis has been undertaken.

As shown the peak process contribution from the CC facility is predicted to be greater than the ERF. This is attributed to the cooler release of the emissions post the CC process.

At the point of maximum impact the change in impact cannot be screened out as ‘insignificant’ for the following pollutants:

- Annual mean nitrogen dioxide impacts;
- Annual mean cadmium impacts;
- Annual mean nitrosamines and nitramines impacts; and
- 15-minute sulphur dioxide impacts when operating at the half-hourly ELV.

In addition, the total impact of the Proposed Facility cannot be screened out as ‘insignificant’ for the following pollutants:

- Hourly mean nitrogen dioxide impacts when operating at the half-hourly ELV; and
- Hourly mean and 15-minute mean sulphur dioxide impacts when operating at the half-hourly ELV.

Further analysis of these impacts has been undertaken to determine whether the change in impact as a result of the operation of the CC facility or the total impact of the Proposed Facility would result in a significant impact.

Table 41: Dispersion Modelling Results – Point of Maximum Impact - Daily ELVs

Pollutant	Quantity	Units	AQAL	Bg conc.	Permitted Facility		Proposed Facility				Change in PC	
					Max PC	Max PC as % of AQAL	Max PC	Max PC as % of AQAL	Max PEC	Max PEC as % of AQAL	Conc.	as % of AQAL
Nitrogen dioxide	Annual mean	µg/m^3	40	19.9	0.53	**1.32%**	0.94	**2.35%**	20.84	52.10%	0.41	**1.03%**
	99.79th %ile of hourly means	µg/m^3	200	39.8	6.86	3.43%	13.16	6.58%	52.96	26.48%	6.30	3.15%
Sulphur dioxide	99.18th %ile of daily means	µg/m^3	125	10.4	1.45	1.16%	3.29	2.63%	13.69	10.95%	1.84	1.47%
	99.73rd %ile of hourly means	µg/m^3	350	10.4	4.13	1.18%	8.14	2.33%	18.54	5.30%	4.01	1.14%
	99.9th %ile of 15 min. means	µg/m^3	266	10.4	5.27	1.98%	11.36	4.27%	21.76	8.18%	6.10	2.29%
PM$_{10}$	Annual mean	µg/m^3	40	15.5	0.02	0.05%	0.04	0.09%	15.54	38.84%	0.02	0.04%
	90.41st %ile of daily means	µg/m^3	50	31	0.08	0.16%	0.14	0.29%	31.14	62.29%	0.06	0.13%
PM$_{2.5}$	Annual mean	µg/m^3	10	11.5	0.02	0.21%	0.04	0.37%	11.54	115.37%	0.02	0.16%
Carbon monoxide	8 hour running mean	µg/m^3	10,000	828	5.25	0.05%	10.71	0.11%	838.71	8.39%	5.46	0.05%
	Hourly mean	µg/m^3	30,000	828	10.58	0.04%	23.55	0.08%	851.55	2.84%	12.97	0.04%
Hydrogen chloride	Hourly mean	µg/m^3	750	1.42	1.69	0.23%	3.77	0.50%	5.19	0.69%	2.08	0.28%
Hydrogen fluoride	Annual mean	µg/m^3	16	2.35	<0.01	0.03%	0.01	0.05%	2.36	14.73%	<0.01	0.02%
	Hourly mean	µg/m^3	160	4.7	0.21	0.13%	0.47	0.29%	5.17	3.23%	0.26	0.16%
Ammonia	Annual mean	µg/m^3	180	4.7	0.06	0.03%	0.11	0.06%	4.81	2.67%	0.05	0.03%
	Hourly mean	µg/m^3	2,500	9.4	3.17	0.13%	7.06	0.28%	16.46	0.66%	3.89	0.16%

Pollutant	Quantity	Units	AQAL	Bg conc.	Permitted Facility		Proposed Facility				Change in PC	
					Max PC	Max PC as % of AQAL	Max PC	Max PC as % of AQAL	Max PEC	Max PEC as % of AQAL	Conc.	as % of AQAL
VOCs (as benzene)	Annual mean	µg/m^3	5	1.09	0.04	0.84%	0.07	**1.49%**	1.16	23.29%	0.03	0.66%
	Daily mean	µg/m^3	30	2.18	0.53	1.77%	1.24	4.14%	3.42	11.41%	0.71	2.38%
Mercury	Daily mean	ng/m^3	60	38.0	1.06	1.77%	2.48	4.14%	40.48	67.47%	1.43	2.38%
	Hourly mean	ng/m^3	600	38.0	4.23	0.71%	9.42	1.57%	47.42	7.90%	5.19	0.86%
Cadmium	Annual mean	ng/m^3	5	0.12	0.08	**1.67%**	0.15	**2.98%**	0.27	5.38%	0.07	**1.31%**
	Daily mean	ng/m^3	30	0.24	1.06	3.53%	2.48	8.28%	2.72	9.08%	1.43	4.75%
PAHs	Annual mean	pg/m^3	250	180	0.84	0.33%	1.49	0.60%	181.49	72.60%	0.66	0.26%
Dioxins	Annual mean	fg/m^3	-	32.99	0.33	-	0.60	-	33.59	-	0.26	-
PCBs	Annual mean	ng/m^3	200	0.13	0.02	0.01%	0.04	0.02%	0.17	0.08%	0.02	0.01%
	Hourly mean	ng/m^3	6,000	0.26	1.06	0.02%	2.35	0.04%	2.61	0.04%	1.30	0.02%
Sum of amines (as MEA)	Hourly mean	µg/m^3	400	0	-	-	4.06	1.01%	4.06	1.01%	-	-
	Daily mean	µg/m^3	100	0	-	-	1.07	1.07%	1.07	1.07%	-	-
Sum of NS (as NDMA)	Annual mean	pg/m^3	200	0	-	-	2.50	**1.25%**	2.50	1.25%	-	-
Sum of NS + NA (as NDMA)	Annual mean	pg/m^3	200	0	-	-	9.19	**4.60%**	9.19	4.60%	-	-
Aldehydes (as formaldehyde)	Annual mean	µg/m^3	5	2.37	-	-	0.03	0.61%	2.40	48.01%	-	-
	30-minute mean	µg/m^3	100	4.74	-	-	2.17	2.17%	6.91	6.91%	-	-

Notes:

All assessment is based on the maximum PC using all 5 years of weather data.

Table 42: Dispersion Modelling Results – Point of Maximum Impact - Short-Term ELVs

Pollutant	Quantity	Units	AQAL	Bg conc.	Operational Facility		Proposed Facility				Change in PC	
					Max PC	Max PC as % of AQAL	Max PC	Max PC as % of AQAL	Max PEC	Max PEC as % of AQAL	Conc.	as % of AQAL
Nitrogen dioxide	99.79th%ile of hourly means	µg/m³	200	39.8	15.23	7.62%	29.23	**14.62%**	69.03	34.52%	14.00	7.00%
Sulphur dioxide	99.73rd%ile of hourly means	µg/m³	350	10.4	20.67	5.91%	40.70	**11.63%**	51.10	14.60%	20.03	5.72%
	99.9th%ile of 15 min. means	µg/m³	266	10.4	26.34	9.90%	56.82	**21.36%**	67.22	25.27%	30.48	**11.46%**
Carbon monoxide	8 hour running mean	µg/m³	10,000	828	15.76	0.16%	32.13	0.32%	860.13	8.60%	16.37	0.16%
	Hourly mean	µg/m³	30,000	828	31.73	0.11%	70.64	0.24%	898.64	3.00%	38.91	0.13%
Hydrogen chloride	Hourly mean	µg/m³	750	1.42	12.69	1.69%	28.26	3.77%	29.68	3.96%	15.57	2.08%
Hydrogen fluoride	Hourly mean	µg/m³	160	4.7	0.85	0.53%	1.88	1.18%	6.58	4.11%	1.04	0.65%

Notes:

All assessment is based on the maximum PC using all 5 years of weather data.

Assumes the Permitted and Proposed Facility operates for 100% of the time at the half-hourly ELVs.

8.2.1 Further analysis – annual mean nitrogen dioxide

As shown in the detailed tables in Appendix C and Appendix D, there is predicted to be an increase in annual mean nitrogen dioxide impacts as a result of the proposed EP variation.

The maximum annual mean contribution from the Proposed Facility is 2.35% of the AQAL compared to 1.32% for the Permitted Facility. The change in maximum impact between the two scenarios is 1.03% of the AQAL, although due to the change in dispersion pattern between the two scenarios the maximum change in impact at any single point may be greater than 1.03% of the AQAL.

Figure 9 of Appendix A shows the distribution of emissions from the Proposed Facility and the area where the change in impact and the total impact of the Proposed Facility cannot be screened out as 'insignificant' and further consideration of baseline concentrations is needed. The area where the change in impact exceeds 1% of the AQAL is small and covers a section of Runcorn. The total impact of the Proposed Facility exceeds 1% of the AQAL across two larger areas, one to the south-east across Runcorn and one to the north-west, to the west of Widnes. No AQMAs lie within these areas, and as such the change in impact and the total impact of the Proposed Facility within AQMAs can be screened out as 'insignificant'. There are two monitoring locations in Runcorn, as detailed in Table 10. The maximum monitored nitrogen dioxide concentration in the most recent 5 years of monitoring data is 26.5 µg/m³ at both of these sites. There is no monitoring undertaken near the area west of Widnes.

As there is little monitoring data available, consideration has been given to modelled roadside concentrations along roads in the affected areas. Defra provides a map of roadside concentrations[13] for major roads in urban areas, including the A557 and A553 in Runcorn, and the A562 Speke Road west of Widnes. The maximum modelled roadside concentration for 2022 along any of these roads is 27.04 µg/m³. As a conservative measure this value has been used as the baseline concentration at all receptor locations. As an additional conservative measure, no allowance has been made for the potential double-counting of emissions from the Permitted Facility.

Table 43 sets out the process contribution from the Permitted Facility, the Proposed Facility, the change in impact, and the PEC at all receptor locations, conservatively assuming the baseline concentration is 27.04 µg/m³. The change in impact only exceeds 1% of the AQAL at one receptor location. At all receptor locations the contribution from the Proposed Facility can either be screened out as 'insignificant' or the PEC is less than 70% of the AQAL and it can be concluded that there is little risk of the PEC exceeding the AQAL, so the impact is 'not significant'.

Table 43: Annual Mean Nitrogen Dioxide - Impacts at Receptors

Receptor	Annual mean concentration as % of AQAL							
	Permitted Facility		Proposed Facility		Change		PEC	
	µg/m³	% AQAL	µg/m³	% AQAL	µg/m³	% AQAL	µg/m³	% AQAL
R1	<0.01	<0.01%	0.01	0.04%	0.01	0.03%	27.05	67.64%
R2	0.02	0.04%	0.10	0.25%	0.09	0.21%	27.14	67.85%
R3	0.04	0.10%	0.16	0.41%	0.13	0.31%	27.20	68.01%
R4	0.31	0.78%	0.80	**2.01%**	0.49	**1.23%**	27.84	69.61%
R5	0.20	0.51%	0.44	**1.09%**	0.23	0.58%	27.48	68.69%
R6	0.20	0.51%	0.50	**1.26%**	0.30	0.75%	27.54	68.86%

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[13] Available at https://uk-air.defra.gov.uk/data/gis-mapping/

Receptor	**Annual mean concentration as % of AQAL**							
	Permitted Facility		**Proposed Facility**		**Change**		**PEC**	
	µg/m^3	**% AQAL**	**µg/m^3**	**% AQAL**	**µg/m^3**	**% AQAL**	**µg/m^3**	**% AQAL**
R7	0.30	0.76%	0.66	**1.65%**	0.35	0.88%	27.70	69.25%
R8	0.51	**1.27%**	0.83	**2.07%**	0.32	0.80%	27.87	69.67%
R9	0.18	0.46%	0.45	**1.12%**	0.26	0.66%	27.49	68.72%
R10	0.33	0.83%	0.62	**1.54%**	0.28	0.70%	27.66	69.14%
R11	0.15	0.36%	0.24	0.60%	0.09	0.24%	27.28	68.20%
Notes: *PEC includes baseline concentration of 27.04 µg/m^3 or 67.6% of the AQAL.* *Maximum impact using 5 years of weather data.*								

8.2.2 Further analysis – annual mean VOCs

As shown in the detailed tables in Appendix C and Appendix D, there is predicted to be an increase in annual mean VOC impacts as a result of the proposed EP variation. These results are calculated under the conservative assumption that all VOCs are emitted as benzene.

The maximum annual mean contribution from the Proposed Facility is 1.49% of the AQAL for benzene compared to 0.84% for the Permitted Facility. The change in maximum impact between the two scenarios is 0.66% of the AQAL, although due to the change in dispersion pattern between the two scenarios the maximum change in impact at any single point may be greater than 0.66% of the AQAL. Baseline concentrations of VOCs are unlikely to exceed the baseline concentration presented in Table 15 (taken as the maximum mapped background concentration within 5 km of the Facility). The use of the mapped background concentration is considered appropriate for the point of maximum impact and all receptor locations.

Figure 10 of Appendix A shows the distribution of emissions from the Proposed Facility and the area where the impact of the Proposed Facility cannot be screened out as ‘insignificant’ and further consideration of baseline concentrations is needed.

Table 44 sets out the process contribution from the Permitted Facility, the Proposed Facility, the change in impact, and the PEC at all receptor locations, assuming the baseline concentration is 1.09 µg/m^3. The change in impact is less than 1% of the AQAL at all receptor locations and can be screened out as ‘insignificant’. The contribution from the Proposed Facility can either be screened out as ‘insignificant’ or the PEC is less than 70% of the AQAL and it can be concluded that there is little risk of the PEC exceeding the AQAL, so the impact is ‘not significant’.

Table 44: Annual Mean VOC (as benzene) - Impacts at Receptors

Receptor	**Annual mean concentration as % of AQAL**							
	Permitted Facility		**Proposed Facility**		**Change**		**PEC**	
	µg/m^3	**% AQAL**	**µg/m^3**	**% AQAL**	**µg/m^3**	**% AQAL**	**µg/m^3**	**% AQAL**
R1	<0.001	<0.01%	0.001	0.02%	0.001	0.02%	1.09	21.82%
R2	0.001	0.02%	0.008	0.16%	0.007	0.14%	1.10	21.96%
R3	0.003	0.06%	0.013	0.26%	0.010	0.20%	1.10	22.06%
R4	0.025	0.50%	0.064	**1.28%**	0.039	0.78%	1.15	23.08%
R5	0.016	0.32%	0.035	0.69%	0.018	0.37%	1.12	22.49%

Receptor	Annual mean concentration as % of AQAL							
	Permitted Facility		Proposed Facility		Change		PEC	
	µg/m³	% AQAL	µg/m³	% AQAL	µg/m³	% AQAL	µg/m³	% AQAL
R6	0.016	0.32%	0.040	0.80%	0.024	0.48%	1.13	22.60%
R7	0.024	0.48%	0.052	**1.04%**	0.028	0.56%	1.14	22.84%
R8	0.040	0.81%	0.066	**1.32%**	0.025	0.51%	1.16	23.12%
R9	0.015	0.29%	0.036	0.71%	0.021	0.42%	1.13	22.51%
R10	0.026	0.53%	0.049	0.98%	0.022	0.45%	1.14	22.78%
R11	0.012	0.23%	0.019	0.38%	0.007	0.15%	1.11	22.18%

Notes:

PEC includes baseline concentration of 1.09 µg/m³ or 21.8% of the AQAL.

Maximum impact using 5 years of weather data.

8.2.3 Further analysis – annual mean cadmium

As shown in the detailed tables in Appendix C and Appendix D, there is predicted to be an increase in annual mean cadmium impacts as a result of the proposed EP variation. These results are calculated under the conservative assumption that cadmium is emitted at the combined cadmium and thallium ELV.

The maximum annual mean contribution from the Proposed Facility is 2.98% of the AQAL for cadmium compared to 1.67% for the Permitted Facility. The change in maximum impact between the two scenarios is 1.31% of the AQAL, although due to the change in dispersion pattern between the two scenarios the maximum change in impact at any single point may be greater than 1.31% of the AQAL.

Further analysis has been carried out to determine the impact at receptor locations. The use of the baseline concentration detailed in Table 15 is considered appropriate at the point of maximum impact and all receptor locations.

Figure 11 of Appendix A shows the area where the change in impact and the impact of the Proposed Facility cannot be screened out as 'insignificant' and further consideration of baseline concentrations is needed.

Table 45 sets out the process contribution from the Permitted Facility, the Proposed Facility, the change in impact, and the PEC at all receptor locations, conservatively assuming the baseline concentration is 0.12 ng/m³. The change in impact only exceeds 1% of the AQAL at 3 receptor locations. At all receptor locations the contribution from the Proposed Facility can either be screened out as 'insignificant' or the PEC is less than 70% of the AQAL and it can be concluded that there is little risk of the PEC exceeding the AQAL, so the impact is 'not significant'.

Table 45: Annual Mean Cadmium - Impacts at Receptors

Receptor	Annual mean concentration as % of AQAL							
	Permitted Facility		Proposed Facility		Change		PEC	
	ng/m³	% AQAL	ng/m³	% AQAL	ng/m³	% AQAL	ng/m³	% AQAL
R1	<0.001	0.01%	0.002	0.05%	0.002	0.04%	0.12	2.45%
R2	0.002	0.05%	0.016	0.32%	0.014	0.27%	0.14	2.72%
R3	0.006	0.12%	0.026	0.52%	0.020	0.40%	0.15	2.92%

Receptor	Annual mean concentration as % of AQAL							
	Permitted Facility		Proposed Facility		Change		PEC	
	ng/m³	% AQAL	ng/m³	% AQAL	ng/m³	% AQAL	ng/m³	% AQAL
R4	0.050	0.99%	0.128	**2.55%**	0.078	**1.56%**	0.25	4.95%
R5	0.032	0.65%	0.069	**1.38%**	0.037	0.73%	0.19	3.78%
R6	0.032	0.65%	0.080	**1.60%**	0.048	0.95%	0.20	4.00%
R7	0.048	0.97%	0.104	**2.09%**	0.056	**1.12%**	0.22	4.49%
R8	0.081	**1.61%**	0.132	**2.63%**	0.051	**1.02%**	0.25	5.03%
R9	0.029	0.59%	0.071	**1.42%**	0.042	0.83%	0.19	3.82%
R10	0.053	**1.06%**	0.098	**1.95%**	0.045	0.90%	0.22	4.35%
R11	0.023	0.46%	0.038	0.76%	0.015	0.30%	0.16	3.16%

Notes:

PEC includes baseline concentration of 0.12 ng/m³ or 2.4% of the AQAL.

Maximum impact using 5 years of weather data.

8.2.4 Further analysis – annual mean nitrosamines and nitramines

As shown in Table 41, at the point of maximum impact of emissions the total impact of nitrosamine and nitramines when summed and compared to the AQAL of 0.2 ng/Nm³ is predicted to be 4.60% of the AQAL. The annual mean contribution from each substance has been summed for each grid point and the maximum of all grid points determined. This approach has been used as the peak impact for each substance occurs in different locations owing to the atmospheric reactions. This conservatively assumes that the CC facility continually operates and no allowance for periods when the CC facility would be offline have been accounted for. Additional consideration of the sensitivity of the modelling to the choice of amine chemistry inputs has been carried out within Appendix E. This shows that whilst there is some variability in the results based on the choice of value used the impact remains low and there is no risk of the AQAL being exceeded.

As noted in section 4.5.9, no monitoring of nitrosamines and nitramines is available and baseline concentrations are assumed to be below the LOD and effectively zero. Therefore, as the maximum impact is much less than 70% of the AQAL, it follows that the PEC is also much less than 70% of the AQAL and the impact is 'not significant'. Nonetheless, consideration has been given to the extent of impacts that cannot be screened out as 'insignificant'.

The following plot files are presented in Appendix A to illustrate the distribution of emissions:

Figure 12 – annual mean nitrosamines;

Figure 13 – annual mean nitramines;

Figure 14 – annual mean nitrosamines + nitramines as % of AQAL.

Table 44 sets out the process contribution from the Proposed Facility at receptor locations. As shown, the annual mean impact on concentrations of nitrosamines + nitramines cannot be screened out as 'insignificant' at a number of receptor locations; however, as the baseline is assumed to be zero, the PEC is much less than 70% of the AQAL and the impact is 'not significant'.

Table 46: Annual Mean Nitrosamines + Nitramines - Impacts at Receptors

Receptor	Annual mean concentration			
	Sum of nitrosamines		Sum of nitrosamines + nitramines	
	pg/m³	% AQAL	pg/m³	% AQAL
R1	0.07	0.04%	0.21	0.10%
R2	0.29	0.14%	0.75	0.38%
R3	0.72	0.36%	2.30	**1.15%**
R4	2.05	**1.02%**	5.32	**2.66%**
R5	1.30	0.65%	4.05	**2.02%**
R6	1.37	0.68%	3.90	**1.95%**
R7	1.79	0.89%	5.18	**2.59%**
R8	2.27	**1.13%**	6.39	**3.20%**
R9	1.46	0.73%	6.95	**3.47%**
R10	1.64	0.82%	5.82	**2.91%**
R11	0.74	0.37%	3.55	**1.78%**

Notes:

Maximum impact using 5 years of weather data. Impacts presented as % of the AQAL for NDMA of 0.2 ng/m³ (200 pg/m³).

As noted in section 5.9 it is known that there is a CC facility proposed for the Protos ERF, approximately 5.6 km south-west of the Facility. The Protos ERF is under construction and will process approximately 500,000 tonnes of waste per annum, approximately half the capacity of the Facility. As the Protos ERF has a similar stack height, it is anticipated that the maximum impact of the Protos ERF CC facility on concentrations of amines and amine degradation products would be approximately half the maximum impact of the Proposed Facility. On this basis, even if the maximum impacts of the Proposed Facility and the Protos ERF CC facility occurred in the same location, the total concentration of nitrosamines + nitramines would be around 7% of the AQAL for NDMA. In reality the cumulative impact would be much less than this due to the distance between the emission sources. As such, there is no risk of the AQAL being exceeded and the cumulative impact would not be significant.

8.2.5 Further analysis – hourly nitrogen dioxide

As shown in the detailed tables in Appendix C and Appendix D, there is predicted to be an increase in the short term nitrogen dioxide impacts as a result of the proposed EP variation. If it is assumed that all 4 lines of the ERF operate at the half-hourly ELVs and these emissions are passed through to the CC facility and that this occurs during the worst-case conditions for dispersion at the point of maximum impact the contribution from the Proposed Facility is 14.62% of the AQAL and cannot be screened out as 'insignificant'. The change in maximum impact is 7.00% and can be screened out as 'insignificant'.

Figure 15 of Appendix A shows the change in impact, and the area where the impact of the Proposed Facility cannot be screened out as 'insignificant'. Whilst this does cover some areas where members of the public are expected to spend a period of an hour or more, the maximum PC is only

18.2% of the headroom. As this is less than 20% of the headroom, it can be concluded that there is little risk of the PEC exceeding the AQAL and the impact is 'not significant'.

8.2.6 Further analysis – hourly mean and 15-minute mean sulphur dioxide

As shown in the detailed tables in Appendix C, there is predicted to be an increase in the short term sulphur dioxide impacts as a result of the proposed EP variation. If it is assumed that all 4 lines of the ERF operate at the half-hourly ELVs and these emissions are passed through to the CC facility and that this occurs during the worst-case conditions for dispersion at the point of maximum impact the contribution from the Proposed Facility is 21.36% of the AQAL for 15-minute mean sulphur dioxide and 11.63% of the AQAL for hourly mean sulphur dioxide. The change in maximum impact for hourly mean sulphur dioxide is 5.72% and can be screened out as 'insignificant'. The change in maximum impact for 15-minute mean sulphur dioxide is 11.46% of the AQAL.

Figure 16 and Figure 17 of Appendix A (for hourly mean and 15-minute mean concentrations respectively) show the change in impact, and the area where the impact of the Proposed Facility cannot be screened out as 'insignificant'.

Whilst the impact of the Proposed Facility on hourly and 15-minute mean sulphur dioxide concentrations cannot be screened out as 'insignificant', it is considered highly unlikely that the impact will ever approach the maximum predicted values, as they are based on all 4 lines of the ERF operating at the half-hourly ELV concurrently during the worst-case conditions for dispersion, and no additional abatement of sulphur dioxide by the CC facility.

When operating at the daily ELV, which still is a conservative assumption, the peak impact is only 4.27% of the AQAL (for 15-minute mean sulphur dioxide). As each ERF line operates independently, it is highly unlikely that all 4 lines will operate at the half-hourly ELV concurrently. In addition, the CC facility will include a caustic wash which will significantly reduce the actual concentrations of sulphur dioxide emitted from the absorber stack. Therefore, it can be concluded that there is little risk of the PEC exceeding the AQAL at the point of maximum impact.

8.2.7 Heavy metals – at the point of maximum impact

The detailed results tables in Appendix C detail the predicted impact of emissions of metals from the Proposed Facility.

If the process contribution is greater than 1% of the long-term AQAL or 10% of the short-term AQAL when it is assumed that each metal is emitted at the total metal ELV, further analysis has been undertaken. The EA's metals guidance details the maximum monitored concentrations of Group 3 metals emitted by Municipal Waste Incinerators and Waste Wood Co-Incinerators as a percentage of the ELV for Group 3 metals. The maximum monitored emission presented in the EA's analysis has been used as a conservative assumption.

As shown, if it is assumed that the entire emissions of metals consist of only one metal, the impact of the operation of the Proposed Facility is generally less than 1% of the long-term AQAL and less than 10% of the short-term AQAL, with the exception of annual mean impacts of arsenic, chromium VI, manganese and nickel, daily mean copper and hourly mean nickel. If it is assumed that the ERF would perform no worse than the maximum monitored concentration from the EA metals guidance, the impact of the Proposed Facility would be below 1% of the long-term AQAL and 10% of the short-term AQAL for all metals with the exception of annual mean arsenic and nickel and hourly mean Nicel. The PEC is only predicted to exceed the long term AQAL for chromium VI, which is due to the high assumed background concentration, the process contribution from the Proposed

Facility is well below 1% of the AQAL (0.39%). For annual mean arsenic and nickel and daily mran Nickel the PEC is well below the AQAL so can be screened out as 'insignificant'.

This analysis has shown there is no risk of exceeding an AQAL for any metals either on a long-term or short-term basis as a result of emissions from the Proposed Facility. This analysis conservatively assumes that the CC facility would continually operate and there is no additional abatement of metals through the CC process. The preceding analysis has shown that when accounting for availability, and when including the contribution from ERF when the CC facility is offline the impact would be lower.

8.2.8 Further analysis – amines

The results in Table 41 compare the total sum of amines to the EAL for MEA published by the EA in lieu of any published EALs for the other amines released (namely DEA and DMA). EALs for have been derived using the EA approach as set out within Appendix F.

Table 47 provides a summary of the peak impact of each amine with reference to the EALs.

Table 47: Further Analysis Amines

Amine	**Averaging period**	**EAL (µg/m^3)**	**Maximum PC**	
			Conc. (µg/m^3)	**As % of EAL**
Total amines$^{(1)}$	Maximum 1-hour mean	400	4.06	1.01%
	Maximum daily mean	100	1.07	1.07%
MEA	Maximum 1-hour mean	400	3.86	0.97%
	Maximum daily mean	100	1.02	1.02%
DEA	Maximum 1-hour mean	-	0.097	-
	Maximum daily mean	0.2	0.026	12.76%
DMA	Maximum 1-hour mean	-	0.097	-
	Maximum daily mean	3.3	0.026	0.77%

Notes:

Maximum PC across the modelling domain using all 5-years of weather data.

(1) Total amines calculated by summing the contribution from each amine and taking the maximum across the modelling domain. This impact has been compared to the EAL for MEA as per the main analysis.

As shown, for MEA and DMA the process contribution can be screened out as 'insignificant' even if it is conservatively assumed that the CC facility continually operates at the emission concentrations shown in Table 21. For DEA, the maximum process contribution is slightly above the 10% screening criterion, at 12.76% of the EAL. As there are no other significant sources of DEA in the vicinity, it is considered that there is no risk of exceedance of the EAL.

8.2.9 Pollutants emitted from hybrid coolers

Emissions of pollutants from the hybrid coolers have been modelled in accordance with the parameters set out in section 5.4. This has conservatively assumed that each cooler unit operates continually at full load; in reality, the flow rate from the coolers would decrease in cold weather, so the predicted concentrations are likely to be a significant over-estimate.

Table 48: Impact of Emissions of Pollutants from Hybrid Coolers

Pollutant	Quantity	Units	AQAL	Max PC	as % of AQAL
VOCs (as benzene)	Annual mean	µg/m³	5	0.171	**3.43%**
	Daily mean	µg/m³	30	0.330	1.10%
Ammonia	Annual mean	µg/m³	180	0.028	0.016%
	Hourly mean	µg/m³	2,500	0.068	0.003%
Mercury	Daily mean	ng/m³	60	0.009	0.015%
	Hourly mean	ng/m³	600	0.011	0.002%
Cadmium	Annual mean	ng/m³	5	0.005	0.093%
	Daily mean	ng/m³	30	0.009	0.030%
Other metals	Annual mean	ng/m³	-	0.046	-
	Daily mean	ng/m³	-	0.089	-
	Hourly mean	ng/m³	-	0.111	-

As shown, the maximum PC from the hybrid coolers is well below 1% of the annual mean AQAL and 10% of the short-term AQAL for all pollutants except for annual mean VOCs as benzene. The concentrations of metals are much less than 1 ng/m³ across all averaging periods, compared to 2.24 ng/m³ as the annual mean PC from the Proposed Facility (with higher maximum daily and hourly concentrations), so no significant effects due to emissions of metals would occur.

Due to the low height of the cooling towers (assumed to be 20 m, subject to detailed design), the impact would be very local to the source and would not overlap with emissions from the absorber stack. Even if the maximum emissions did overlap, taking into account the baseline of 1.09 µg/m³ and PC from the Proposed ERF, the maximum PEC would be 1.09 µg/m³ + 0.17 µg/m³ + 0.07 µg/m³ = 1.34 µg/m³, which is 26.7% of the AQAL. Therefore, the PEC would remain well below 70% of the AQAL and the impact would be ‘not significant’.

9 Impact at Ecological Receptors

9.1 Screening

The EA's Air Emissions Guidance states that to screen out impacts as 'insignificant' at European and UK statutory designated sites:

- the long-term PC must be less than 1% of the long-term environmental standard (i.e. the Critical Level or Load); and
- the short-term PC must be less than 10% of the short-term environmental standard.

If the above criteria are met, no further assessment is required. If the long-term PC exceeds 1% of the long-term environmental standard, the PEC must be calculated and compared to the standard. If the resulting PEC is less than 70% of the long-term environmental standard, the Air Emissions Guidance states that the emissions are 'insignificant' and further assessment is not required. In accordance with the guidance, calculation of the PEC for short-term standards is not required.

The EA's Air Emissions Guidance states further that to screen out impacts as 'insignificant' at local nature sites[14]:

- the long-term PC must be less than 100% of the long-term environmental standard; and
- the short-term PC must be less than 100% of the short-term environmental standard.

In accordance with the guidance, calculation of the PEC for local nature sites is not required. However, this has been calculated for completeness.

9.2 Daily mean Critical Level

The closest site which monitors ozone and sulphur dioxide concentrations is Liverpool Speke, located approximately 3.6 km to the north of the site.

To supplement the monitoring at Liverpool Speke a review of the monitoring of ozone from all sites across the UK has been carried out. The AO40 has been calculated and results graphed showing where the baseline concentration exceeds the AO40 in each year in Figure 18 of Appendix A. As shown, there are some locations across the UK where the AO40 exceeded the Critical Level, typically located in the south of the UK. In the north-west there were a few exceedences of the AO40 in 2018 but since then the levels have been below the Critical Level.

The APIS baseline sulphur dioxide concentrations presented in Table 8 shows that the baseline sulphur dioxide concentrations are well below the Critical Level.

This analysis demonstrates that the concentrations of sulphur dioxide are well below the Critical Level in the areas affected by emissions from the Facility and on average the ozone concentration is below the Critical Level. As such it is considered that the daily mean NOx Critical Level of 200 µg/m^3 is appropriate and this has been used for the purpose of this assessment.

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[14] Ancient woodlands, local wildlife sites and national and local nature reserves.

9.3 Methodology

9.3.1 Atmospheric emissions – Critical Levels

The impact of emissions has been compared to the Critical Levels listed in Table 4. Further assessment would be undertaken where the process contribution of a particular pollutant is greater than 1% of the long term or 10% of the short-term Critical Level for European and UK designated sites, and where the process contribution of a particular pollutant is greater than 100% of the Critical Level for locally designated sites.

9.3.2 Deposition of emissions – Critical Loads

In addition to the Critical Levels for the protection of ecosystems, habitat specific Critical Loads for nature conservation sites at risk from acidification and nitrogen deposition (eutrophication) are outlined in APIS. In terms of acid deposition, the APIS Database contains a maximum critical load for sulphur (ClmaxS), a minimum Critical Load for nitrogen (CLminN) and a maximum Critical Load for nitrogen (ClmaxN). These components define the Critical Load function for acid deposition. Where the acid deposition flux falls within the area under the Critical Load function, no exceedances are predicted.

An assessment has been made for each habitat feature identified in APIS and identified in the SSSI citation for the specific site. The map function tool has been used to identify the features and habitat specific Critical Loads. However, the APIS database does not include many of the local wildlife sites. As such the project ecologist has been consulted to determine the most appropriate Critical Load for assessment purposes. The relevant Critical Loads are presented in Appendix B. The lowest Critical Load for each designated site has been used to ensure a robust assessment.

9.3.3 Calculation methodology

9.3.3.1 Nitrogen deposition

The impact of deposition has been assessed using the methodology detailed within the Habitats Directive AQTAG 6 (March 2014). The steps to this method are as follows.

1. Determine the annual mean ground level concentrations of nitrogen dioxide, ammonia and amines at each site.
2. Calculate the dry deposition flux (µg/m^2/s) at each site by multiplying the annual mean ground level concentration by the relevant deposition velocity presented in Table 49.
3. Convert the dry deposition flux into units of kgN/ha/yr using the conversion factors presented in Table 49.
4. Compare this result to the nitrogen deposition Critical Load.

Table 49: Deposition Factors

Pollutant	**Deposition velocity (m/s)**		**Conversion factor (µg/m^2/s to kg/ha/year)**
	Grassland	**Woodland**	
Nitrogen dioxide	0.0015	0.003	96.0
Sulphur dioxide	0.0120	0.024	157.7
Ammonia	0.0200	0.030	259.7

Pollutant	Deposition velocity (m/s)		Conversion factor ($\mu g/m^2/s$ to kg/ha/year)
	Grassland	Woodland	
Hydrogen chloride	0.0250	0.060	306.7
MEA	0.0200	0.030	72.2
DEA			41.9
DMA			97.8

Source: AQTAG 6 (March 2014), except for amines which are detailed below.

As amines are derived from ammonia, as a screening assumption it has been assumed that amines have the same deposition velocity as ammonia. The conversion factor from $\mu g/m^2/s$ to kg/ha/year for each amine has been derived from the percentage of the molecular mass of each amine that is nitrogen (each amine contains one nitrogen atom).

The concentration of amines has been factored from a non-reactive pollutant (particulate matter). This is considered appropriate as a screening assumption, as the sensitivity analysis presented in Appendix E.3 shows that the maximum predicted concentrations of amines are not highly sensitive to the inclusion of amine chemistry. In addition, the predicted concentrations of nitrosamines and nitramines (and therefore their contribution to total nitrogen and acid deposition) are exceptionally small in comparison to amines, so their exclusion from the analysis will not affect the results.

9.3.3.2 Acidification

Deposition of nitrogen, sulphur, hydrogen chloride, ammonia and amines can cause acidification and should be taken into consideration when assessing the impact of the Facility.

The steps to determine the acid deposition flux are as follows.

1. Determine the dry deposition rate in kg/ha/yr of nitrogen, sulphur, hydrogen chloride, ammonia and amines using the methodology outlined in Section 9.3.3.
2. Apply the conversion factor for N outlined in Table 50 to the nitrogen, ammonia and amine deposition rate in kg/ha/year to determine the total keq N/ha/year.
3. Apply the conversion factor for S to the sulphur deposition rate in kg/ha/year to determine the total keq S/ha/year.
4. Apply the conversion factor for HCl to the hydrogen chloride deposition rate in kg/ha/year to determine the dry keq Cl/ha/year.
5. Add the contribution from S to HCl and treat this sum as the total contribution from S.
6. Plot the results against the Critical Load functions.

Table 50: Conversion Factors

Pollutant	Conversion factor (kg/ha/year to keq/ha/year)
Nitrogen	Divide by 14
Sulphur	Divide by 16
Hydrogen chloride	Divide by 35.5

Source: AQTAG (March 2014)

The March 2014 version of the AQTAG 6 document states that, for installations with an HCl emission, the PC of HCl, in addition to S and N, should be considered in the acidity Critical Load assessment. The H+ from HCl should be added to the S contribution (and treated as S in APIS tool). This should include the contribution of HCl from wet deposition.

Consultation with AQMAU confirmed that the maximum of the wet or dry deposition rate for HCl should be included in the calculation. For the purpose of this analysis, it has been assumed that wet deposition of HCl is double dry deposition.

The contribution from the Facility has been calculated using APIS formula:

Where PEC N Deposition < CLminN:

PC as % of CL function = PC S deposition / ClmaxS

Where PEC N Deposition > CLminN:

PC as % of CL function = (PC S + N deposition) / ClmaxN

9.4 Results

Detailed results tables are provided in Appendix D. The results are based on the following:

- Modelling domain size – 10 km x 10 km;
- Buildings – included;
- ERF stack height – 105 m;
- Stack height on top of the absorber column – 110 m;
- 5 years of weather data 2018 to 2022 from Liverpool Airport meteorological recording station;
- Operation at the long term ELVs for the entire year;
- Operation at the short term ELVs during the worst-case conditions for dispersion of emissions;
- Worst case conversion of NOx to nitrogen dioxide;
- The nitrogen deposition impacts include the contribution from nitrogen dioxide, ammonia and amine emissions;
- The acid deposition impacts include the contribution from nitrogen dioxide, ammonia, amines, sulphur dioxide and hydrogen chloride;
- Wet deposition of HCl has been included in the acid S calculation as double dry deposition;
- It has been assumed the most sensitive habitat is present at the point of maximum impact of emissions in each site; and
- There is no additional abatement of emissions through the CC facility.

Process contributions that cannot be screened out as ‘insignificant’ are highlighted. Where the process contribution cannot be screened out as ‘insignificant’, further analysis has been undertaken.

As shown the peak process contribution from the CC facility is predicted to be greater than the ERF. This is attributed to the cooler release of the emissions post the CC process.

9.4.1 European and UK designated sites

9.4.1.1 Mersey Estuary

The peak annual mean impact on oxides of nitrogen, sulphur dioxide, ammonia, and nitrogen deposition from the Proposed Facility cannot be screened out as ‘insignificant’. All other impacts can be screened out as ‘insignificant’ as the contribution from the Proposed Facility is less than 1% of the long term and less than 10% of the short term Critical Levels and Loads.

Table 51 sets out a summary of the peak impact across the designated site for the Permitted Facility and Proposed Facility. For airborne pollutant impacts (annual mean oxides of nitrogen, sulphur dioxide and ammonia) the maximum impact at any point within the designated site has been presented. For deposition on saltmarsh and grazing marsh habitats the maximum impact at the location of that habitat has been presented. The location of each habitat has been determined using the 2023 Priority Habitat Inventory dataset.

The extent of the impact of the Proposed Facility and the change in impacts that cannot be screened out as ‘insignificant’ are shown on the following figures:

- Figure 19: Annual Mean Oxides of Nitrogen;
- Figure 20: Annual Mean Sulphur Dioxide;
- Figure 21: Annual Mean Ammonia; and
- Figure 22: Nitrogen Deposition.

Table 51: Peak Impact in Mersey Estuary

Parameter	Units	Permitted Facility		Proposed Facility		Change		Background		Proposed Facility PEC	
		PC	% CL	PC	% CL	PC	% CL	PC	% CL	PEC	% CL
Annual mean NOx	µg/m³	0.50	**1.67%**	1.21	**4.04%**	0.71	**2.37%**	16.90	56.33%	18.11	60.37%
Annual mean SO_2	µg/m³	0.11	0.56%	0.27	**1.35%**	0.16	0.79%	2.80	14.00%	3.07	15.35%
Annual mean NH_3	µg/m³	0.04	**1.39%**	0.10	**3.37%**	0.06	**1.97%**	2.60	86.67%	2.70	**90.03%**
Nitrogen deposition – saltmarsh	kgN/ha/yr	0.14	**1.40%**	0.42	**4.19%**	0.28	**2.79%**	21.80	218.0%	22.22	**222.2%**
Nitrogen deposition – grazing marsh	kgN/ha/yr	0.12	**1.21%**	0.26	**2.65%**	0.14	**1.44%**	21.80	218.0%	22.06	**220.6%**

9.4.1.2 Further assessment – oxides of nitrogen and sulphur dioxide

As shown in Table 51, the Proposed Facility PEC is less than 70% of the Critical Level for oxides of nitrogen and sulphur dioxide, so the impact can be screened out as ‘not significant’. In addition, the change in sulphur dioxide impact is less than 1% of the Critical Level and can be screened out as ‘insignificant’.

9.4.1.3 Further assessment – ammonia

For ammonia, the PEC exceeds 70% of the Critical Level but does not exceed the PEC. Given that the point of maximum impact within the Mersey Estuary designated site occurs in the middle of the estuary over a wide area of tidal mudflats, it is considered that no significant effects would occur due emissions of ammonia.

Furthermore, the impact presented assumes that ammonia is emitted continually at the ELV of 15 mg/Nm³ (at IED reference conditions, see Table 18), resulting in a release rate of 3.506 g/s. In reality, the ERF operates with ammonia emissions much lower than the ELV, averaging 0.45 mg/Nm³ across the 4 lines in 2021[15], equivalent to a release rate of 0.105 g/s. The CC facility could result in additional ammonia emissions; however, additional abatement will be fitted to minimise ammonia (and amine) emissions. The maximum anticipated ammonia emissions resulting from the CC facility (i.e. in addition to the ERF emissions) is less than 5 mg/Nm³ on a daily basis, and considerably lower on an annual mean basis. If it is conservatively assumed that the CC facility continually emits an additional 5 mg/Nm³ of ammonia at the reference conditions for the treated flue gas shown in Table 20, the release rate from the CC facility would be 0.959 g/s and the total release rate would be 1.065 g/s, or 30.4% of the release rate of 3.506 g/s that was initially assumed.

Factoring the impact of the Proposed Facility by 30.4% results in a maximum ammonia impact of 1.02%; although this slightly exceeds the 1% screening criterion, the impact would only occur over tidal mudflats which are not vegetated and therefore not sensitive to ammonia. As such, no significant effects would occur.

9.4.1.4 Further assessment – nitrogen deposition

For nitrogen deposition, the change in impact and the overall impact of the Proposed Facility exceeds 1% of the Critical Loads and the PEC exceeds the Critical Loads, so the impacts cannot be screened out. Whilst the maximum impact of the Permitted Facility is 1.40% of the Critical Load and the maximum impact of the Proposed Facility is 4.19% of the Critical Load, this is under the assumption that ammonia is emitted at 3.506 g/s. As detailed in section 9.4.1.3, the average ammonia release rate from the Permitted Facility has been recorded as 0.105 g/s, and the release rate from Proposed Facility is more likely to be a maximum of 1.065 g/s. Taking these values as the ammonia release rate, the maximum nitrogen deposition impacts are as detailed in:

Table 52: Peak Impact in Mersey Estuary

Parameter	**Units**	**Permitted Facility**		**Proposed Facility**		**Change**	
		PC	**% CL**	**PC**	**% CL**	**PC**	**% CL**
Nitrogen deposition – saltmarsh	kgN/ha/yr	0.03	0.30%	0.21	**2.14%**	0.18	**1.85%**

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[15] Runcorn EfW Annual Performance Report 2021

Parameter	Units	Permitted Facility		Proposed Facility		Change	
		PC	% CL	PC	% CL	PC	% CL
Nitrogen deposition – grazing marsh	kgN/ha/yr	0.03	0.26%	0.14	**1.36%**	0.11	**1.10%**

Whilst the impact and change in impact still exceed the screening criterion, the magnitude of the impact of the Proposed Facility is less than 2% of the lower Critical Load of 10 kgN/ha/yr and less than 1% of the upper Critical Load of 20 kgN/ha/yr. In the context of the saltmarsh fringe of the Mersey Estuary, nitrogen input from air emissions is likely to be very small in comparison to river and tidal inputs, whilst the change in impact at grazing marsh habitats is only marginally above the 1% screening criterion and is not likely to result in a perceptible impact in reality. Therefore, no significant effects on the designated site are likely.

9.4.2 Local nature sites

As shown in Appendix D, the process contribution is not predicted to exceed the Critical Level or Load at any of the local nature sites considered. Applying the EA’s screening criteria the impacts at all local nature sites can be screened out as ‘insignificant’.

10 Carbon Dioxide Venting

During normal operation of the CC facility the CO_2 will be captured and exported from the Facility by pipeline. However, there may be occasions where the capture CO_2 cannot be exported, such as when the CO_2 is not pure enough to meet the export specification, or the export infrastructure is not available.

If the interruption to CO_2 export is short, the CC facility would continue to operate until export is available, with CO_2 being stored in a header tank system before being manually vented if necessary. However, if a longer interruption to the export capability is expected, the CC facility would shut down and the flue gas be discharged via the existing ERF stack instead. Any CO_2 captured during shut down of the CC facility would be stored in the header tank before being manually vented. Full details of the CO_2 venting philosophy and scenarios are provided in the Supporting Information document submitted with the application.

The ADMS 6 dispersion model has been run with the input parameters set out in Section 5.5. The maximum 15-minute and 8-hour concentration has been predicted and the impacts compared to the AQALs (in this case the WEL). A summary is provided in Table 53.

Table 53: Impact of CO_2 Vent

Averaging period	**Maximum as a % of the WEL**	
	Ground level	**Receptor max**
Maximum 15-minute	34%	17%
Maximum 8-hour	15%	5%

The peak 15-minute ground-level concentration occur 270 m south-east of the vent stack, along Picow Farm Road where members of the public may be present for 15 minutes or more. However, even if the CO_2 vent operated during the worst-case weather conditions for dispersion the maximum impact would be 34% of the WEL. Baseline CO_2 concentrations do not vary significantly from the background value of slightly over 400 ppm. Therefore, the maximum CO_2 concentration during venting at areas of relevant exposure (including where workers may be exposed) will remain well below the WEL and no significant effects are predicted.

11 Abnormal Operations

11.1 Background

The Environmental Permitting Regulations require that abnormal event scenarios are considered. Article 46(6) of the Industrial Emissions Directive (IED) states that:

"… the waste incineration plant … shall under no circumstances continue to incinerate waste for a period of more than 4 hours uninterrupted where emission limit values are exceeded.

The cumulative duration or operation in such conditions over 1 year shall not exceed 60 hours."

Article 47 continues with:

"In the case of a breakdown, the operator shall reduce or close down operations as soon as practicable until normal operations can be restored."

The conditions detailed in Article 46(6) are considered to be "abnormal operating conditions" for the purpose of this assessment applies to the Facility.

11.2 Identification of abnormal operating conditions

The following are considered to be examples of abnormal operating conditions which may lead to 'abnormal emission levels' of pollutants:

1. Reduced efficiency of lime injection system such as through blockages or failure of fans leading to elevated acid gas emissions (with the exception of hydrogen chloride);
2. Complete failure of the lime injection system leading to unabated emissions of hydrogen chloride. (Note: this would require the ERF to have complete failure of the bag filter system. As an ERF of modern design the ERF would have shut down before reaching these operating conditions);
3. Reduced efficiency of particulate filtration system due to bag failure and inadequate isolation, leading to elevated particulate emissions and metals in the particulate phase;
4. Reduced efficiency of the Selective Non-Catalytic Reduction (SNCR) system as a result of blockages or failure of ammonia injection system, leading to elevated oxides of nitrogen emissions; and
5. Complete failure of the activated carbon injection system and loss of temperature control leading to high levels of dioxin reformation and their unabated release.

The CC facility is designed to treat flue gas during normal operation. Depending on the cause of abnormal operating conditions, the CC facility would be bypassed during abnormal operation.

If the lime injection and/or SNCR system failed, elevated NOx and acid gas concentrations would significantly degrade the amine solvent in the CC facility. High levels of metals and particulates resulting from a failure of the bag filter and/or activated carbon filter would also degrade the amine solvent and the reduce the overall performance of the CC facility. Therefore, as soon as any failure of abatement technology was identified, bypass of the CC facility would be implemented.

Depending on detailed design and development of operational procedures, the CCS system may also be bypassed during periods when the continuous emissions monitoring system (CEMS) is unavailable, i.e. the pollutant concentrations are unknown. If the CC facility is not bypassed during these periods, the monitoring of the combustion, reagent dosing and CCS processes would be used as proxies to ensure that the processes and resulting emissions remain controlled.

As the flue gas would bypass the CC facility and be emitted from the main stack during abnormal operation, the impact of emissions during abnormal operation would be no worse than previously assessed for the Facility.

11.3 ERF Plant start-up and shutdown

The CC facility requires steam from the combustion process to operate. Therefore, the CC facility will be bypassed during start-up and shut-down of the ERF . Start-up from cold will be conducted with clean support fuel (low sulphur light fuel oil). Waste is not introduced onto the grate unless the temperature is above the minimum requirement (850ºC) and other operating parameters (for example, air flow and oxygen levels) are within the range stipulated in the permit. During the warming up period the gas cleaning plant will be operational as will be the control systems and monitoring equipment.

The same is true during plant shutdown. The waste remaining on the grate is allowed to burn out, the temperature not being permitted to drop below 850ºC by the simultaneous introduction of clean support auxiliary fuel. After complete burnout of the waste, the burners are turned off and the ERF is allowed to cool. During this period, the gas cleaning equipment, control systems and monitoring equipment will be fully operational.

It should also be noted that start-up and shutdown are infrequent events; the Facility is designed to operate continuously, and ideally only close down for its annual maintenance programme.

In relation to the magnitude of dioxin emissions during plant start-up and shutdown, research has been undertaken by AEA Technology on behalf of the Environment Agency (EA). Whilst elevated emissions of dioxins (within one order of magnitude) were found during shutdown and start-up phases where the waste was not fully established on the grate, the report concluded that:

"The mass of dioxin emitted during start-up and shutdown for a 4-5 day planned outage was similar to the emission which would have occurred during normal operation in the same period. The emission during the shutdown and restart is equivalent to less than 1 % of the estimated annual emission (if operating normally all year)."

There is therefore no reason why such start-up and shutdown operations will affect the long term impact of the Facility.

11.4 Summary

The CC facility will be bypassed during any periods of abnormal operation during which elevated emissions may occur. Therefore, the impact of emissions during abnormal operation as permissible under the IED (Article 46) would be no worse than currently allowed for within the EP for the Facility.

12 Conclusions

This Dispersion Modelling Assessment has been undertaken to support an application for a variation to the EP for the Facility. The modelling has assumed that the ERF operates at the ELVs in the existing EP, and these are passed through to the CC facility before emitting to atmosphere. It is assumed that the CC facility does not offer any additional abatement of emissions which is extremely conservative given that the CC facility is likely to reduce emissions of some pollutants by more than 80%.

This assessment has included a review of baseline pollution levels, dispersion modelling of emissions and quantification of the impact of these emissions on local air quality.

The primary conclusions of the assessment are presented below.

1. In relation to the impact on human health:
    a. Emissions from the operation of the CC facility will not cause a breach of any AQAL.
    b. There is predicted to be an increase in the impacts as a result of the operation of the CC facility, but the overall impact of the Installation is not significant. This includes for the additional products released from the CC facility such as amines, nitrosamines and nitramines.
    c. There is no risk of exceeding an AQAL for any metal either on a long or short term basis.
2. In relation to the impact on ecologically sensitive sites:
    a. All impacts at local nature sites can be screened out as ‘insignificant’;
    b. The change in impact due to the operation of the CC facility and overall impact of emissions from the Installation at the Mersey Estuary SSSI cannot be screened out for airborne ammonia impacts and nitrogen deposition impacts. Further assessment of likely emission concentrations and the sensitivity of the affected habitats has shown that no significant effects are likely.
3. CO_2 venting would have an insignificant impact on air quality and human health.

In summary, the assessment has shown that the air quality impact of the Installation would not have a significant impact on local air quality, the general population or the local community. As such there should be no air quality constraint in granting an EP for the CC facility.

Appendices

A Figures

Legend

● Site Location

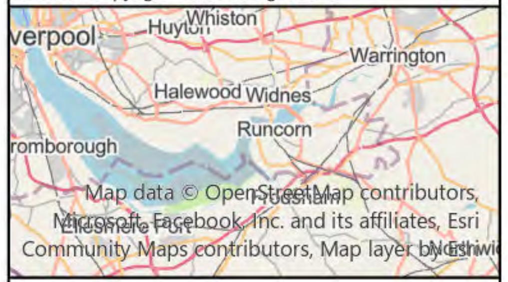
Client:	Viridor
Site:	Runcorn CC Facility
Project:	Dispersion Modelling Assessment

Title:

Figure 1. Site Location

Drawn by: SMN

Date: 17/11/2023



0 0.5 1 2 km

N

Scale: 1:50,000

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Legend

- ● Site location
- ♦ Monitoring locations
- 🏠 Human sensitive receptors
- 🟦 AQMAs

Client: Viridor
Site: Runcorn CC Facility
Project: Dispersion Modelling Assessment
Title:

Figure 2. Human Receptors, AQMAs and Monitoring

Drawn by: SMN
Date: 17/11/2023

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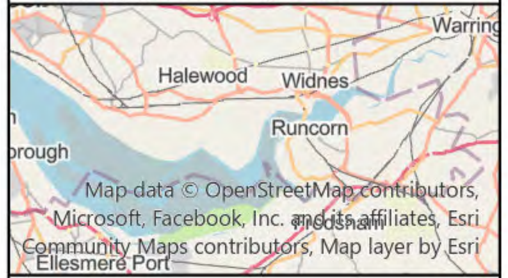

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0 0.3 0.6 1.2 km

N

Scale: 1:30,000

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Legend

● Site location

🌲 Ecological sensitive receptors

🟪 Grazing marsh in Mersey Estuary SPA

🟩 Saltmarsh in Mersey Estuary SPA

▨ SPAs

🟦 SSSIs

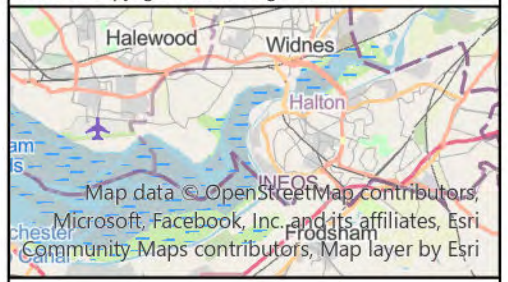
🟩 LNRs

Client:	Viridor
Site:	Runcorn CC Facility
Project:	Dispersion Modelling Assessment

Title:

Figure 3. Ecological Receptors

Drawn by: SMN	Date: 20/11/2023



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0 0.17 0.35 0.7 km

Scale: 1:17,500

N

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Client:	Viridor
Site:	Runcorn CC Facility
Project:	Dispersion Modelling Assessment
Title:	

Figure 4. Modelling Domain

Drawn by: SMN
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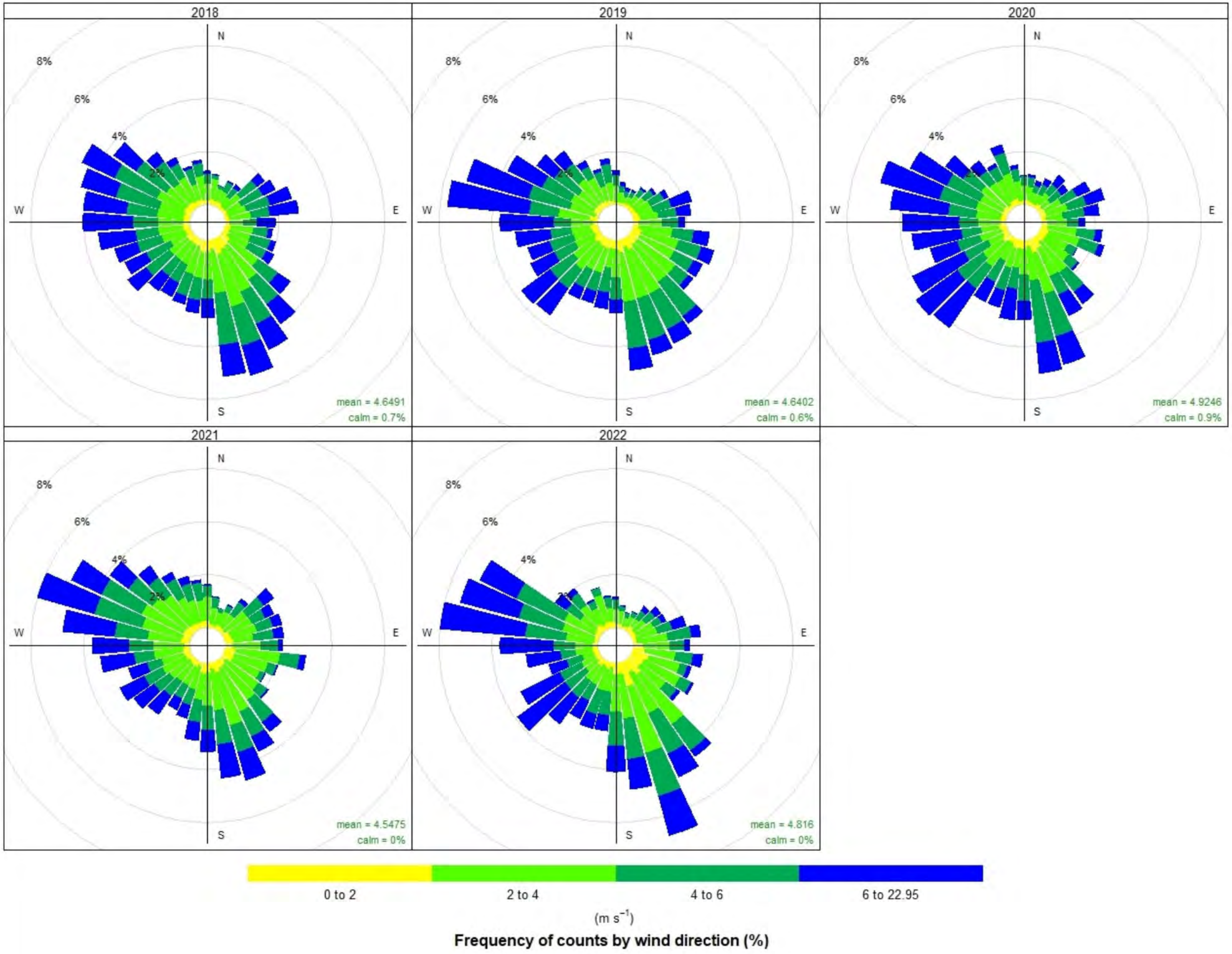

Client: Viridor
Site: Runcorn CC Facility
Project: Dispersion Modelling Assessment
Title:

Figure 5. Wind Roses - Liverpool 2018 - 2022

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Client:	Viridor
Site:	Runcorn CC Facility
Project:	Dispersion Modelling Assessment
Title:	

Figure 6. Surface Roughness File

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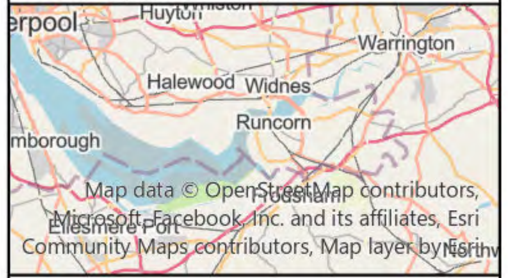

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Scale: 1:45,000

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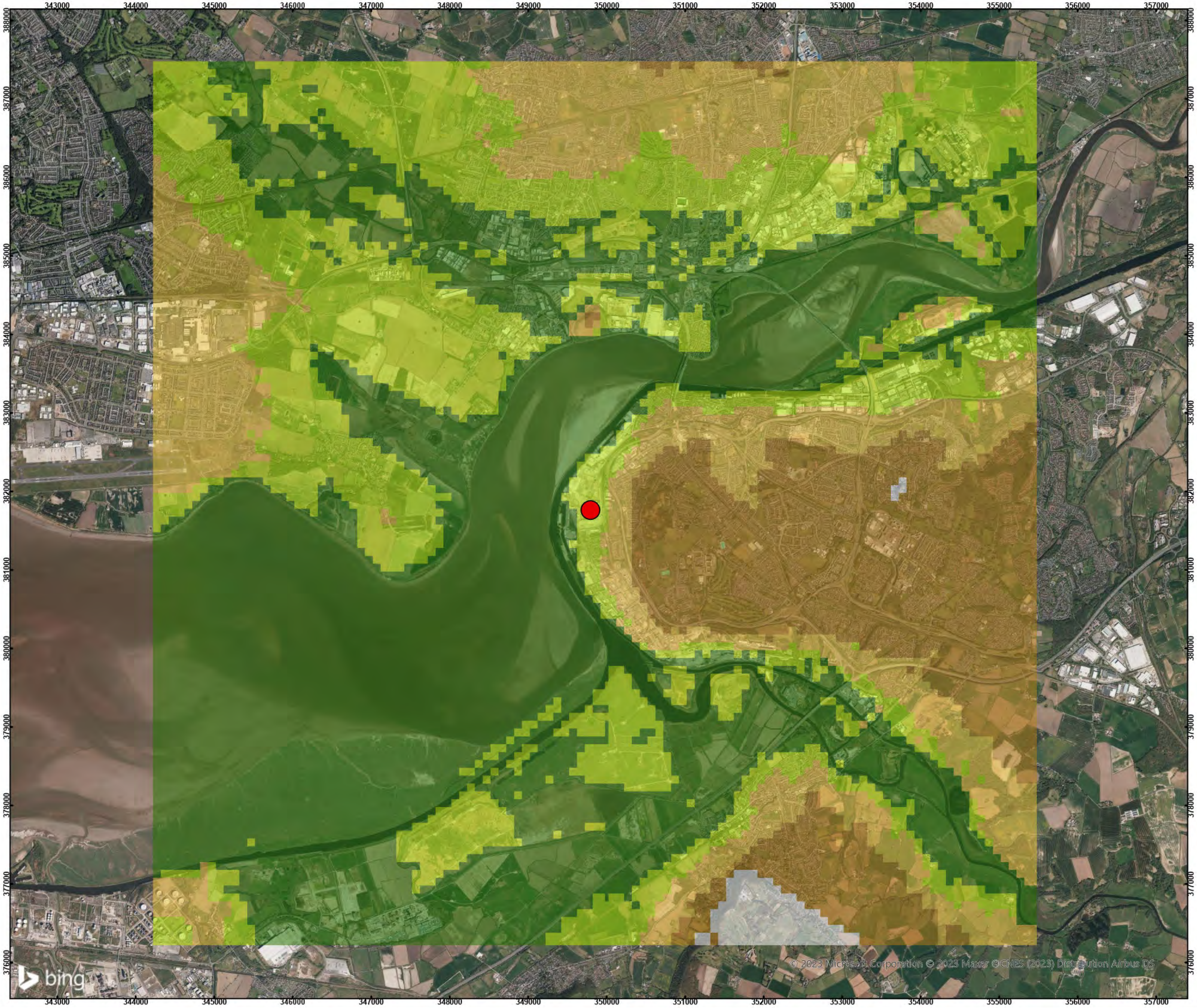

Legend

● Site Location

Elevation (m)

- 🟩 <10
- 🟩 10 - 20
- 🟨 20 - 40
- 🟫 40 - 80
- >80

Client:	Viridor
Site:	Runcorn CC Facility
Project:	Dispersion Modelling Assessment
Title:	

Figure 7. Terrain File

Drawn by: SMN	Date: 20/11/2023

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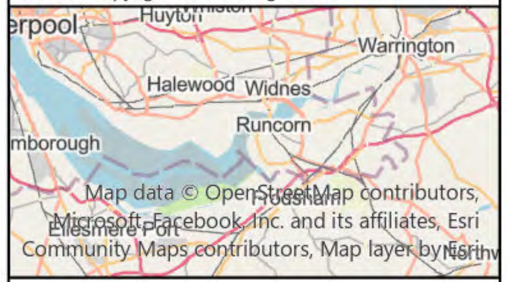

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0 0.45 0.9 1.8 km

Scale: 1:45,000

N

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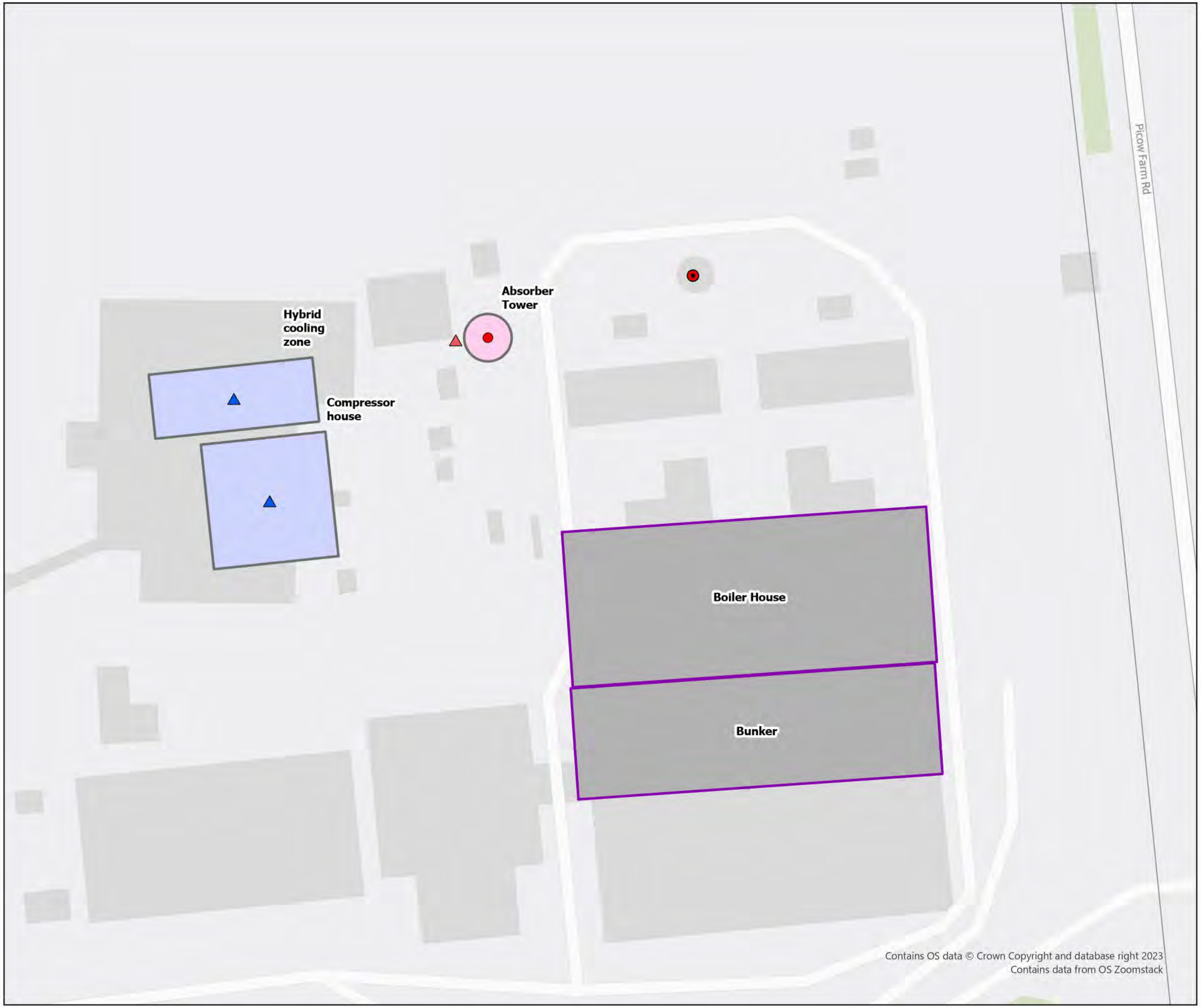

Legend

- ● Absorber stack
- ⊙ Existing stack
- ▲ Hybrid cooler sources
- ▲ CO2 vent
- ▨ ERF buildings modelled
- ▨ Hybrid cooler model buildings
- ▨ Absorber tower

Client:	Viridor
Site:	Runcorn CC Facility
Project:	Dispersion Modelling Assessment
Title:	

Figure 8. Buildings modelled

Drawn by: SMN	Date: 20/11/2023

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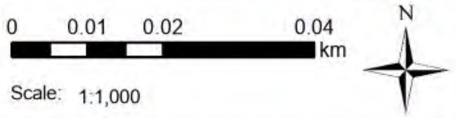

Scale: 1:1,000

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Legend

- ⦿ Existing stack
- ● Absorber stack
- ⌂ Human sensitive receptors
- ♦ Monitoring locations
- ▭ AQMAs
- — Annual mean NO2 as % of AQAL - Proposed Facility
- — Annual mean NO2 as % of AQAL - Change

Notes:
Assumes 70% NOx to NO2 conversion rate

Client:	Viridor
Site:	Runcorn CC Facility
Project:	Dispersion Modelling Assessment
Title:	Figure 9. Annual Mean Nitrogen Dioxide
Drawn by: SMN	Date: 20/11/2023

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0 0.35 0.7 1.4 km
N

Scale: 1:35,000

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Legend

- ◉ Existing stack
- ● Absorber stack
- 🏠 Human sensitive receptors
- — Annual mean benzene as % of AQAL - Proposed Facility
- - - Annual mean benzene as % of AQAL - change

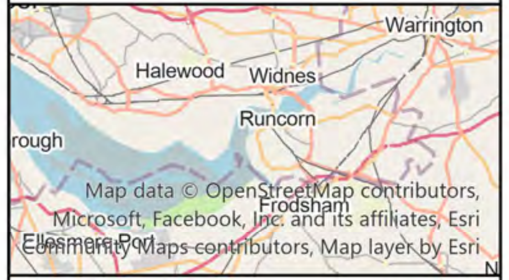
Notes:
Assumes all VOCs emitted as benzene

Client:	Viridor
Site:	Runcorn CC Facility
Project:	Dispersion Modelling Assessment
Title:	

Figure 10. Annual Mean Benzene

Drawn by: SMN

Date: 20/11/2023



0 0.35 0.7 1.4 km

Scale: 1:35,000

N

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Legend

◉	Existing stack
●	Absorber stack
🏠	Human sensitive receptors
—	Annual mean cadmium as % of AQAL - Proposed Facility
—	Annual mean cadmium as % of AQAL - change

Notes:
Assumes cadmium emitted at combined cadmium and thallium ELV

Client:	Viridor
Site:	Runcorn CC Facility
Project:	Dispersion Modelling Assessment
Title:	

Figure 11. Annual Mean Cadmium

Drawn by: SMN
Date: 20/11/2023

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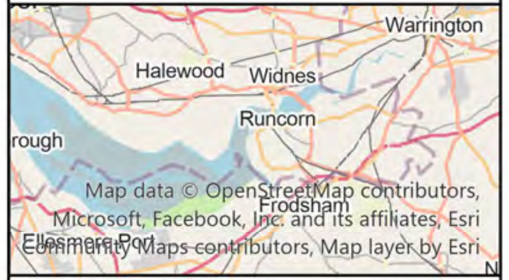

0 0.35 0.7 1.4 km

N

Scale: 1:35,000

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Legend

- ● Existing stack
- ● Absorber stack
- 🏠 Human sensitive receptors
- — Annual mean nitrosamines - pg/m³

Client:	Viridor
Site:	Runcorn CC Facility
Project:	Dispersion Modelling Assessment

Title:

Figure 12. Annual Mean Nitrosamines

Drawn by: SMN	Date: 20/11/2023

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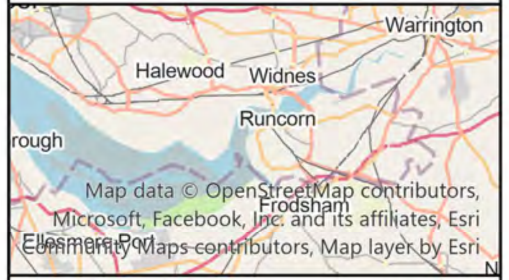

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Scale: 1:35,000

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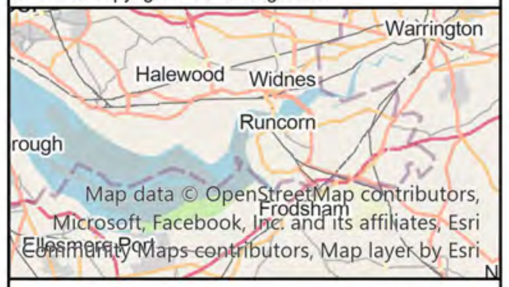
Legend

●	Existing stack
●	Absorber stack
⌂	Human sensitive receptors
—	Annual mean nitramines - pg/m³

Client:	Viridor
Site:	Runcorn CC Facility
Project:	Dispersion Modelling Assessment
Title:	Figure 13. Annual Mean Nitramines
Drawn by: SMN	Date: 20/11/2023



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0 0.35 0.7 1.4 km

Scale: 1:35,000

N

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Legend

◉ Existing stack

● Absorber stack

⌂ Human sensitive receptors

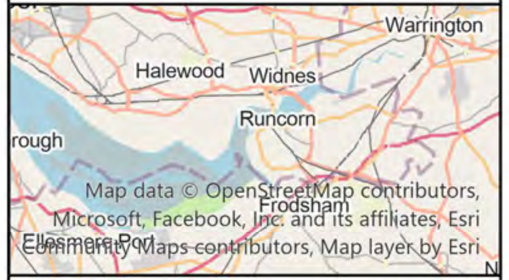
— Annual mean nitrosamines + nitramines as % of AQAL

Notes:
Total nitrosamines + nitramines (as NDMA) as % of AQAL of 0.2 ng/m³

Client:	Viridor
Site:	Runcorn CC Facility
Project:	Dispersion Modelling Assessment
Title:	

Figure 14. Annual Mean Nitrosamines + Nitramines

Drawn by: SMN	Date: 20/11/2023



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0 0.35 0.7 1.4 km

N

Scale: 1:35,000

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Legend

◉	Existing stack
●	Absorber stack
⌂	Human sensitive receptors
—	99.79%ile hourly mean NO2 as % of AQAL - Proposed Facility
- - -	99.79%ile hourly mean NO2 as % of AQAL - change

Notes:
Assumes 35% conversion of NOx to NO2 and all 4 lines operating at half-hourly ELV.

Client:	Viridor
Site:	Runcorn CC Facility
Project:	Dispersion Modelling Assessment
Title:	

Figure 15. Hourly Mean Nitrogen Dioxide

Drawn by: SMN	Date: 20/11/2023

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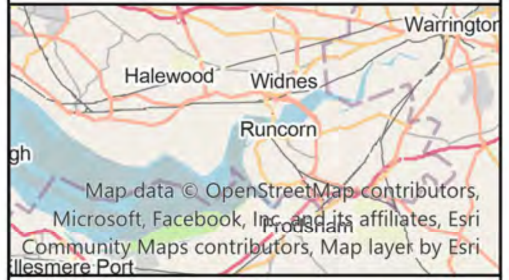

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0 0.3 0.6 1.2 km

N

Scale: 1:29,000

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Legend

◉ Existing stack

● Absorber stack

🏠 Human sensitive receptors

— 99.73%ile hourly mean SO2 as % of AQAL - Proposed Facility

- - 99.73%ile hourly mean SO2 as % of AQAL - change

Notes:
Assumes all 4 lines operating at half-hourly ELV and no additional abatement via CC facility

Client:	Viridor
Site:	Runcorn CC Facility
Project:	Dispersion Modelling Assessment
Title:	

Figure 16. Hourly Mean Sulphur Dioxide

Drawn by: SMN	Date: 20/11/2023

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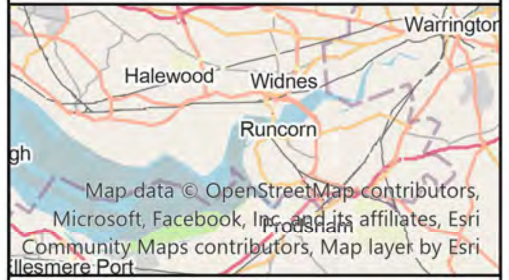

0 0.3 0.6 1.2 km

Scale: 1:29,000

N

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Legend

● Existing stack

● Absorber stack

⌂ Human sensitive receptors

— 99.9%ile 15-min mean SO2 as % of AQAL - Proposed Facility

— 99.9%ile 15-min mean SO2 as % of AQAL - change

Notes:
Assumes all 4 lines operating at half-hourly ELV and no additional abatement via CC facility

Client:	Viridor
Site:	Runcorn CC Facility
Project:	Dispersion Modelling Assessment
Title:	

Figure 17. 15-Minute Mean Sulphur Dioxide

Drawn by: SMN	Date: 20/11/2023

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0 0.3 0.6 1.2 km

Scale: 1:29,000

N

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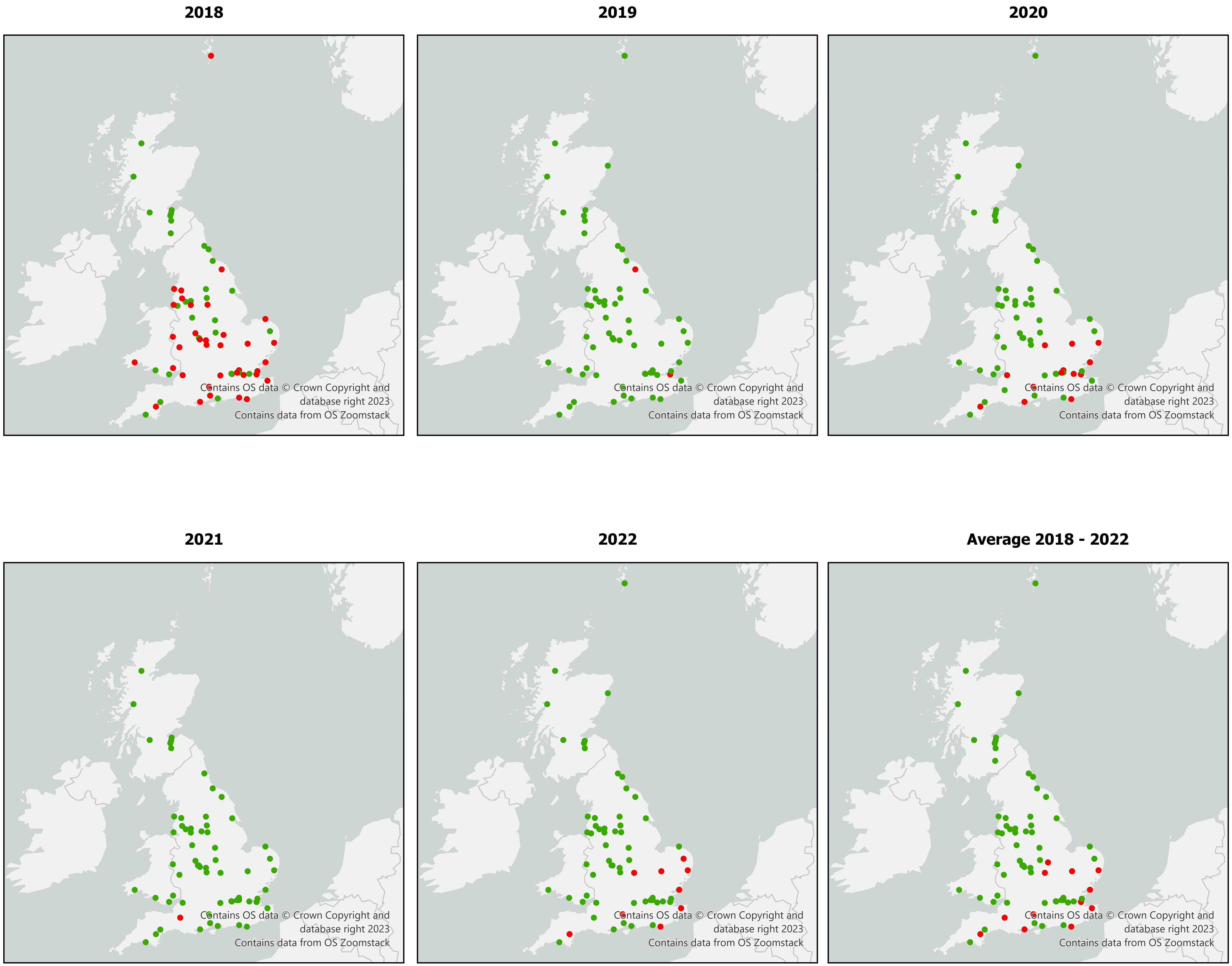


Legend

AOT40

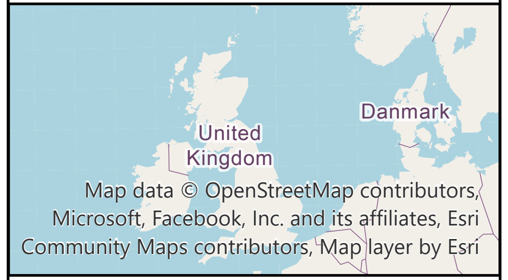
- 🟢 < 3,000 ppb.hr
- 🔴 > 3,000 ppb.hr

AOT40 calculated from accumulated hourly ozone concentrations - sum of the difference between each hourly daytime (08:00 to 20:00 Central European Time) ozone concentration greater than 40 ppb and 40 ppb for the period between 01 May and 31 July

Title:

Figure 18 - Ozone Analysis

Drawn by: RSF	Date: 20/02/2023



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0 115 230 460 km

N

Scale: 1:11,000,000

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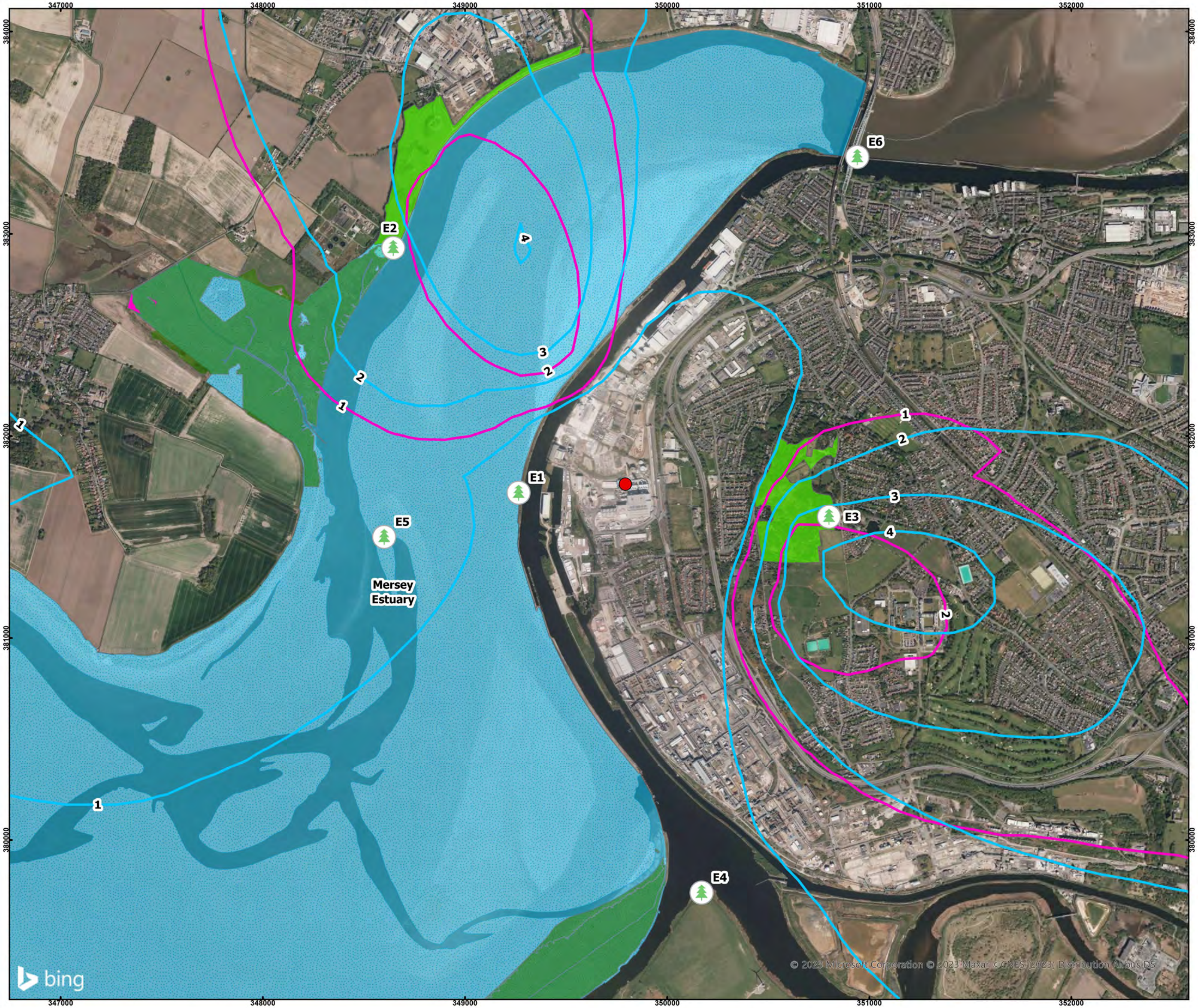


Legend

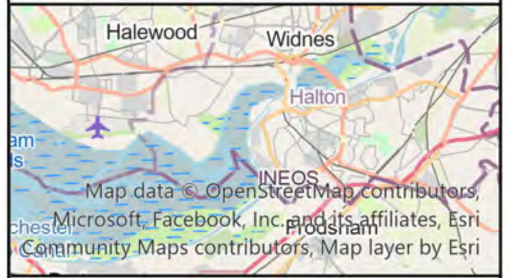
●	Site location
🌲	Ecological sensitive receptors
—	Annual mean NOx as % of CL - Proposed Facility
—	Annual mean NOx as % of CL - change
🟪	Grazing marsh in Mersey Estuary SPA
🟩	Saltmarsh in Mersey Estuary SPA
▨	SPAs
🟦	SSSIs
🟩	LNRs

Client:	Viridor
Site:	Runcorn CC Facility
Project:	Dispersion Modelling Assessment

Title:

Figure 19. Annual Mean NOx

Drawn by: SMN Date: 21/11/2023



Map data © OpenStreetMap contributors, Microsoft, Facebook, Inc. and its affiliates, Esri Community Maps contributors, Map layer by Esri

0 0.17 0.35 0.7 km

Scale: 1:17,500

N

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Fax: 0161 474 0618

Client:	Viridor
Site:	Runcorn CC Facility
Project:	Dispersion Modelling Assessment

Title:

Figure 20. Annual Mean SO2

Drawn by: SMN Date: 21/11/2023

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Scale: 1:17,500

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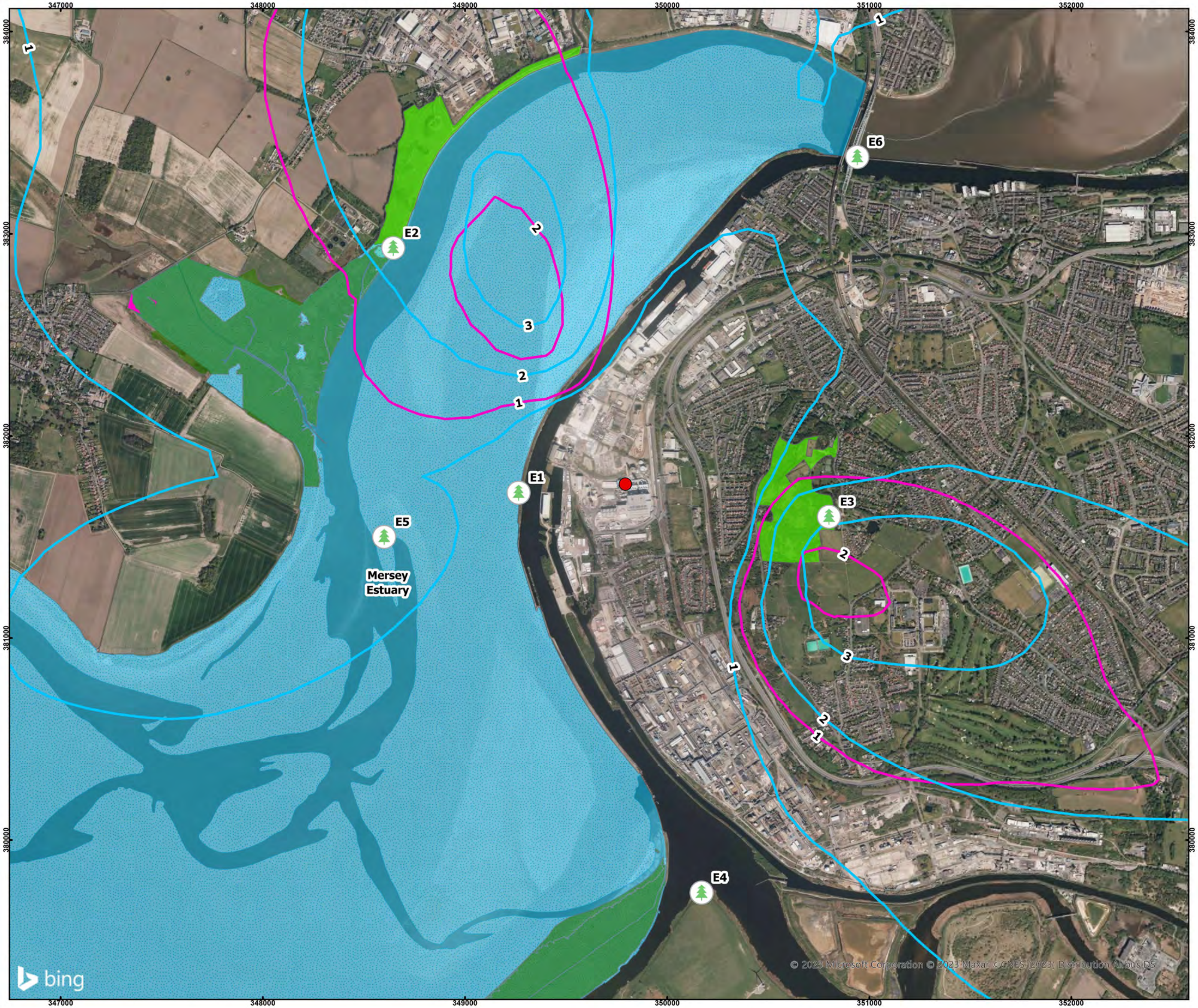

Legend

- ● Site location
- 🌲 Ecological sensitive receptors
- — Annual mean ammonia as % of CL - Proposed Facility
- — Annual mean ammonia as % of CL - change
- 🟪 Grazing marsh in Mersey Estuary SPA
- 🟩 Saltmarsh in Mersey Estuary SPA
- ▨ SPAs
- 🟦 SSSIs
- 🟩 LNRs

Client:	Viridor
Site:	Runcorn CC Facility
Project:	Dispersion Modelling Assessment
Title:	

Figure 21. Annual Mean Ammonia

Drawn by: SMN	Date: 21/11/2023

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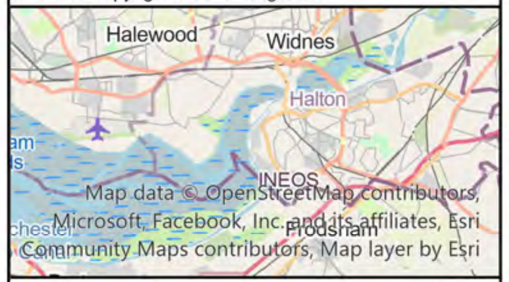

0 0.17 0.35 0.7 km

Scale: 1:17,500

N

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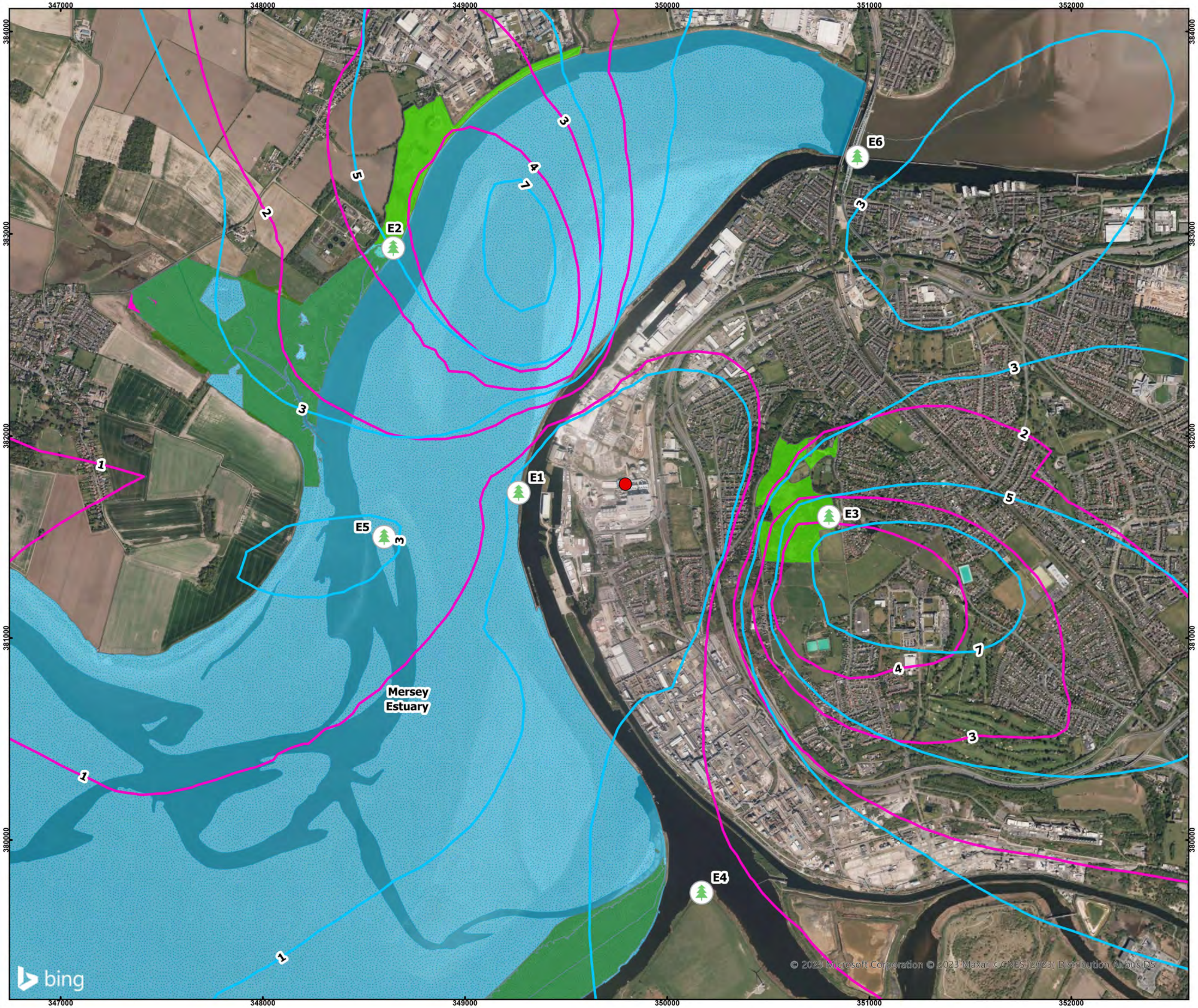


Legend

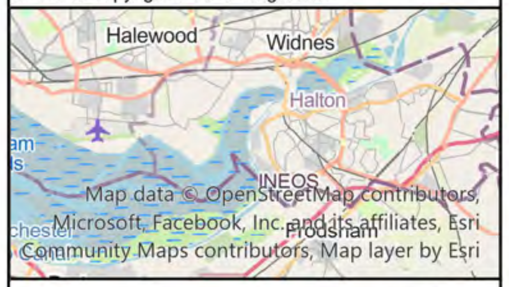
●	Site location
🌲	Ecological sensitive receptors
—	Annual mean nitrogen deposition as % of CL - Proposed Facility
—	Annual mean nitrogen deposition as % of CL - change
🟪	Grazing marsh in Mersey Estuary SPA
🟩	Saltmarsh in Mersey Estuary SPA
▨	SPAs
🟦	SSSIs
🟩	LNRs

Notes:

Nitrogen deposition as % of Critical Load of 10 kgN/ha/yr

Client:	Viridor
Site:	Runcorn CC Facility
Project:	Dispersion Modelling Assessment
Title:	Figure 22. Nitrogen Deposition

Drawn by: SMN	Date: 21/11/2023



0 0.17 0.35 0.7 km

N

Scale: 1:17,500

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B APIS Critical Loads

Table 54: Nitrogen Deposition Critical Loads

ID	Site	Species/Habitat Type	NCL Class	Nitrogen Deposition kgN/hr/yr		
				Lower Critical Load	Upper Critical Load	Bg(1)
European and UK designated sites						
E1	Mersey Estuary	Various bird species	Atlantic upper-mid & mid-low salt marshes	10	20	24.28
		Various bird species	Low and medium altitude hay meadows	10	20	24.28
Local nature sites						
E2	Pickering's Pasture	Neutral grassland	Low and medium altitude hay meadows	10	20	21.58
E3	Runcorn Hill	Lowland health	Dry heaths	5	15	22.57
		Woodland	Broadleaved deciduous woodland	10	15	38.17
E4	Frodsham And Helsby And Ince Marshes	Calcareous grassland	Semi-dry Perennial calcareous grassland (basic meadow steppe)	10	20	22.31
E5	Upper Mersey Estuary Intertidal Areas and Mudflats	Saltmarsh	Atlantic upper-mid & mid-low salt marshes	10	20	24.28
E6	Upper Mersey Estuary	Saltmarsh	Atlantic upper-mid & mid-low salt marshes	10	20	24.28

Note:

(1) Background deposition taken as the maximum across the European UK designated site as reported on APIS. For Local nature sites the background deposition rates reported on APIS for the receptor points presented in Table 7 have been used.

Source: APIS

Table 55: Acid Deposition Critical Loads

ID	Site	Species/Habitat Type	Acidity Class	Critical Load Function (keq/ha/yr)			Background (keq/ha/yr) (N+S)[1]
				CLminN	CLmaxN	CLmaxS	
European and UK designated sites							
E1	Mersey Estuary	Various bird species	Species not sensitive to effects of acidity	-	-	-	-
Local nature sites							
E2	Pickering's Pasture	Neutral grassland	Calcareous grassland (using base cation)	4.000	5.071	1.071	1.72
E3	Runcorn Hill	Lowland heath	Dwarf shrub heath	0.892	1.342	0.450	1.78
		Broadleaved, Mixed and Yew Woodland	Broadleafed/Coniferous unmanaged woodland	0.142	1.15	0.1008	2.94
E4	Frodsham And Helsby And Ince Marshes	Calcareous grassland	Calcareous grassland (using base cation)	4.000	5.071	1.071	1.83
E5	Upper Mersey Estuary Intertidal Areas and Mudflats	Saltmarsh	Not sensitive	-	-	-	-
E6	Upper Mersey Estuary	Saltmarsh	Not sensitive	-	-	-	-

Note:

(1) Background deposition taken as the maximum across the European UK designated site as reported on APIS. For Local nature sites the background deposition rates reported on APIS for the receptor points presented in Table 7 have been used.

Source: APIS

C Detailed Results Tables – Human Health

Table 56: Dispersion Modelling Results – PC at Point of Maximum Ground Level Impact - Daily ELVs - Permitted Facility

Pollutant	**Quantity**	**Units**	**AQAL**	**Bg Conc.**	**2018**	**2019**	**2020**	**2021**	**2022**	**Max**	**Max as % of AQAL**	**PEC**	**PEC as % of AQAL**
Nitrogen dioxide	Annual mean	µg/m³	40	19.9	0.37	0.48	0.40	0.42	0.53	0.53	**1.32%**	20.43	51.07%
	99.79th %ile of hourly means	µg/m³	200	39.8	6.86	5.79	6.25	6.60	6.40	6.86	3.43%	46.66	23.33%
Sulphur dioxide	99.18th %ile of daily means	µg/m³	125	10.4	1.45	1.21	1.18	1.35	1.39	1.45	1.16%	11.85	9.48%
	99.73rd %ile of hourly means	µg/m³	350	10.4	4.13	3.48	3.84	4.07	3.89	4.13	1.18%	14.53	4.15%
	99.9th %ile of 15 min. means	µg/m³	266	10.4	5.27	4.88	4.78	4.75	5.10	5.27	1.98%	15.67	5.89%
Particulates (PM_{10})	Annual mean	µg/m³	40	15.5	0.01	0.02	0.02	0.02	0.02	0.02	0.05%	15.52	38.80%
	90.41st %ile of daily means	µg/m³	50	31	0.06	0.08	0.06	0.06	0.08	0.08	0.16%	31.08	62.16%
Particulates ($PM_{2.5}$)	Annual mean	µg/m³	10	11.5	0.01	0.02	0.02	0.02	0.02	0.02	0.21%	11.52	115.2%
Carbon monoxide	8 hour running mean	µg/m³	10,000	828	4.65	4.21	4.34	4.39	5.25	5.25	0.05%	833.25	8.33%
	Hourly mean	µg/m³	30,000	828	8.35	10.58	8.18	7.81	8.99	10.58	0.04%	838.58	2.80%
Hydrogen chloride	Hourly mean	µg/m³	750	1.42	1.34	1.69	1.31	1.25	1.44	1.69	0.23%	3.11	0.41%
Hydrogen fluoride	Annual mean	µg/m³	16	2.35	0.003	0.004	0.003	0.003	0.004	0.004	0.03%	2.35	14.71%
	Hourly mean	µg/m³	160	4.7	0.17	0.21	0.16	0.16	0.18	0.21	0.13%	4.91	3.07%
Ammonia	Annual mean	µg/m³	180	4.7	0.04	0.06	0.05	0.05	0.06	0.06	0.03%	4.76	2.65%

Pollutant	Quantity	Units	AQAL	Bg Conc.	2018	2019	2020	2021	2022	Max	Max as % of AQAL	PEC	PEC as % of AQAL
	Hourly mean	µg/m³	2,500	9.4	2.51	3.17	2.46	2.34	2.70	3.17	0.13%	12.57	0.50%
VOCs (as benzene)	Annual mean	µg/m³	5	1.09	0.03	0.04	0.03	0.03	0.04	0.04	0.84%	1.13	22.64%
	Daily mean	µg/m³	30	2.18	0.50	0.48	0.44	0.53	0.49	0.53	1.77%	2.71	9.03%
Mercury	Daily mean	ng/m³	60	38	0.99	0.97	0.88	1.06	0.97	1.06	1.77%	39.06	65.10%
	Hourly mean	ng/m³	600	38	3.34	4.23	3.27	3.13	3.60	4.23	0.71%	42.23	7.04%
Cadmium	Annual mean	ng/m³	5	0.12	0.06	0.08	0.06	0.07	0.08	0.08	**1.67%**	0.20	4.07%
	Daily mean	ng/m³	30	0.24	0.99	0.97	0.88	1.06	0.97	1.06	3.53%	1.30	4.33%
PaHs	Annual mean	pg/m³	250	180	0.59	0.76	0.64	0.67	0.84	0.84	0.33%	180.84	72.33%
Dioxins and Furans	Annual mean	fg/m³	-	32.99	0.24	0.30	0.26	0.27	0.33	0.33	-	33.32	-
PCBs	Annual mean	ng/m³	200	0.13	0.01	0.02	0.02	0.02	0.02	0.02	0.01%	0.15	0.07%
	Hourly mean	ng/m³	6,000	0.26	0.84	1.06	0.82	0.78	0.90	1.06	0.02%	1.32	0.02%

Note:
Assumes continuous operation at the daily ELVs.

Table 57: Dispersion Modelling Results – PC at Point of Maximum Ground Level Impact - Short-Term ELVs - Permitted Facility

Pollutant	**Quantity**	**Units**	**AQAL**	**Bg Conc.**	**2018**	**2019**	**2020**	**2021**	**2022**	**Max**	**Max as % of AQAL**	**PEC**	**PEC as % of AQAL**
Nitrogen dioxide	99.79th %ile of hourly means	µg/m³	200	39.8	15.23	12.86	13.90	14.67	14.21	15.23	7.62%	55.03	27.52%
Sulphur dioxide	99.73rd %ile of hourly means	µg/m³	350	10.4	20.67	17.39	19.21	20.33	19.45	20.67	5.91%	31.07	8.88%
	99.9th %ile of 15 min. means	µg/m³	266	10.4	26.34	24.38	23.91	23.74	25.49	26.34	9.90%	36.74	13.81%
Carbon monoxide	8 hour running mean	µg/m³	10,000	828	13.95	12.62	13.02	13.18	15.76	15.76	0.16%	843.76	8.44%
	Hourly mean	µg/m³	30,000	828	25.06	31.73	24.55	23.44	26.98	31.73	0.11%	859.73	2.87%
Hydrogen chloride	Hourly mean	µg/m³	750	1.42	10.02	12.69	9.82	9.38	10.79	12.69	1.69%	14.11	1.88%
Hydrogen fluoride	Hourly mean	µg/m³	160	4.7	0.67	0.85	0.65	0.63	0.72	0.85	0.53%	5.55	3.47%

Note:
Assumes continuous operation of all 4 lines of the ERF at the short term ELVs.

Table 58: Dispersion Modelling Results – PC at Point of Maximum Ground Level Impact - Daily ELVs - Proposed Facility

Pollutant	Quantity	Units	AQAL	Bg Conc.	2018	2019	2020	2021	2022	Max	Max as % of AQAL	PEC	PEC as % of AQAL
Nitrogen dioxide	Annual mean	µg/m^3	40	19.9	0.83	0.87	0.82	0.86	0.94	0.94	**2.35%**	20.84	52.10%
	99.79th %ile of hourly means	µg/m^3	200	39.8	13.16	12.36	12.74	12.86	11.96	13.16	6.58%	52.96	26.48%
Sulphur dioxide	99.18th %ile of daily means	µg/m^3	125	10.4	3.29	2.78	2.56	3.21	2.61	3.29	2.63%	13.69	10.95%
	99.73rd %ile of hourly means	µg/m^3	350	10.4	8.14	7.60	7.83	7.79	7.54	8.14	2.33%	18.54	5.30%
	99.9th %ile of 15 min. means	µg/m^3	266	10.4	11.36	9.19	9.41	10.15	10.27	11.36	4.27%	21.76	8.18%
Particulates (PM_{10})	Annual mean	µg/m^3	40	15.5	0.03	0.03	0.03	0.03	0.04	0.04	0.09%	15.54	38.84%
	90.41st %ile of daily means	µg/m^3	50	31	0.13	0.14	0.12	0.12	0.14	0.14	0.29%	31.14	62.29%
Particulates ($PM_{2.5}$)	Annual mean	µg/m^3	10	11.5	0.03	0.03	0.03	0.03	0.04	0.04	0.37%	11.54	115.4%
Carbon monoxide	8 hour running mean	µg/m^3	10,000	828	10.71	7.91	8.38	9.55	7.72	10.71	0.11%	838.71	8.39%
	Hourly mean	µg/m^3	30,000	828	21.16	23.55	23.32	18.95	18.01	23.55	0.08%	851.55	2.84%
Hydrogen chloride	Hourly mean	µg/m^3	750	1.42	3.39	3.77	3.73	3.03	2.88	3.77	0.50%	5.19	0.69%
Hydrogen fluoride	Annual mean	µg/m^3	16	2.35	0.007	0.007	0.007	0.007	0.007	0.007	0.05%	2.36	14.73%
	Hourly mean	µg/m^3	160	4.7	0.42	0.47	0.47	0.38	0.36	0.47	0.29%	5.17	3.23%
Ammonia	Annual mean	µg/m^3	180	4.7	0.10	0.10	0.10	0.10	0.11	0.11	0.06%	4.81	2.67%
	Hourly mean	µg/m^3	2,500	9.4	6.35	7.06	6.99	5.68	5.40	7.06	0.28%	16.46	0.66%
	Annual mean	µg/m^3	5	1.09	0.07	0.07	0.07	0.07	0.07	0.07	**1.49%**	1.16	23.29%

Pollutant	Quantity	Units	AQAL	Bg Conc.	2018	2019	2020	2021	2022	Max	Max as % of AQAL	PEC	PEC as % of AQAL
VOCs (as benzene)	Daily mean	µg/m^3	30	2.18	1.24	0.96	0.80	1.09	0.90	1.24	4.14%	3.42	11.41%
Mercury	Daily mean	ng/m^3	60	38	2.48	1.92	1.60	2.17	1.80	2.48	4.14%	40.48	67.47%
	Hourly mean	ng/m^3	600	38	8.46	9.42	9.33	7.58	7.21	9.42	1.57%	47.42	7.90%
Cadmium	Annual mean	ng/m^3	5	0.12	0.13	0.14	0.13	0.14	0.15	0.15	**2.98%**	0.27	5.38%
	Daily mean	ng/m^3	30	0.24	2.48	1.92	1.60	2.17	1.80	2.48	8.28%	2.72	9.08%
PaHs	Annual mean	pg/m^3	250	180	1.32	1.39	1.30	1.37	1.49	1.49	0.60%	181.49	72.60%
Dioxins and Furans	Annual mean	fg/m^3	-	32.99	0.53	0.55	0.52	0.55	0.60	0.60	-	33.59	-
PCBs	Annual mean	ng/m^3	200	0.13	0.03	0.03	0.03	0.03	0.04	0.04	0.02%	0.17	0.08%
	Hourly mean	ng/m^3	6,000	0.26	2.12	2.35	2.33	1.89	1.80	2.35	0.04%	2.61	0.04%
Sum of amines (as MEA)	Hourly mean	µg/m^3	400	0	3.63	4.06	4.01	3.27	3.10	4.06	1.01%	4.06	1.01%
	Daily mean	µg/m^3	100	0	1.07	0.83	0.69	0.94	0.77	1.07	1.07%	1.07	1.07%
Sum of NS (as NDMA)	Annual mean	pg/m^3	200	0	2.50	2.31	2.05	2.05	2.41	2.50	**1.25%**	2.50	1.25%
Sum of NS + NA (as NDMA)	Annual mean	pg/m^3	300	0	9.19	8.56	8.01	5.63	7.93	9.19	**4.60%**	9.19	4.60%
Aldehydes (as formaldehyde)	Annual mean	µg/m^3	5	2.37	0.03	0.03	0.03	0.03	0.03	0.03	0.61%	2.40	48.01%
	30-minute mean	µg/m^3	100	4.74	1.76	2.17	2.16	1.82	1.71	2.17	2.17%	6.91	6.91%

Note:

Assumes continuous operation of all 4 lines of the ERF at the daily ELVs and emitting via the CC facility.

Sum of NS = sum of nitrosamines, Sum of NS + NA = sum of nitrosamines and nitramines

Table 59: Dispersion Modelling Results – PC at Point of Maximum Ground Level Impact - Short-Term ELVs - Proposed Facility

Pollutant	**Quantity**	**Units**	**AQAL**	**Bg Conc.**	**2018**	**2019**	**2020**	**2021**	**2022**	**Max**	**Max as % of AQAL**	**PEC**	**PEC as % of AQAL**
Nitrogen dioxide	99.79th %ile of hourly means	µg/m³	200	39.8	29.23	27.47	28.31	28.58	26.58	29.23	**14.62%**	69.03	34.52%
Sulphur dioxide	99.73rd %ile of hourly means	µg/m³	350	10.4	40.70	38.01	39.16	38.96	37.71	40.70	**11.63%**	51.10	14.60%
	99.9th %ile of 15 min. means	µg/m³	266	10.4	56.82	45.97	47.05	50.75	51.33	56.82	**21.36%**	67.22	25.27%
Carbon monoxide	8 hour running mean	µg/m³	10,000	828	32.13	23.73	25.13	28.65	23.16	32.13	0.32%	860.13	8.60%
	Hourly mean	µg/m³	30,000	828	63.49	70.64	69.95	56.85	54.04	70.64	0.24%	898.64	3.00%
Hydrogen chloride	Hourly mean	µg/m³	750	1.42	25.40	28.26	27.98	22.74	21.62	28.26	3.77%	29.68	3.96%
Hydrogen fluoride	Hourly mean	µg/m³	160	4.7	1.69	1.88	1.87	1.52	1.44	1.88	1.18%	6.58	4.11%

Notes:

Assumes continuous operation of all 4 lines of the ERF at the short term ELVs and emitting via the CC facility.

Table 60: Long-Term Metals Results at Point of Maximum Impact – Permitted Facility

Metal	**AQAL**	**Baseline conc.**	**Metals emitted at combined metal limit**				**Metal as % of ELV** (1)	**Each metal emitted at the maximum concentration from the EA metals guidance document**			
			PC		**PEC**			**PC**		**PEC**	
	ng/m^3	**ng/m^3**	**ng/m^3**	**as % AQAL**	**ng/m^3**	**as % AQAL**		**ng/m^3**	**as % AQAL**	**ng/m^3**	**as % AQAL**
Arsenic	6	0.83	1.25	**20.90%**	2.08	34.73%	8.3%	0.10	**1.74%**	0.93	15.57%
Antimony	5,000	1.30	1.25	0.03%	2.55	0.05%	3.8%	0.05	0.001%	1.35	0.03%
Chromium	-	1.70	1.25	-	2.95	-	30.7%	0.38	-	2.08	-
Chromium (VI)	0.25	0.34	1.25	**501.5%**	1.59	**637.5%**	0.043%	0.001	0.22%	0.34	136.22%
Cobalt	-	0.39	1.25	-	1.64	-	1.9%	0.02	-	0.41	-
Copper	-	6.00	1.25	-	7.25	-	9.7%	0.12	-	6.12	-
Lead	250	7.00	1.25	0.50%	8.25	3.30%	16.8%	0.21	0.08%	7.21	2.88%
Manganese	150	3.30	1.25	0.84%	4.55	3.04%	20.0%	0.25	0.17%	3.55	2.37%
Nickel	20	1.50	1.25	**6.27%**	2.75	13.77%	73.3%	0.92	**4.60%**	2.42	12.10%
Vanadium	-	1.10	1.25	-	2.35	-	2.0%	0.03	-	1.13	-

Notes:

(1) Metal as maximum percentage of the group 3 ELV of 0.3 mg/Nm^3, recalculated from the data presented in EA's metals guidance document (V.4) Table A1.

Table 61: Short-Term Metals Results at Point of Maximum Impact – Permitted Facility

Metal	**AQAL**	**Baseline conc.**	**Metals emitted at combined metal limit**				**Metal as % of ELV (1)**	**Each metal emitted at the maximum concentration from the EA metals guidance document**			
			PC		**PEC**			**PC**		**PEC**	
	ng/m^3	**ng/m^3**	**ng/m^3**	**as % AQAL**	**ng/m^3**	**as % AQAL**		**ng/m^3**	**as % AQAL**	**ng/m^3**	**as % AQAL**
Arsenic	-	1.66	63.46	-	65.12	-	8.3%	5.29	-	6.95	-
Antimony	150,000	2.60	63.46	0.04%	66.06	0.04%	3.8%	2.43	0.002%	5.03	0.003%
Chromium (daily mean)	2,000	3.40	15.89	0.79%	19.29	0.96%	30.7%	4.87	0.24%	8.27	0.41%
Chromium (VI)	-	0.68	63.46	-	64.14	-	0.043%	0.03	-	0.71	-
Cobalt	-	0.78	63.46	-	64.24	-	1.9%	1.18	-	1.96	-
Copper (daily mean)	50	12.00	15.89	**31.78%**	27.89	55.78%	9.7%	1.54	3.07%	13.54	27.07%
Lead	-	14.00	63.46	-	77.46	-	16.8%	10.64	-	24.64	-
Manganese	1,500,000	6.60	63.46	0.004%	70.06	0.005%	20.0%	12.69	0.001%	19.29	0.001%
Nickel	700	3.00	63.46	9.07%	66.46	9.49%	73.3%	46.53	6.65%	49.53	7.08%
Vanadium (daily mean)	1,000	2.20	15.89	1.59%	18.09	1.81%	2.0%	0.32	0.032%	2.52	0.25%

Notes:

(1) Metal as maximum percentage of the group 3 ELV of 0.3 mg/Nm^3, recalculated from the data as presented in EA's metals guidance document (V.4) Table A1.

Table 62: Long-Term Metals Results at Point of Maximum Impact – Proposed Facility

Metal	**AQAL**	**Baseline conc.**	**Metals emitted at combined metal limit**				**Metal as % of ELV (1)**	**Each metal emitted at the maximum concentration from the EA metals guidance document**			
			PC		**PEC**			**PC**		**PEC**	
	ng/m^3	**ng/m^3**	**ng/m^3**	**as % AQAL**	**ng/m^3**	**as % AQAL**		**ng/m^3**	**as % AQAL**	**ng/m^3**	**as % AQAL**
Arsenic	6	0.83	2.24	**37.28%**	3.07	51.11%	8.3%	0.19	**3.11%**	1.02	16.94%
Antimony	5,000	1.30	2.24	0.04%	3.54	0.07%	3.8%	0.09	0.002%	1.39	0.03%
Chromium	-	1.70	2.24	-	3.94	-	30.7%	0.69	-	2.39	-
Chromium (VI)	0.25	0.34	2.24	**894.6%**	2.58	**1030.6%**	0.043%	0.001	0.39%	0.34	136.39%
Cobalt	-	0.39	2.24	-	2.63	-	1.9%	0.04	-	0.43	-
Copper	-	6.00	2.24	-	8.24	-	9.7%	0.22	-	6.22	-
Lead	250	7.00	2.24	0.89%	9.24	3.69%	16.8%	0.37	0.15%	7.37	2.95%
Manganese	150	3.30	2.24	**1.49%**	5.54	3.69%	20.0%	0.45	0.30%	3.75	2.50%
Nickel	20	1.50	2.24	**11.18%**	3.74	18.68%	73.3%	1.64	**8.20%**	3.14	15.70%
Vanadium	-	1.10	2.24	-	3.34	-	2.0%	0.04	-	1.14	-

Notes:

(1) Metal as maximum percentage of the group 3 ELV of 0.3 mg/Nm^3, recalculated from the data presented in EA's metals guidance document (V.4) Table A1.

Table 63: Short-Term Metals Results at Point of Maximum Impact – Proposed Facility

Metal	AQAL	Baseline conc.	Metals emitted at combined metal limit				Metal as % of ELV [(1)]	Each metal emitted at the maximum concentration from the EA metals guidance document			
			PC		PEC			PC		PEC	
	ng/m^3	ng/m^3	ng/m^3	as % AQAL	ng/m^3	as % AQAL		ng/m^3	as % AQAL	ng/m^3	as % AQAL
Arsenic	-	1.66	141.28	-	142.94	-	8.3%	11.77	-	13.43	-
Antimony	150,000	2.60	141.28	0.09%	143.88	0.10%	3.8%	5.42	0.004%	8.02	0.01%
Chromium (daily mean)	2,000	3.40	37.27	1.86%	40.67	2.03%	30.7%	11.43	0.57%	14.83	0.74%
Chromium (VI)	-	0.68	141.28	-	141.96	-	0.043%	0.06	-	0.74	-
Cobalt	-	0.78	141.28	-	142.06	-	1.9%	2.64	-	3.42	-
Copper (daily mean)	50	12.00	37.27	**74.55%**	49.27	98.55%	9.7%	3.60	7.21%	15.60	31.21%
Lead	-	14.00	141.28	-	155.28	-	16.8%	23.69	-	37.69	-
Manganese	1,500,000	6.60	141.28	0.01%	147.88	0.01%	20.0%	28.26	0.002%	34.86	0.002%
Nickel	700	3.00	141.28	**20.18%**	144.28	20.61%	73.3%	103.61	**14.80%**	106.61	15.23%
Vanadium (daily mean)	1,000	2.20	37.27	3.73%	39.47	3.95%	2.0%	0.75	0.075%	2.95	0.29%

Notes:

(1) Metal as maximum percentage of the group 3 ELV of 0.3 mg/Nm^3, recalculated from the data as presented in EA's metals guidance document (V.4) Table A1.

Table 64: Long-Term Metals Results at Point of Maximum Impact – Change in Impact

Metal	AQAL	Baseline conc.	Metals emitted at combined metal limit				Metal as % of ELV (1)	Each metal emitted at the maximum concentration from the EA metals guidance document			
			PC		PEC(2)			PC		PEC(2)	
	ng/m^3	ng/m^3	ng/m^3	as % AQAL	ng/m^3	as % AQAL		ng/m^3	as % AQAL	ng/m^3	as % AQAL
Arsenic	6	0.83	0.98	**16.38%**	1.81	30.21%	8.3%	0.08	**1.36%**	0.91	15.20%
Antimony	5,000	1.30	0.98	0.02%	2.28	0.05%	3.8%	0.04	0.001%	1.34	0.03%
Chromium	-	1.70	0.98	-	2.68	-	30.7%	0.30	-	2.00	-
Chromium (VI)	0.25	0.34	0.98	**393.1%**	1.32	**529.1%**	0.043%	0.0004	0.17%	0.34	136.17%
Cobalt	-	0.39	0.98	-	1.37	-	1.9%	0.02	-	0.41	-
Copper	-	6.00	0.98	-	6.98	-	9.7%	0.09	-	6.09	-
Lead	250	7.00	0.98	0.39%	7.98	3.19%	16.8%	0.16	0.07%	7.16	2.87%
Manganese	150	3.30	0.98	0.66%	4.28	2.86%	20.0%	0.20	0.13%	3.50	2.33%
Nickel	20	1.50	0.98	**4.91%**	2.48	12.41%	73.3%	0.72	**3.60%**	2.22	11.10%
Vanadium	-	1.10	0.98	-	2.08	-	2.0%	0.02	-	1.12	-

Notes:

(1) Metal as maximum percentage of the group 3 ELV of 0.3 mg/Nm^3, recalculated from the data presented in EA's metals guidance document (V.4) Table A1.

(2) PEC presented is for the Proposed Facility.

Table 65: Short-Term Metals Results at Point of Maximum Impact – Change in Impact

Metal	AQAL	Baseline conc.	Metals emitted at combined metal limit				Metal as % of ELV (1)	Each metal emitted at the maximum concentration from the EA metals guidance document			
			PC		PEC			PC		PEC	
	ng/m^3	ng/m^3	ng/m^3	as % AQAL	ng/m^3	as % AQAL		ng/m^3	as % AQAL	ng/m^3	as % AQAL
Arsenic	-	1.66	77.83	-	79.49	-	8.3%	6.49	-	8.15	-
Antimony	150,000	2.60	77.83	0.05%	80.43	0.05%	3.8%	2.98	0.002%	5.58	0.00%
Chromium (daily mean)	2,000	3.40	21.38	1.07%	24.78	1.24%	30.7%	6.56	0.33%	9.96	0.50%
Chromium (VI)	-	0.68	77.83	-	78.51	-	0.043%	0.03	-	0.71	-
Cobalt	-	0.78	77.83	-	78.61	-	1.9%	1.45	-	2.23	-
Copper (daily mean)	50	12.00	21.38	**42.77%**	33.38	66.77%	9.7%	2.07	4.13%	14.07	28.13%
Lead	-	14.00	77.83	-	91.83	-	16.8%	13.05	-	27.05	-
Manganese	1,500,000	6.60	77.83	0.01%	84.43	0.01%	20.0%	15.57	0.001%	22.17	0.001%
Nickel	700	3.00	77.83	**11.12%**	80.83	11.55%	73.3%	57.07	8.15%	60.07	8.58%
Vanadium (daily mean)	1,000	2.20	21.38	2.14%	23.58	2.36%	2.0%	0.43	0.043%	2.63	0.26%

Notes:

(1) Metal as maximum percentage of the group 3 ELV of 0.3 mg/Nm^3, recalculated from the data as presented in EA's metals guidance document (V.4) Table A1.

(2) PEC presented is for the Proposed Facility.

D Detailed Results Tables – Ecology

Table 66: Impact at Ecological Sites - Permitted Facility - µg/m³

ID	Site	Oxides of nitrogen (µg/m³)		Sulphur dioxide (µg/m³)	Hydrogen fluoride (µg/m³)		Ammonia (µg/m³)
		Annual mean	Daily mean	Annual mean	Weekly mean	Daily mean	Annual mean
European and UK designated sites							
E1	Mersey Estuary	0.50	9.53	0.11	0.02	0.05	0.04
Local nature sites							
E2	Pickering's Pasture	0.48	7.24	0.11	0.01	0.04	0.04
E3	Runcorn Hill	0.47	4.35	0.10	0.01	0.02	0.04
E4	Frodsham And Helsby And Ince Marshes	0.27	4.40	0.06	0.01	0.02	0.02
E5	Upper Mersey Estuary Intertidal Areas and Mudflats	0.25	6.76	0.06	0.02	0.04	0.02
E6	Upper Mersey Estuary	0.28	3.84	0.06	0.01	0.02	0.02
Note: *Assumes continuous operation of all 4 lines of the ERF at the daily ELVs.*							

Table 67: Impact at Ecological Sites - Permitted Facility - % of Critical Level

ID	Site	Oxides of nitrogen (% CL)		Sulphur dioxide (% CL)	Hydrogen fluoride (% CL)		Ammonia (% CL)
		Annual mean	Daily mean	Annual mean	Weekly mean	Daily mean	Annual mean
Critical level (µg/m^3)		**30**	**200**	**20**	**0.5**	**5**	**3**
European and UK designated sites							
E1	Mersey Estuary	**1.67%**	4.77%	0.56%	4.39%	1.06%	**1.39%**
Local nature sites							
E2	Pickering's Pasture	1.60%	3.62%	0.53%	2.65%	0.80%	1.33%
E3	Runcorn Hill	1.56%	2.17%	0.52%	2.14%	0.48%	1.30%
E4	Frodsham And Helsby And Ince Marshes	0.90%	2.20%	0.30%	1.45%	0.49%	0.75%
E5	Upper Mersey Estuary Intertidal Areas and Mudflats	0.85%	3.38%	0.28%	3.44%	0.75%	0.71%
E6	Upper Mersey Estuary	0.93%	1.92%	0.31%	1.22%	0.43%	0.77%
Note: *Assumes continuous operation of all 4 lines of the ERF at the daily ELVs.*							

Table 68: Impact at Ecological Sites - Proposed Facility - µg/m³

ID	Site	Oxides of nitrogen (µg/m³)		Sulphur dioxide (µg/m³)	Hydrogen fluoride (µg/m³)		Ammonia (µg/m³)
		Annual mean	Daily mean	Annual mean	Weekly mean	Daily mean	Annual mean
European and UK designated sites							
E1	Mersey Estuary	1.21	22.37	0.27	0.04	0.12	0.10
Local nature sites							
E2	Pickering's Pasture	0.92	10.20	0.20	0.02	0.06	0.08
E3	Runcorn Hill	1.01	9.63	0.22	0.02	0.05	0.08
E4	Frodsham And Helsby And Ince Marshes	0.51	6.62	0.11	0.01	0.04	0.04
E5	Upper Mersey Estuary Intertidal Areas and Mudflats	0.50	10.90	0.11	0.03	0.06	0.04
E6	Upper Mersey Estuary	0.54	5.84	0.12	0.01	0.03	0.04

Note:

Assumes continuous operation of all 4 lines of the ERF at the daily ELVs and emitting via the CC facility.

Table 69: Impact at Ecological Sites - Proposed Facility - % of Critical Level

ID	Site	Oxides of nitrogen (% CL)		Sulphur dioxide (% CL)	Hydrogen fluoride (% CL)		Ammonia (% CL)
		Annual mean	Daily mean	Annual mean	Weekly mean	Daily mean	Annual mean
Critical level (µg/m^3)		**30**	**200**	**20**	**0.5**	**5**	**3**
European and UK designated sites							
E1	Mersey Estuary	**4.04%**	**11.18%**	**1.35%**	8.84%	2.48%	**3.37%**
Local nature sites							
E2	Pickering’s Pasture	3.05%	5.10%	1.02%	4.24%	1.13%	2.54%
E3	Runcorn Hill	3.37%	4.81%	1.12%	4.49%	1.07%	2.81%
E4	Frodsham And Helsby And Ince Marshes	1.70%	3.31%	0.57%	2.66%	0.74%	1.42%
E5	Upper Mersey Estuary Intertidal Areas and Mudflats	1.68%	5.45%	0.56%	5.50%	1.21%	1.40%
E6	Upper Mersey Estuary	1.79%	2.92%	0.60%	2.25%	0.65%	1.49%

Note:

Assumes continuous operation of all 4 lines of the ERF at the daily ELVs and emitting via the CC facility.

Table 70: Impact at Ecological Sites - Change in Impact - µg/m³

ID	Site	Oxides of nitrogen (µg/m³)		Sulphur dioxide (µg/m³)	Hydrogen fluoride (µg/m³)		Ammonia (µg/m³)
		Annual mean	Daily mean	Annual mean	Weekly mean	Daily mean	Annual mean
European and UK designated sites							
E1	Mersey Estuary	0.71	12.83	0.16	0.02	0.07	0.06
Local nature sites							
E2	Pickering's Pasture	0.44	2.96	0.10	0.01	0.02	0.04
E3	Runcorn Hill	0.54	5.28	0.12	0.01	0.03	0.05
E4	Frodsham And Helsby And Ince Marshes	0.24	2.22	0.05	0.01	0.01	0.02
E5	Upper Mersey Estuary Intertidal Areas and Mudflats	0.25	4.15	0.06	0.01	0.02	0.02
E6	Upper Mersey Estuary	0.26	2.00	0.06	0.01	0.01	0.02

Table 71: Impact at Ecological Sites - Change in Impact - % of Critical Level

ID	Site	Oxides of nitrogen (% CL)		Sulphur dioxide (% CL)	Hydrogen fluoride (% CL)		Ammonia (% CL)
		Annual mean	Daily mean	Annual mean	Weekly mean	Daily mean	Annual mean
Critical level (µg/m^3)		**30**	**200**	**20**	**0.5**	**5**	**3**
European and UK designated sites							
E1	Mersey Estuary	**2.37%**	6.42%	0.79%	4.45%	1.43%	**1.97%**
Local nature sites							
E2	Pickering's Pasture	1.45%	1.48%	0.48%	1.58%	0.33%	1.21%
E3	Runcorn Hill	1.82%	2.64%	0.61%	2.35%	0.59%	1.51%
E4	Frodsham And Helsby And Ince Marshes	0.79%	1.11%	0.26%	1.21%	0.25%	0.66%
E5	Upper Mersey Estuary Intertidal Areas and Mudflats	0.84%	2.07%	0.28%	2.05%	0.46%	0.70%
E6	Upper Mersey Estuary	0.87%	1.00%	0.29%	1.03%	0.22%	0.72%

Table 72: Annual Mean PC used for Deposition Analysis - Permitted Facility

ID	**Site**	**Annual mean PC (ng/m³)**			
		Nitrogen dioxide	**Sulphur dioxide**	**Hydrogen chloride**	**Ammonia**
E1	Mersey Estuary – max at saltmarsh	183.7	58.3	11.7	21.9
E1	Mersey Estuary – max at grazing marsh	158.9	50.4	10.1	18.9
E2	Pickering's Pasture	336.2	106.7	21.3	40.0
E3	Runcorn Hill	327.3	103.9	20.8	39.0
E4	Frodsham And Helsby And Ince Marshes	189.9	60.3	12.1	22.6
E5	Upper Mersey Estuary Intertidal Areas and Mudflats	178.0	56.5	11.3	21.2
E6	Upper Mersey Estuary	194.3	61.7	12.3	23.1

Note:

Assumes continuous operation of all 4 lines of the ERF at the daily ELVs.

Table 73: Annual Mean PC used for Deposition Analysis - Proposed Facility

ID	**Site**	**Annual mean PC (ng/m^3)**						
		Nitrogen dioxide	**Sulphur dioxide**	**Hydrogen chloride**	**Ammonia**	**MEA**	**DEA**	**DMA**
E1	Mersey Estuary – max at saltmarsh	474.6	150.7	30.1	56.5	37.7	0.94	0.94
E1	Mersey Estuary – max at grazing marsh	300.3	95.3	19.1	35.7	23.8	0.60	0.60
E2	Pickering's Pasture	641.0	203.5	40.7	76.3	50.9	1.27	1.27
E3	Runcorn Hill	708.5	224.9	45.0	84.3	56.2	1.41	1.41
E4	Frodsham And Helsby And Ince Marshes	356.8	113.3	22.7	42.5	28.3	0.71	0.71
E5	Upper Mersey Estuary Intertidal Areas and Mudflats	353.4	112.2	22.4	42.1	28.0	0.70	0.70
E6	Upper Mersey Estuary	376.1	119.4	23.9	44.8	29.9	0.75	0.75

Note:

Assumes continuous operation of all 4 lines of the ERF at the daily ELVs and emitting via the CC facility.

Table 74: Deposition Calculation - Permitted Facility

ID	**Site**	**Deposition (kg/ha/yr)**				**Total N Deposition (kgN/ha/yr)**	**Acid Deposition (keq/ha/yr)**	
		Nitrogen dioxide	**Sulphur dioxide**	**Hydrogen chloride**	**Ammonia**		**N**	**S**
E1	Mersey Estuary – max at saltmarsh	0.03	0.11	0.18	0.11	0.14	0.010	0.012
E1	Mersey Estuary – max at grazing marsh	0.02	0.10	0.15	0.10	0.12	0.009	0.010
E2	Pickering's Pasture	0.05	0.20	0.33	0.21	0.26	0.018	0.022
E3	Runcorn Hill - grassland	0.05	0.20	0.32	0.20	0.25	0.018	0.021
E3	Runcorn Hill - woodland	0.09	0.39	0.76	0.30	0.40	0.028	0.046
E4	Frodsham And Helsby And Ince Marshes	0.03	0.11	0.18	0.12	0.14	0.010	0.012
E5	Upper Mersey Estuary Intertidal Areas and Mudflats	0.03	0.11	0.17	0.11	0.14	0.010	0.012
E6	Upper Mersey Estuary	0.03	0.12	0.19	0.12	0.15	0.011	0.013

Notes:

Assumes continuous operation of all 4 lines of the ERF at the daily ELVs.

All deposition calculated using the grassland deposition velocities except where stated.

Table 75: Deposition Calculation - Proposed Facility

ID	Site	Deposition (kg/ha/yr)							Total N Deposition (kgN/ha/yr)	Acid Deposition (keq/ha/yr)	
		Nitrogen dioxide	Sulphur dioxide	Hydrogen chloride	Ammonia	MEA	DEA	DMA		N	S
E1	Mersey Estuary – max at saltmarsh	0.07	0.29	0.46	0.29	0.05	0.001	0.002	0.42	0.030	0.031
E1	Mersey Estuary – max at grazing marsh	0.04	0.18	0.29	0.19	0.03	0.000	0.001	0.26	0.019	0.020
E2	Pickering’s Pasture	0.09	0.39	0.62	0.40	0.07	0.001	0.002	0.57	0.040	0.042
E3	Runcorn Hill	0.10	0.43	0.69	0.44	0.08	0.001	0.003	0.63	0.045	0.046
E3	Runcorn Hill - woodland	0.20	0.85	1.66	0.66	0.12	0.002	0.004	0.99	0.071	0.100
E4	Frodsham And Helsby And Ince Marshes	0.05	0.21	0.35	0.22	0.04	0.001	0.001	0.31	0.022	0.023
E5	Upper Mersey Estuary Intertidal Areas and Mudflats	0.05	0.21	0.34	0.22	0.04	0.001	0.001	0.27	0.019	0.023
E6	Upper Mersey Estuary	0.05	0.23	0.37	0.23	0.04	0.001	0.001	0.29	0.020	0.024

Note:

Assumes continuous operation of all 4 lines of the ERF at the daily ELVs and emitting via the CC facility.

All deposition calculated using the grassland deposition velocities except where stated.

Table 76: Nitrogen Deposition - Permitted Facility

ID	Site	NCL Class	Lower CL (kgN/ha/yr)	Upper CL (kgN/ha/yr)	Background (kgN/ha/yr)	Process Contribution			Predicted Environmental Concentration		
						kgN/ha/yr	% of Lower CL	% of Upper CL	kgN/ha/yr	% of Lower CL	% of Upper CL
European and UK designated sites											
E1	Mersey Estuary	Atlantic upper-mid & mid-low salt marshes	10	20	24.28	0.14	**1.40%**	0.70%	24.4	**244.2%**	**122.1%**
		Coastal and floodplain grazing marsh	10	20	24.28	0.12	**1.21%**	0.61%	24.4	**244.0%**	**122.0%**
Local nature sites											
E2	Pickering's Pasture	Low and medium altitude hay meadows	10	20	21.58	0.26	2.56%	1.28%	21.8	218.4%	109.2%
E3	Runcorn Hill	Dry heaths	5	15	22.57	0.25	4.99%	1.66%	22.8	456.4%	152.1%
		Broadleaved deciduous woodland	10	15	38.17	0.40	3.98%	2.65%	38.6	385.7%	257.1%
E4	Frodsham And Helsby And Ince Marshes	Semi-dry Perennial calcareous grassland (basic meadow steppe)	10	20	22.31	0.14	1.45%	0.72%	22.5	224.5%	112.3%
E5	Upper Mersey Estuary Intertidal Areas and Mudflats	Atlantic upper-mid & mid-low salt marshes	10	20	24.28	0.14	1.36%	0.68%	24.4	244.1%	122.1%
E6	Upper Mersey Estuary	Atlantic upper-mid & mid-low salt marshes	10	20	24.28	0.15	1.48%	0.74%	24.4	244.3%	122.1%

Table 77: Nitrogen Deposition - Proposed Facility

ID	Site	NCL Class	Lower CL (kgN/ha/yr)	Upper CL (kgN/ha/yr)	Background (kgN/ha/yr)	Process Contribution			Predicted Environmental Concentration		
						kgN/ha/yr	% of Lower CL	% of Upper CL	kgN/ha/yr	% of Lower CL	% of Upper CL
European and UK designated sites											
E1	Mersey Estuary	Atlantic upper-mid & mid-low salt marshes	10	20	24.28	0.42	**4.19%**	**2.09%**	**24.7**	**247.0%**	**123.5%**
		Coastal and floodplain grazing marsh	10	20	24.28	0.26	**2.65%**	**1.32%**	**24.5**	**245.4%**	**122.7%**
Local nature sites											
E2	Pickering's Pasture	Low and medium altitude hay meadows	10	20	21.58	0.57	5.66%	2.83%	22.1	221.5%	110.7%
E3	Runcorn Hill	Dry heaths	5	15	22.57	0.63	12.50%	4.17%	23.2	463.9%	154.6%
		Broadleaved deciduous woodland	10	15	38.17	0.99	9.89%	6.59%	39.2	391.6%	261.1%
E4	Frodsham And Helsby And Ince Marshes	Semi-dry Perennial calcareous grassland (basic meadow steppe)	10	20	22.31	0.31	3.15%	1.57%	22.6	226.2%	113.1%
E5	Upper Mersey Estuary Intertidal Areas and Mudflats	Atlantic upper-mid & mid-low salt marshes	10	20	24.28	0.31	3.12%	1.56%	24.6	245.9%	123.0%
E6	Upper Mersey Estuary	Atlantic upper-mid & mid-low salt marshes	10	20	24.28	0.33	3.32%	1.66%	24.6	246.1%	123.1%

Table 78: Nitrogen Deposition - Change in Impact

ID	Site	NCL Class	Lower CL (kgN/ha/yr)	Upper CL (kgN/ha/yr)	Background (kgN/ha/yr)	Change in Process Contribution			Predicted Environmental Concentration		
						kgN/ha/yr	% of Lower CL	% of Upper CL	kgN/ha/yr	% of Lower CL	% of Upper CL
European and UK designated sites											
E1	Mersey Estuary	Atlantic upper-mid & mid-low salt marshes	10	20	24.28	0.28	**2.79%**	**1.39%**	24.7	**247.0%**	**123.5%**
		Coastal and floodplain grazing marsh	10	20	24.28	0.14	**1.44%**	0.72%	24.5	**245.4%**	**122.7%**
Local nature sites											
E2	Pickering's Pasture	Low and medium altitude hay meadows	10	20	21.58	0.31	3.09%	1.55%	22.1	221.5%	110.7%
E3	Runcorn Hill	Dry heaths	5	15	22.57	0.38	7.51%	2.50%	23.2	463.9%	154.6%
		Broadleaved deciduous woodland	10	15	38.17	0.59	5.91%	3.94%	39.2	391.6%	261.1%
E4	Frodsham And Helsby And Ince Marshes	Semi-dry Perennial calcareous grassland (basic meadow steppe)	10	20	22.31	0.17	1.70%	0.85%	22.6	226.2%	113.1%
E5	Upper Mersey Estuary Intertidal Areas and Mudflats	Atlantic upper-mid & mid-low salt marshes	10	20	24.28	0.18	1.76%	0.88%	24.6	245.9%	123.0%
E6	Upper Mersey Estuary	Atlantic upper-mid & mid-low salt marshes	10	20	24.28	0.18	1.84%	0.92%	24.6	246.1%	123.1%

Table 79: Acid Deposition - Permitted Facility

ID	Site	Acidity class	CLmaxN	Background	Process Contribution			Predicted Environmental Concentration	
				N+S (keq/ha/yr)	N (keq/ha/yr)	S (keq/ha/yr)	% of CL	Keq/ha/yr	% of CL
European and UK designated sites									
E1	Mersey Estuary	No designated features sensitive to the effect of acid deposition	-	-	-	-	-	-	-
Local nature sites									
E2	Pickering's Pasture	Low and medium altitude hay meadows	5.071	1.72	0.018	0.022	2.04%	1.76	34.7%
E3	Runcorn Hill	Dry heaths	1.342	1.78	0.018	0.021	2.91%	1.82	135.6%
		Broadleaved deciduous woodland	1.15	2.94	0.028	0.046	6.48%	3.01	262.1%
E4	Frodsham And Helsby And Ince Marshes	Semi-dry Perennial calcareous grassland (basic meadow steppe)	5.071	1.83	0.010	0.012	1.15%	1.85	36.5%
E5	Upper Mersey Estuary Intertidal Areas and Mudflats	Saltmarsh – not sensitive to acid deposition	-	-	-	-	-	-	-
E6	Upper Mersey Estuary	Saltmarsh – not sensitive to acid deposition	-	-	-	-	-	-	-

Table 80: Acid Deposition - Proposed Facility

ID	Site	Acidity class	CLmaxN	Background	Process Contribution			Predicted Environmental Concentration	
				N+S (keq/ha/yr)	N (keq/ha/yr)	S (keq/ha/yr)	% of CL	Keq/ha/yr	% of CL
European and UK designated sites									
E1	Mersey Estuary	No designated features sensitive to the effect of acid deposition	-	-	-	-	-	-	-
Local nature sites									
E2	Pickering's Pasture	Low and medium altitude hay meadows	5.071	1.72	0.040	0.042	3.89%	1.80	35.5%
E3	Runcorn Hill	Dry heaths	1.342	1.78	0.045	0.046	6.76%	1.87	139.4%
		Broadleaved deciduous woodland	1.15	2.94	0.071	0.100	14.82%	3.11	270.5%
E4	Frodsham And Helsby And Ince Marshes	Semi-dry Perennial calcareous grassland (basic meadow steppe)	5.071	1.83	0.022	0.023	2.16%	1.88	37.0%
E5	Upper Mersey Estuary Intertidal Areas and Mudflats	Saltmarsh – not sensitive to acid deposition	-	-	-	-	-	-	-
E6	Upper Mersey Estuary	Saltmarsh – not sensitive to acid deposition	-	-	-	-	-	-	-

E Amine Chemistry Modelling

E.1 Introduction

The proposed CC facility would use an amine-based solution to capture carbon dioxide from the flue gas. Amines are nitrogen-based compounds which are structurally similar to ammonia (NH_3), with one or more of the hydrogen atoms substituted by a substituent which is typically a functional group such as a methyl or alcohol group. Amines are categorised as primary, secondary or tertiary, depending on whether one, two, or three of the hydrogen atoms are substituted.

Amines are highly effective at absorbing carbon dioxide, which is the process that takes place in the absorber column. The 'rich' amine, combined with the carbon dioxide, is transported to the stripper column where the mixture is heated to release the carbon dioxide to be taken for storage, while the 'lean' amine is returned to the absorber column to repeat the process. Full details of the process are provided in the supporting information submitted with the application to vary the EP.

Amines can react with oxides of nitrogen either in the absorber column or the atmosphere. The reaction with nitric oxide (NO) forms nitrosamines, and the reaction with nitrogen dioxide (NO_2) forms nitramines. The most toxic nitrosamine, NDMA, is categorised by the International Agency for Research on Cancer as a group 2A carcinogen, meaning it is "probably carcinogenic to humans". NDMA is a known carcinogen in animals. Other nitrosamines and nitramines are also toxic and/or carcinogenic, albeit to a lesser degree or with greater uncertainty than is known for NDMA. NDMA is the only nitrosamine or nitramine for which an AQAL has been set.

As shown in Table 1 this assessment has applied the EA's EAL of 0.2 ng/m^3 for NDMA as the AQAL for total nitrosamines, and the NIPH's value of 0.3 ng/m^3, nominally for NDMA, as the AQAL for total nitrosamines and nitramines. This is considered appropriate as the supporting documentation published by the NIPH[16] explicitly recommends that the total amount of nitrosamines and nitramines should not exceed 0.3 ng/m^3.

Although the process will be designed to minimise emissions of amines, nitrosamines, and nitramines, there will be small quantities released. An MEA solvent is to be used in the CC facility and as such it has been assumed that all emissions of the primary amine are of MEA. It is also likely that much smaller quantities of secondary amines would be released. For the purpose of this assessment it has been assumed to be equally proportioned between DMA and DEA. DMA is the precursor to NDMA, which is the only nitrosamine for which there is an AQAL.

E.2 Amine chemistry reaction scheme

ADMS 6 includes an amine chemistry reaction scheme which models the chemical reactions which occur once amines, nitrosamines and nitramines are released into the atmosphere. The reaction scheme does not account for reactions that occur prior to release, which are accounted for in the release rate of direct emissions of nitrosamines and nitramines.

The amine chemistry reaction scheme accounts for reactions that occur in the atmosphere that cause amines and amine degradation products to react and form different compounds. The first reaction that occurs is between the amine and the hydroxyl radical (OH), labelled k1. The OH radical attacks the amine at either an N-H bond, which results in the formation of an amino radical, or at a C-H bond, forming other compounds which are not significantly harmful to human health and are therefore not relevant to this assessment. The ratio of the attack on the N-H bond and C-H bond is

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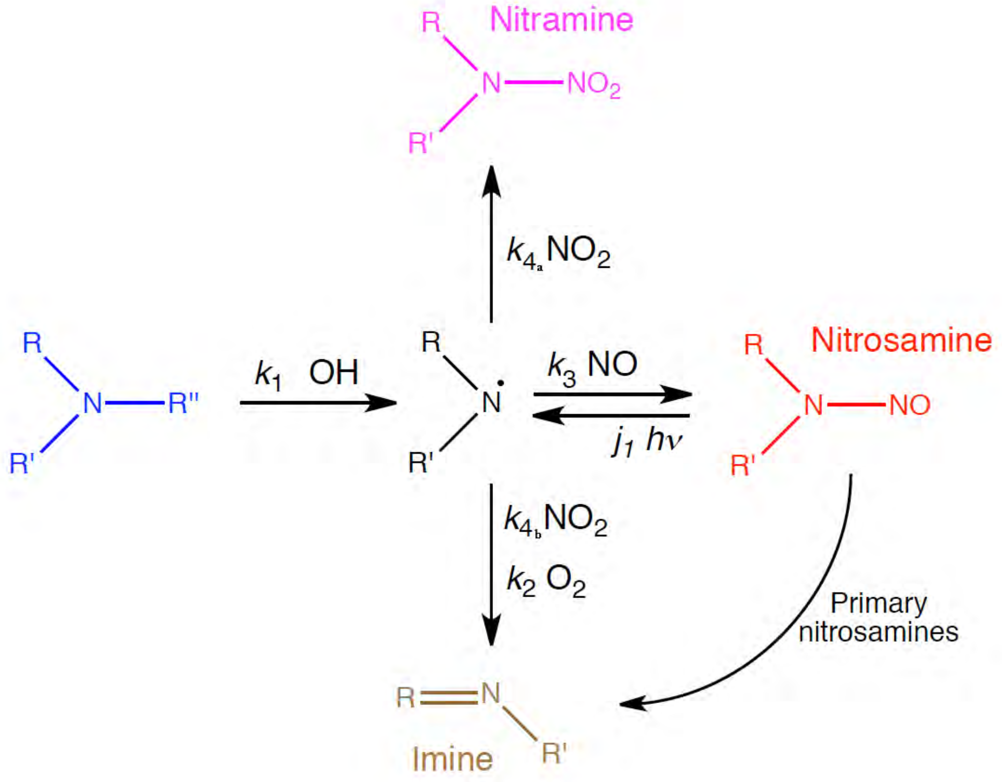
[16] NIPH, Health effects of amines and derivatives associated with CO_2 capture, 2011

called the branching ratio. Similar reactions occur with nitrate ions (NO_3), but these reactions are much slower than the OH radical reactions[17] and are not considered further in this assessment. The amino radical can then react with nitric oxide (NO) to form a nitrosamine (k3), nitrogen dioxide (NO_2) to form a nitramine (k4a) or an imine (k4b), or oxygen (O_2) to form an imine (k2). Nitrosamines do not have a long atmospheric lifetime and undergo photolysis (i.e., are broken down to the amino radical by sunlight). Furthermore, nitrosamines formed from primary amines are unstable and rapidly change structure to form imines within around 1 second of formation. Imines are not significantly harmful to human health and therefore are not relevant to this assessment. A schematic of the reactions included in the scheme is shown in Figure 23.

Figure 23: Reactions included in ADMS Chemistry Reaction Scheme



Source: Adapted from Nielsen et al (2012)[18]

The ADMS amine chemistry module requires the user to input values for the kinetic parameters (i.e. reaction rates) for these reactions, along with the branching ratio for the k1 reaction, the ratio between the photolysis rate (J) of nitrosamine compared to the photolysis rate of nitrogen dioxide, and a constant to determine the OH radical concentration, which is based on estimated annual average background OH, ozone and NOx concentrations, and incoming solar radiation.

A number of studies have been published in literature which attempt to determine the values for these parameters, either theoretically or experimentally. For some parameters there is broad agreement, while for others there is a wide range of published values. In September 2022 the CCSA published an updated position paper which was most recently updated in January 2023 (referenced in section 5.8.1), co-authored by Claus Nielsen who is a recognised authority on the atmospheric chemistry of amines, which "seeks to provide one consolidated set of amines chemistry data for

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[17] CERC, Atmospheric Chemistry Modelling Executive Summary, May 2012

[18] Nielsen et al, Atmospheric Degradation of Amines – Summary report from atmospheric chemistry studies of amines, nitrosamines, nitramines and amides, February 2012

use in modelling of amine emissions". The values presented in the CCSA paper and reproduced in Table 33 in section 5.8.1 have been used in the main model runs, with the exception of the values for DEA as these are not provided in the CCSA position paper. The values for DEA have been provided by CERC via direct email correspondence. The references for each value are given in Table 81. Where values specific to DEA are unknown, the values have been assumed to be the same as for DMA.

The ADMS amine chemistry module requires the user to input the amine, nitrosamine and nitramine species modelled. As noted above, the nitrosamine formed from a primary amine rapidly forms an imine. Therefore, the direct emissions of nitrosamines have been split equally between NDMA (formed from DMA) and NDELA (formed from DEA). The direct emissions of nitramines have been apportioned to those formed from MEA, DMA, and DEA in the same proportions as the emissions of their parent amines.

The amine chemistry module treats these direct releases of nitrosamines the same as those formed in atmospheric chemical reactions, so that the nitrosamines undergo photolysis and the resultant amino radical can react with atmospheric NO, NO_2 and O_2. A sensitivity analysis has been undertaken assuming that the nitrosamines do not undergo chemical reactions after release, and a further sensitivity analysis undertaken with no direct emissions of nitrosamines and nitramines, to determine the quantity formed indirectly via atmospheric reactions compared to those directly emitted from the stack (refer to section E.3).

The amine chemistry scheme allows the user to select the option 'low concentration dilution and entrainment' which improves the way the model accounts for dilution of pollutant species and the entrainment of background pollutants into the plume. CERC strongly recommends that this option is selected when running the amine chemistry module, so this option has been selected.

The amine chemistry scheme also allows the user to model aqueous partitioning of amines, nitrosamines, and nitramines. As many amines and their degradation products are soluble, they will dissolve in any liquid water contained within the plume. This reduces their concentration in ambient air, and their availability for atmospheric reactions. A sensitivity analysis has been run to determine the effect of including aqueous partitioning (refer to section E.3).

E.3 Sensitivity analysis

A series of sensitivity analyses have been undertaken the kinetic parameters and other inputs to the amine chemistry modules, using a range of values from available published literature. The values used and their sources are presented in Table 81. Where it has not been possible to determine alterative values that are higher or lower than the mid-range value, the relevant cells have been left blank.

Table 81: Amine Chemistry Module Inputs

Parameter	Units	Value	MEA	DEA	DMA
k1 - Amine/OH reaction rate constant	ppb^{-1}s^{-1}	Low	0.775$^{(B)}$	2.318$^{(E)}$	1.623$^{(D)}$
		Mid	1.900	2.525$^{(F)}$	1.625
		High	2.328$^{(C)}$	-	1.775$^{(D)}$
k2 - Amino radical/O2 reaction rate constant	ppb^{-1}s^{-1}	Low	2.39x10$^{-9(B)}$	-	2.39x10$^{-9(B)}$
		Mid	3.10x10^{-9}	4.45x10$^{-10(G)}$	3.10x10^{-9}
		High	-	-	-
k3 - Rate constant for formation of nitrosamine	ppb^{-1}s^{-1}	Low	1.41x10$^{-3(C)}$	-	-
		Mid	2.13x10^{-3}	1.78x10$^{-2(G)}$	2.13x10^{-3}
		High	4.78x10$^{-3(B)}$	-	4.78x10$^{-3(B)}$
k4a - Rate constant for formation of nitramine	ppb^{-1}s^{-1}	Low	2.10x10$^{-4(C)}$	-	-
		Mid	7.95x10$^{-3(A)}$	7.95x10^{-3}	7.95x10^{-3}
		High	-	-	-
k4 - Amino radical/NO2 reaction rate constant	ppb^{-1}s^{-1}	Low	3.14x10$^{-4(C)}$	8.20x10$^{-3(C)}$	8.20x10$^{-3(C)}$
		Mid	9.70x10^{-3}	9.70x10^{-3}	9.70x10^{-3}
		High	-	-	-
k1 branching ratio	Unitless	Low	-	0.37$^{(C)}$	0.37$^{(C)}$
		Mid	0.08	0.41	0.41
		High	0.38$^{(H)}$	0.42$^{(B)}$	0.42$^{(B)}$
Ratio of J(nitrosamine) to J(NO_2)	Unitless	Low	-	0.32$^{(B)}$	0.32$^{(B)}$
		Mid	-	0.34	0.34
		High	-	1.24$^{(C)}$	1.24$^{(C)}$

<table>
<tr><th>Parameter</th><th>Units</th><th>Value</th><th>MEA</th><th>DEA</th><th>DMA</th></tr>
<tr><td colspan="6">References:
A – CCSA, Carbon Capture Chemistry Parameters, N-Amines Chemistry, January 2023. Refer to CCSA paper for original source of each value. All ‘mid’ values taken from CCSA paper.
B – Nielsen et al, Atmospheric Degradation of Amines Summary Report, February 2012, as used by CERC in “Atmospheric Chemistry Modelling Executive Summary”. May 2012.
C – Manzoor et al, Atmospheric chemistry modelling of amine emissions from post combustion CO2 capture technology, 2014.
D – Lee & Wexler, Atmospheric amines - Part III: Photochemistry and toxicity, 2013.
E – Carter, Reactivity Estimates for Selected Consumer Product Compounds, 2008.
F – da Silva et al, Protocol for evaluation of solvents – process and atmospheric chemistry, 2010.
G – Liu et al, Mechanism and predictive model development of reaction rate constants for N-center radicals with O_2, 2019.
H – Onel et al, Branching ratios for the reactions of OH with ethanol amines used in carbon capture and the potential impact on carcinogen formation in the emission plume from a carbon capture plant, 2015.</td></tr>
</table>

The effect of varying each of the parameters on concentrations of nitramines and nitrosamines is summarised in Table 82.

Table 82: Effect of Increasing Amine Chemistry Parameters

Parameter	**Effect of Increase on Nitrosamines**	**Effect of Increase on Nitramines**
k1 amine/OH reaction rate constant	Increase – faster reaction rate results in more amino radical, the precursor to both nitrosamines and nitramines	
k2 amino radical/O_2 reaction rate constant	Decrease – this reaction forms an imine, which is a sink for the amino radical	
k3 rate constant for formation of nitrosamine	Increase	Decrease – less amino radical available to form nitramine
k4a rate constant for formation of nitramine	Decrease – less amino radical available to form nitrosamine	Increase.
k4 Amino radical/NO_2 reaction rate constant	Decrease – less amino radical available to form nitrosamine	Increase – some reactions from this path form nitramine (via k4a)
Branching ratio for amine/OH reaction	Increase – higher values result in more amino radical formation	
Ratio of J(nitrosamine)to J(NO_2)	Decrease – as this increases the rate of photolysis of the nitrosamine back to the amino radical	Increase – more radical available to form nitramine

Based on the relationships detailed in Table 82 the model has been run with the parameters that produce the maximum and minimum concentrations of nitramines and nitrosamines. The results are presented in Table 85.

The sensitivity of the model results to other parameters used in the amine chemistry scheme has been tested. The model is sensitive to the total NOx emission concentration and the percentage of the NOx release which is NO_2, as these values affect the amount of NO and NO_2 available to react with the amino radical, as well as the constant 'c' used to determine the concentration of the OH radical. This constant is directly proportional to the annual mean OH concentration. Advice from CERC and published literature[19] is that OH concentrations are typically $1x10^6$ molecules/cm³ at UK latitudes, but values are up to 3 times higher at equatorial latitudes. Therefore, a 2x multiplier has been applied to the OH radical constant as a reasonable assumption for the sensitivity analysis.

The parameters tested and their modelled values are presented in Table 83.

Table 83: Additional Sensitivity Analysis Parameters

Parameter	Units	Minimum	Main Runs	Maximum
NOx emission concentration	mg/Nm³	50(1)	180	**180**
% of primary NOx as NO_2	%	1.81%	1.81%	**10%**
Constant 'c' for OH concentration	s	0.00016	0.00016	**0.00032**

Note:

(1) NOx concentration of 50 mg/Nm³ represents use of selective catalytic reduction (SCR)

The proportion of nitrosamines and nitramines formed from atmospheric chemical reactions (indirect emissions) has also been compared to those emitted from the stack (direct emissions). A further sensitivity analysis has been undertaken assuming that directly emitted nitrosamines and nitramines do not undergo any chemical reactions following release.

Finally, a sensitivity analysis has been run using the aqueous partitioning scheme included in the ADMS 6 amine chemistry module. As amines, nitrosamines and nitramines are soluble in water, when there is liquid water in the atmosphere or the plume, some of these substances dissolve, decreasing the concentration of pollutants in the gaseous phase and reducing their availability for gaseous phase reactions. This option requires the user to input Henry's Law constants for each amine modelled and their resultant nitrosamine and nitramine species. The values used are presented in Table 84.

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[19] Stevenson et al, Trends in global tropospheric hydroxyl radical and methane lifetime since 1850 from AerChemMIP, 2020

Table 84: Henry's Law Constants Used in Aqueous Partitioning Scheme

Parent Amine Species	**Henry's Law Solubility Constant (mol/L atm)**		
	Amine	**Nitrosamine**	**Nitramine**
MEA	6.08 x 10^{6}(1)	-	6.08 x 10^{7}(5)
DEA	2.53 x 10^{7}(2)	2.03 x 10^{8}(2)	2.03 x 10^{8}(5)
DMA	56.7(3)	618(4)	618(5)

Notes:

(1) Bone et al., Solvent effects on equilibria of addition of nucleophiles to acetaldehyde and the hydrophilic character of diols, 1983

(2) HSDB: Hazardous Substances Data Bank, TOXicology data NETwork (TOXNET), National Library of Medicine (US), 2015

(3) Christie & Crisp, Activity coefficients on the n-primary, secondary and tertiary aliphatic amines in aqueous solution, 1967

(4) Klein, Calculations and measurements on the volatility of N-nitrosamines and their aqueous solutions, 1982.

(5)No published values available for nitramines. Tan et al., Experimental and Theoretical Study of the OH-Initiated Degradation of Piperazine under Simulated Atmospheric Conditions, 2020, states "There are no data for the Henry's law solubility constants for nitramines, but to a first approximation, they are expected to be the same as those of the nitrosamines." Nielsen et al., Atmospheric chemistry and environmental impact of the use of amines in carbon capture and storage (CCS), 2012, states "In general, the Henry's Law constants for nitrosamines are an order of magnitude smaller than that of the corresponding amine".

Therefore, where there is a published value for a certain nitrosamine, the same value has been assumed for the corresponding nitramine. As the Nielsen et al. reference reports the Henry's Law constants in reciprocal units to those required as an input for ADMS, where there are no values available for the nitrosamine or nitramine, these have been assumed to be an order of magnitude greater *than for the corresponding amine.*

The sensitivity analysis runs have been run for a single year (2022) and the maximum results for nitrosamine and nitramine concentrations at the point of maximum impact are presented in Table 85. The maximum amine, nitrosamine and nitramine concentrations and the percentage change from the main model run has been presented.

Table 85: Sensitivity Analysis Results – Amine Chemistry Parameters

Scenario	**Annual mean concentration**							
	Max amines		**Max nitrosamines**		**Max nitramines**		**Max nitrosamines + nitramines**	
	ng/m³	**As % of main run**	**pg/m³**	**As % of main run**	**pg/m³**	**As % of main run**	**pg/m³**	**As % of main run**
Main model run	64.14	-	2.41	-	6.20	-	7.93	-
Minimum nitramine formation	64.24	100.2%	2.31	96.1%	2.35	37.9%	4.23	53.4%
Maximum nitramine formation	64.11	99.9%	2.08	86.4%	38.06	613.7%	39.23	494.7%
Minimum nitrosamine formation	64.24	100.2%	1.74	72.4%	2.56	41.3%	3.72	46.9%
Maximum nitrosamine formation	64.11	99.9%	2.79	115.9%	37.77	609.1%	39.90	503.1%
NOx emission at 50 mg/Nm³	64.09	99.9%	2.29	94.9%	6.86	110.6%	8.54	107.6%
Primary NO_2 = 10%	64.13	100.0%	2.39	99.4%	6.81	109.9%	8.63	108.9%
2x increase in OH conc.	63.97	99.7%	4.26	177.0%	11.89	191.7%	14.90	187.9%
Aqueous partitioning	54.91	85.6%	2.06	85.7%	5.63	90.7%	6.82	86.0%
No direct NS + NA emissions	64.14	100.0%	1.86	77.4%	5.91	95.3%	7.15	90.2%
No direct amine emissions (NS+NA only)	-	-	0.56	23.4%	0.63	10.1%	1.19	15.0%
No amine chemistry (direct emissions only)	64.28	100.2%	0.61	26.8%	0.61	9.9%	1.22	14.3%

The following conclusions can be drawn from these results:

- The concentration of amines is not sensitive to any of the parameters. This is because the large majority of the amine remains unreacted (by the time the plume reaches the point of maximum impact) in all scenarios.
- Varying the amine chemistry reaction parameters leads to a range of 72% - 116% of the main model result for nitrosamines and 41% - 614% of the main model result for nitramines. The nitramine results are considerably more sensitive because the majority are formed from MEA; there is a large range of parameters relating to nitramine formation from MEA (see Table 81).
- The concentrations of nitrosamines and nitramines are not highly sensitive to either the NOx emission concentration or the percentage of NOx emission that is primary NO_2.
- Increasing the OH concentration by a factor of 2 results in a near doubling of the concentrations of nitramines and nitrosamines.
- Including aqueous partitioning results in a decrease in concentrations of amines, nitrosamines and nitramines of 10 – 15%.
- When there are no direct emissions of nitrosamines and nitramines (i.e. they are all formed from atmospheric reactions) the concentrations are reduced by nearly a quarter for nitrosamines, but only around 5% for nitramines. Therefore, around 77% the nitrosamines and around 95% of the nitramines in the main model run are formed via atmospheric reactions.
- When there are no emissions of amines and amine chemistry is enabled the concentrations of nitrosamines are reduced by about 75% and nitramines by over 90%. When chemistry is not enabled the concentration of nitramines is almost unchanged, while the concentration of nitrosamines is slightly higher. This indicates that a portion of the directly-emitted nitrosamine would undergo photolysis.

The use of a 2x multiplier for the OH concentration constant would be overly conservative, as there is no evidence that OH concentrations are this high at UK latitudes, while changes to the NOx emission concentration and primary NO_2 are hypothetical scenarios. The main model scenario, in which there are direct emission of amines, nitrosamines and nitramines, and amine chemistry is enabled using the mid-range of chemistry parameters, is considered to be the most realistic scenario.

Under the worst-case scenario that the worst-case amine reaction parameters for the formation of nitrosamines are correct and the total concentration of nitrosamines and nitramines is ~500% of the value predicted in the main model run, the maximum concentration of nitrosamines and nitramines combined would be 40 pg/m^3, which is 20% of the AQAL of 0.2 ng/m^3 set for NDMA. As such, even under these-worst case assumptions, the PEC of total nitrosamines and nitramines would remain well below the AQAL and no significant effects would occur.

F EALs for DMA and DEA

Fichtner

Carbon Capture

Derivation of environmental assessment levels for dimethylamine (DMA)

1 Dimethylamine (CAS Number 124-40-3)

Dimethylamine (DMA) is a water-soluble, basic secondary aliphatic amine which produces an odour similar to that of ammonia and/or rotting fish (US EPA, 2008). DMA is a flammable gas and forms explosive mixtures with air in the range 2.8% to 14.4% volume in air (NIPH, 2011). DMA is present in many foods, including cabbage and fish, and is also formed endogenously from DMA precursors by bacteria in the gut. It is widely used in industry as a precursor and is a raw material in the production of agrichemicals and pharmaceuticals. DMA is rapidly biodegradable in the environment and has an estimated phototransformation half-life in air of about two hours (ECHA dossier).

2 Regulatory standards

- None

3 Recommended environmental assessment level (EAL) in air

- Long-term EAL – 0.0033 mg/m^3 as a 24-hour mean.
- Short-term EAL – none (constrained by compliance with long-term EAL).

4 Overview

There are a few authoritative reviews on the adverse effects from exposure to DMA (US EPA (2008), NIPH (2011) and the industry registration, evaluation, authorisation and restriction of chemicals (REACH) dossier). It is a strong respiratory, ocular and skin irritant, which induces adverse effects when inhaled or ingested.

5 Toxicokinetics

There is limited information available on the metabolism and disposition of DMA by humans. Pharmacokinetic studies indicate that DMA is absorbed from the gastrointestinal tract rapidly ($t_{1/2}$ = 8 min) and extensively (bioavailability = 82%) (US EPA, 2008). The industry REACH dossier indicates that systemic uptake of DMA can occur via inhalation or dermal routes, in addition to the oral route (ECHA dossier). Following uptake, it can be found in human saliva, gastric juices, blood, urine and faeces (Tricker et al., 1992). Investigations of workers in a factory processing DMA showed excretion of the substance in urine when workers were exposed to the amine in air (Bittersohl and Heberer, 1980).

In a study on the metabolism of DMA in mammals McNulty and Heck (1983) studied the disposition and metabolism of DMA in male rats following inhalation of ^{14}C-DMA in concentrations of either 10 or 175 ppm for six hours. 72 hours after the end of exposure, the disposition of recovered radioactivity was similar for each concentration of DMA. The vast majority of the DMA was excreted (predominately in urine) without being metabolised, whilst 7-8% of radioactivity was distributed around the body in internal organs and other tissues, including the nasal mucosa, olfactory mucosa, kidneys, liver and lungs. In vitro studies also carried out by McNulty and Heck (1983) showed that DMA is metabolised by microsomes from rat liver and nasal and tracheal mucosa.

6 Short- and long-term exposures

DMA is a strong irritant to the eyes, skin and mucous membranes (NIPH, 2011). Exposure to the vapour can also result in temporary hazy vision (glaucopsy) which has been reported for amine production workers on several occasions (Mellerio, 1966). Direct contact between DMA vapor or aqueous solutions and skin can cause concentration-dependant damage, particularly in the eyes. Several ocular adverse effects are induced when a 1% DMA solution is applied to the rabbit eye including photophobia, blepharospasm and conjunctivitis, whilst solutions of 5% DMA or more caused severe damage such as vascularisation and clouding of the cornea (MAK Value Documentation, 2012).

Repeated inhalation toxicity of DMA was investigated in F344 rats and B6C3F1 mice[1] who showed significant lesions in the nasal passages when repeatedly exposed to 175 ppm of DMA for six hours a day, five days a week for 12 months (Buckley, 1985). More extensive olfactory lesions were developed in the rats compared to mice, and even when exposed to a concentration of 10 ppm, the animals developed minor lesions. In an investigation of the lethal concentration of DMA, Steinhagen et al. (1982) observed ulceration, necrosis, tracheitis and emphysema, resulting in mortality with a lethal concentration 50 (LC_{50}) value of 4,540 ml/m^3 for rats which had inhaled DMA for six hours.

Darad et al. (1985) investigated the effects of repeated dose oral exposure of DMA on rats by administering 0.2% DMA through drinking water over nine months. The results indicate that DMA may induce free radical-mediated damage to the cellular and subcellular membranes, thus disturbing the protective function of the skin. Ingested DMA has been shown to cause a number of effects in rats, such as coordination disorders, severe irritation of mucous membranes and bleeding of stomach walls, resulting in death. An oral lower dose 50 (LD_{50}) for rats was found to be 689 mg/kg body weight (MAK Value Documentation, 2012).

Guinea pigs exposed to a 0.5 M solution of DMA through a patch test of Magnusson and Kligman produced positive allergenic reactions to the solution. However, no sensitisation of humans handling DMA has been observed to date (MAK Value Documentation, 2012).

Evidence for neurobehavioural effects in humans from DMA inhalation exposure has not been reported (US EPA, 2008). However, a study by Simenhoff et al. (1977) found a correlation between serum levels of DMA and two neurophysiological parameters in uremic dialysis patients: choice reaction time (CRT) and abnormal electroencephalograms (EEG), noting that uremic patients have elevated levels of DMA in the blood, cerebrospinal fluid and brain.

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[1] These are common inbred rats and hybrid strains of mice which are available commercially for use in toxicological studies.

There is very limited research on the reproductive and developmental toxicity of DMA. A study involving intraperitoneal injection of DMA, in doses of up to 137.7 mg/kg, into pregnant Swiss mice observed no toxic effects on dams of foetuses (Varma et al., 1990). However, in vitro experiments performed in the same study found that DMA causes a concentration-dependant reduction in embryo ribonucleic acid (RNA), deoxyribonucleic acid (DNA) and proteins.

6.1 Genotoxicity and carcinogenicity

Green (1978) found DMA to be a weak mutagen in the Ames test of mutagenicity with liver metabolic activation. However, other studies (e.g., Zeiger et al., 1987) have not been able to confirm this result and have concluded that DMA does not cause cytotoxic or genotoxic effects. DMA has not been found to be carcinogenic in rats or mice after exposure via inhalation for 24 months (ECHA dossier) and there has been no evidence to indicate carcinogenic effects in humans.

However, there is the potential for DMA to react with nitrosating agents in the body, to produce N-nitrosodimethylamine (NDMA), which is a potent carcinogen that reacts with DNA to form adducts (NIPH, 2011). This has been shown to occur in vitro, but to date no studies have shown that DMA is carcinogenic in vivo. Fay et al. (1997) investigated whether consuming frozen fish with very high DMA levels, with ingested nitrate, would result in elevated urinary adducts as a result of NDMA formation, but no genetic damage was found. NDMA is also mutagenic and clastogenic. The effects of NDMA and its associated EALs has been reported by the Environmental Agency.[2]

6.2 Pivotal studies

The US EPA (2008) summarised the Mitchell et al. (1982) 90-day inhalation toxicology study in F344 rats which was used as the basis for their derivation of acute exposure guidance levels (AEGL-1). In this study, 10 rats per sex per dose group (80 total) were exposed to DMA for six hours a day, five days a week, for 90 days at concentrations ranging from 0 to 100 ppm.

In the 10 ppm group, no treatment related effects were observed. A slightly lower weight gain was observed in the first two-week period in males and/or females at 30 ppm and 100 ppm, but over the total 13-weeks, weight gain for all groups was similar to that observed for the control groups.

After 13-weeks, all rats were necropsied. In three of the ten females exposed to 100 ppm, gross lesions of the liver red areas were observed with an increased incidence. This was not observed in any other group. Otherwise, no histopathological differences in tissue between the control and test groups were observed in microscopic analysis.

For males at 100 ppm and females at 30 ppm there was an increase in lung weight (approximately 20%). Females at 30 ppm and or 100 ppm also showed increased weight of heart, liver and kidneys (6-11%). The significance of this was unclear.

In a chronic inhalation study cited as the key source by the industry REACH dossier for DMA, male and female F344 rats and B6C3F1 mice were subjected to inhalation exposure of 0, 10, 50, or 175 ppm DMA for six hours a day, five days a week, for 12 months. Groups of 9-10 male and female rats and mice underwent necropsy after six and 12 months of exposure. Notably, no male mice were sacrificed at 12 months due to a high rate of premature deaths in that group, but this was attributed to fighting.

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[2] https://www.gov.uk/government/consultations/environmental-assessment-levels-eals-used-in-air-emissions-risk-assessments/public-feedback/appendix-c-summary-of-toxicological-evidence-for-mea-and-ndma#fnref:1

Rats and mice exposed to 175 ppm DMA experienced a decrease in mean body weight gain to approximately 90% of the control after 3 weeks of exposure. This continued throughout the 12-month period.

The sole other changes linked to treatment were lesions in the nasal passages, which were dose dependent. These lesions occurred in two distinct nasal locations: the respiratory epithelium in the anterior nasal passages and the olfactory epithelium, particularly in the anterior dorsal meatus. In rats, the severity of lesions progressed between six to 12 months in the olfactory epithelium, but there was no progression observed in mice.

Rats exhibited more extensive olfactory lesions compared to mice at the 175 ppm exposure level, showing hyperplasia of small basophilic cells adjacent to the basement membrane. Even at 10 ppm, a 12-month exposure led to a small degree of loss of olfactory sensory cells and their axons in the nasal passages of a few rats and mice. These findings suggested a high sensitivity of olfactory sensory cells to DMA's toxic effects.

The comprehensive two-year study conducted by the Chemical Industry Institute of Toxicology (CIIT, 1990), of which Buckley et al. (1985) reported the first-year portion, served as the foundation for the Scientific Committee of Occupational Exposure Limits (SCOEL, 1991) occupational exposure limit (OEL) recommendation to the Health and Safety Executive (HSE). The study was summarised by the US EPA in their 2008 document where they derived the AEGLs. As described above, female and male F344 rats and B6C3F1 mice were subjected to inhalation exposure of 0, 10, 50, or 175 ppm DMA for six hours a day, five days a week. The total duration of the study was two years. The rats were observed twice a day and weighed weekly or biweekly.

In addition to the six- and 12-month interim sacrifices previously described a further interim sacrifice at 18 months of 9-10 animals per species was undertaken. This only applied to females, as excessive fighting in males lead to high mortality (which also prevented male sacrifice at the 12-month mark).

Decreased gain in body weight persisted throughout the study compared to the control group. Additionally, severity of nasal lesions increased after 18 months. At 10 ppm, minimal lesions were observed in the respiratory epithelium of rats and in the olfactory epithelium in both species. When exposed to 50 ppm, both species showed minimal alterations in the respiratory epithelium and moderate changes in the olfactory epithelium, coupled with mild chronic inflammation. Exposure to 175 ppm resulted in rats developing mild goblet cell hyperplasia, while both species experienced moderate chronic inflammation. Additionally, severe lesions were found in both the respiratory and olfactory epithelium, with these lesions being slightly more extensive in rats than in mice.

7 HBGV for short-term exposure

The industry REACH dossier, HSE (2020) and US EPA (2008) have proposed health based guidance values (HBGVs) for short-term exposure of DMA. The World Health Organisation (WHO) have not recommended any assessment levels for short-term exposure.

7.1 REACH chemical dossier

The industry REACH dossier for DMA on the ECHA dissemination portal derived a derived no effect level (DNEL) of 21.33 mg/m^3 to protect the general population from systemic effects from acute exposure via inhalation (REACH chemical dossier). It was based on a NOAEC of 184.85 mg/m^3

(100 ppm). ECHA applied modified Haber's law[3] using an exponent of 3 to the NOAEC to adjust the NOAEC from a six-hour exposure period to a 15-minute exposure period. The REACH chemical dossier then applied an uncertainty factor[4] (UF) of 25 (a factor of 2.5 for interspecies variation and a factor of 10 for intraspecies variation). ECHA didn't state from which source the NOAEC was taken. However, it is assumed that it was Mitchell et al. (1982) on the basis that they observed the same NOAEC, and their study was also used as the pivotal study for the AEGL-1 derivation by the US EPA.

7.2 United States Environmental Protection Agency

To assess the observed effects of inhalation of DMA, the US EPA reviewed various studies and derived acute exposure guideline levels (AEGLs) for different classifications of exposure levels, averaged over a number of different time frames, as shown in Table 1.

Table 1: Summary of AEGL Values for Dimethylamine

Classification	10-min	30-min	1-h	4-h	8-h
AEGL-1 (Non-disabling)	10 ppm (18 mg/m^3)	10 ppm (18 mg/m^3)	10 ppm (18 mg/m^3)	10 ppm (18 mg/m^3)	10 ppm (18 mg/m^3)
AEGL-2 (Disabling)	130 ppm (240 mg/m^3)	85 ppm (160 mg/m^3)	66 ppm (120 mg/m^3)	40 ppm (74 mg/m^3)	32 ppm (59 mg/m^3)
AEGL-3 (Lethal)	480 ppm (880 mg/m^3)	320 ppm (590 mg/m^3)	250 ppm (460 mg/m^3)	150 ppm (280 mg/m^3)	120 ppm (220 mg/m^3)

Source: US EPA (2008)

The AEGL-1 (non-disabling exposure level) was based on NOAEL for histopathological lesions of the nasal passages of rats following exposure to 100 ppm for six hours/day over 13 weeks, where no nasal lesions were observed (Mitchell et al., 1982). Inter- and intraspecies uncertainty factors of 3 each were applied for a total UF of 10, in accordance with the NRC (2001). The value of 10 ppm was not time-scaled as there is an adaptation to the mild irritation that defines the AEGL-1.

The AEGL-2 (disabling exposure level) was based on a study by Gross et al. (1987), in which rats were exposed to 175 ppm DMA for six hours/day and showed extensive nasal lesions. A total UF of 10 was applied, with UFs of 3 for the inter- and intraspecies uncertainty. Additionally, an adjustment value of 0.5 was applied as the effect was considered mild and below the definition of an AEGL-2 effect. Time-scaling was performed using the relationship $C^n \times t = k$ (ten Berge et al., 1986), where n = 2.8 as derived from a linear regression of LC_{50} studies.

The AEGL-3 (lethal exposure level) was based on a 2-hour $BMCL_{05}$ of 1978 ppm for mice, where internal organ haemorrhages were observed. A total UF of 10, with an UF of 3 for species variability and 3 for human variability was applied, and time-scaling was performed as per ten Berge et al. (1986).

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[3] Modified Haber's law is used by REACH for time extrapolation when the exposure period for the point of departure is different to the desired HGBV exposure period. The law is $c^n * t = k$ where c is concentration, n is an exponent (n = 1 for extrapolating from shorter to longer exposure durations, n=3 for longer to shorter durations), t is the exposure time and k is a constant. The calculation by REACH to derive the adjusted NOAEC was as follows: $184.85\ ^3\ mg/m^3 \times 6\ hours\ = 37897417.4\ ;\ \sqrt[3]{\frac{37897417.4}{0.25\ hours}} = 533.2\ mg/m^3$

[4] Uncertainty factors (UFs), also known as safety factors or assessment factors, are numerical factors used to account for uncertainty when extrapolating data to derive HBGVs. When setting an UF, consideration is usually given to interspecies variability, intraspecies variability, point of departure used to derive the HBGV, completeness of the database, and steepness of the dose response curve. See Appendix A for further detail.

7.3 Health and Safety Executive

The HSE (2020) state a 15-minute short term exposure limit (STEL) of 11 mg/m^3 in their latest workplace exposure limits guidance. This has been highlighted since it is UK authoritative guidance. However, it is unclear how this was derived and the study on which it was based.

8 HBGVs for long-term exposure

The sections below outline the HBGVs which have been proposed for long-term exposure of DMA by the industry REACH dossier and the HSE.

8.1 REACH chemical dossier

ECHA derived 2 long-term REACH DNELs for inhalation for the general population, one systemic and one local. Both derivations were obtained from the findings of Buckley et al. (1985) study. Buckley et al. observed a LOAEC of 18.5 mg/m^3 (10 ppm) based on exposure six hours per day, five days per week for one year. Lesions in the nasal passageways of the rats and mice were the only effect observed at this concentration.

ECHA applied the UF of 30 to the LOAEC (10 for intraspecies differences and 3 for the use of LOAEC) to derive the local DNEL of 0.615 mg/m^3. ECHA did not correct for continuous exposure when calculating the local DNEL but it is unknown why.

The derived systemic REACH DNEL of 0.33 mg/m^3 is based on the NOAEC for systemic effects of 92.26 mg/m^3 (presumed to be from Mitchell et al. 1982). The NOAEC is corrected for continuous exposure, and an uncertainty factor of 50 is used (2 for extrapolation of subchronic to chronic exposure duration, 2.5 for interspecies differences, and 10 for intraspecies differences).

8.2 The HSE

In 2020, the HSE outlined a long-term exposure limit (8-hour TWA ref period) of 3.8 mg/m^3. This value was based on a SCOEL recommendation (SCOEL, 1991) which was derived from a CIIT study (CIIT, 1990), where a LOAEC of 10 ppm (18.5 mg/m^3) was observed. The CIIT (1990) study was the continuation of the Buckley et al. (1985) study for a further year. Therefore, the LOAEC was based on exposure for six hours per day, five days per week for two years. An UF of 5 was applied to calculate the workplace exposure limit (WEL) to account for absence of human data and use of LOAEC.

9 Summary

Although the overall toxicological database is small, several authoritative organisations have proposed HBGVs for DMA.

Short-term exposure guidelines have been proposed by the industry REACH dossier and US EPA (2008) based on nasal irritation observed in rats. Table 2 shows a summary of these guidance values.

Table 2: Summary of health-based guidance values for short-term exposures

Guideline	**Value (mg/m^3)**	**Duration**	**Critical effect**	**Pivotal reference(s)**
Current EAL	None	-	-	-
REACH DNEL	21.33	15 minutes	Irritation	Mitchell et al. 1982 (assumed)
AEGL-1	18	10 mins to 8 hours	Irritation	Mitchell et al. 1982
HSE STEL	11	15 minutes	Unknown	Unknown

Long-term chronic exposure guidelines have been proposed by the industry REACH dossier and HSE (2020) based on nasal irritation and depressed weight gain observed in rats. Table 3 shows a summary of these guidance values.

Table 3: Summary of health-based guidance values for long-term exposures

Guideline	**Value (mg/m^3)**	**Duration**	**Critical effect**	**Pivotal reference(s)**
Current EAL	None	-	-	-
REACH DNEL (systemic)	0.33	24 hours	Decreased body weight gain	Buckley et al. 1985
REACH DNEL (local)	0.615	24 hours	Irritation	Buckley et al. 1985
SCOEL/HSE LTEL	3.8	8 hours, 5 days a week	Irritation	CIIT 1990

10 Recommendations

10.1 Short-term EAL

The primary acute effect from short-term inhalation exposure of DMA is considered to be upper respiratory tract irritation. The HSE (2020) HBGV was not considered in determining the appropriate EAL value due to insufficient detail on the pivotal reference. The ECHA REACH DNEL and the US EPA AEGL-1 both used the same pivotal study: Mitchell et al. (1982). In this study, the rats were exposed to DMA for six hours a day, five days a week, for 90 days. The test concentrations were 0, 10, 30, or 100 ppm DMA, and there were 10 rats per sex per dose group.

Both ECHA and US EPA used the NOAEC of 100 ppm as the point of departure. However, the HBGVs are slightly different as a result of different UFs being applied, and ECHA's use of modified Haber's law to the NOAEC to adjust for a 15-minute exposure period. The US EPA did not adjust for time scale due to irritation being a concentration dependent effect over shorter periods. To be consistent with the Environment Agency's (EA's) 2009 guidance on assessment of contaminants in soil, it is proposed that the UF of 100 (10 for interspecies variation, 10 for intraspecies variation) is instead applied to the NOAEC with no adjustment for time scale For more detail about UFs, see Appendix A. This would provide the short term EAL of 1.8 mg/m^3. However, this is significantly higher than 24 * the long term EAL. Therefore, in accordance with the EA guidance (2020) on compliance constraints for threshold effects, a short term EAL is not recommended.

10.2 Long-term EAL

The critical health effects from long-term inhalation exposure of DMA are considered to be upper respiratory tract irritation and depressed weight gain. The proposed EAL of 0.0033 mg/m^3 is derived from the LOAEC that was used to derive the HSE (2020) WEL, since this was used by a UK authoritative body. The pivotal study used to derive the REACH DNEL, Buckley et al. (1985) is the first-year portion of the two-year CIIT (1990) study that was used to derive the HSE (2020) WEL. In these studies, male and female F344 rats and B6C3F1 mice were subjected to inhalation exposure of 0, 10, 50, or 175 ppm dimethylamine (DMA) for six hours a day, five days a week. Groups of 9-10 male and female rats and mice underwent necropsy after 6, 12, 18 and 24 months of exposure.

The point of departure used by ECHA to derive the REACH DNEL and the HSE to derive the WEL was the same. Differences in the HGBVs are the result of different UFs being used and the values applying to different time periods. To derive the long term EAL of 0.0033 mg/m^3, it is proposed that an UF of 1000 is used after correcting the LOAEC of 18.5 mg/m^3 for continuous exposure ($LOAEC \times \frac{6\ hours}{24\ hours} \times \frac{5\ days}{7\ days} = 3.33\ mg/m^3$). The UF accounts for the following uncertainties: 10 for interspecies variation, 10 for intraspecies variation, and 10 for use of a LOAEC. This uncertainty factor was chosen in line with the EA 2009 guidance on assessment of contaminants in soil. For more detail about UFs, see Appendix A.

10.3 Summary

Table 4 summarises the recommended EALs as described in sections 10.1 and 10.2.

Table 4: Recommended EALs for DMA

Short-term EAL	None - (constrained by compliance with the long-term EAL)
Long-term EAL	0.0033 mg/m^3 as a 24-hour mean

Source: Fichtner

Appendices

A Uncertainty factors

Uncertainty factors, also known as safety factors or assessment factors, are numerical factors used to account for uncertainty when extrapolating data to derive health-based guidance values (HBGVs). There are differences in the approach to the application of the uncertainty factors among groups that derive HBGVs.

Table 5 provides examples of the typical uncertainty factors used in chemical risk assessment, highlighted in the EA's 2009 guidance on assessment of contaminants in soil (EA, 2009).

Table 5: Examples of uncertainty factors used in chemical risk assessment

Consideration	Typical uncertainty factor applied
Interspecies variability	A 10-fold factor is normally used to account for variability in species susceptibility between humans and the animal species in which the chemical was tested.
Intraspecies variability	A 10-fold factor is normally used to account for variability of responses in human populations which may not be present in the inbred strains of animals used for toxicity testing.
LOAEL to NOAEL	A 10-fold factor may be used when a LOAEL instead of a NOAEL is used in the derivation. For a minimal LOAEL, an intermediate factor of three may be used. It is inappropriate to use a LOAEL if the NOAEL is likely to be more than 10 times less than the NOAEL.
Data gaps	A factor, usually 3- to 10-fold, may be used for “incomplete” databases (with missing studies, such as no chronic bioassays or no reproductive toxicity data). It accounts for the inability of any study to consider all toxic endpoints.
Steep dose-response curve	Where the dose-response curve is steep and a small error in the extrapolation would have dramatic consequences, an additional factor may be applied.

Source: Environment Agency (2009)

B Abbreviations and definitions

AEGL - Acute exposure guideline level

AEGL-1

The airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic, non-sensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.

AEGL-2

The airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.

AEGL-3

The airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death.

$BMCL_{05}$ - Benchmark concentration, 95% lower confidence limit with 5% response

CIIT - Chemical Industry Institute of Toxicology

CRT - Choice reaction time

DMA - Dimethylamine

DNA -Deoxyribonucleic acid

DNEL - Derived no-effect level

EAL - Environmental assessment level

ECHA - European Chemicals Agency

EEG - Electroencephalogram

HBGV - Health-based guidance value

HSE - Health and Safety Executive

LC_{50} - Lethal concentration 50

LD_{50} - Lethal dose 50

LOAEL/C - Lowest observed adverse effect level / concentration

LTEL - Long term exposure limit

MAK - Maximale Arbeitsplatz-Konzentration (maximum workplace concentration)

NDMA - N-nitrosodimethylamine

NIOSH - National Institute for Occupational Safety and Health

NIPH - Norwegian Institute of Public Health

NOAEL/C - No observed adverse effect level / concentration **UF - Uncertainty factor**

US EPA - United States Environmental Protection Agency

WEL - Workplace exposure limit

WHO - World Health Organisation

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Carbon Capture

Derivation of environmental assessment levels for diethanolamine (DEA)

1 Diethanolamine (CAS Number 111-42-2)

Diethanolamine (DEA) is a colourless, viscous liquid with a mild ammonia odour (IARC, 2000). It is highly soluble in water and non-flammable (ECHA Dossier). In industry, DEA is used as an emulsifier and dispersing agent for agricultural chemicals and as an intermediate in the rubber chemical industry. DEA is also used in the manufacture of a range of consumer products, such as shampoos, cosmetics, and pharmaceuticals (US EPA, 2016). DEA is readily biodegradable in the environment (Gannon et al. 1978) and has an estimated phototransformation half-life in air of about four hours.

2 Regulatory standards

- None

3 Recommended environmental assessment level (EAL) in air

- Long-term EAL – 0.0002 mg/m^3 as a 24-hour mean.
- Short-term EAL – none recommended due to insufficient evidence.

4 Overview

There are few authoritative reviews on the adverse effects from exposure to DEA. According to the industry registration, evaluation, authorisation and restriction of chemicals (REACH) dossier, the American Conference of Government Industrial Hygienists (ACGIH) and the Office of Environmental Health Hazard (OEHHA) the primary adverse effects are:

1. as an ocular and skin irritant (US EPA, 2016); and
2. as a disruptor of the metabolism of lipids which has been shown to cause systemic toxicity in the nervous system, liver, kidney and blood system in rodents (OEHHA, 2008).

5 Toxicokinetics

Exposure of the general public to DEA is most common via the dermal route through use of consumer products containing DEA (IARC, 2012).

Occupational exposure may occur by inhalation from the use of lubricants containing DEA which are used in machine building and metallurgy (US EPA, 2016). DEA is also absorbed via the oral route. Whilst there is limited quantitative data on human absorption of DEA, absorption by mammals was assessed by Mathews et al. (1997) who found that DEA is well absorbed following oral administration in rats (57%) and absorbed to a lesser degree through the skin (3-16% in rats and 25-60% in mice). Moreover, the higher the concentration of DEA applied to the skin, the higher the quantity of DEA that was absorbed. The route of absorption was not observed to affect the distribution of DEA in tissues.

Pharmocokinetic studies revealed that DEA is incorporated into membrane phospholipids and interacts with lipid metabolism, for example by inhibiting the incorporation of choline and ethanolamine into phospholipids in rat liver and kidneys (IARC, 2000). DEA is primarily excreted in urine, with lesser amounts excreted in faeces (IARC, 2012). It is eliminated from tissues with a half-life of approximately six days (Mathews, 1997). Whilst the majority of DEA is not metabolised and is excreted, small proportions of O-phosphorylated and N-methylated metabolites are produced, notably N-methyldiethanolamine (N-MDEA) and N,N-dimethyldiethanolamine (N,N-DMDEA) (PubChem, 2023).

6 Short- and long-term exposures

There have been no controlled or epidemiological studies of chronic DEA exposure in humans (OEHHA, 2001), although there has been a single report of occupational asthma due to handling of a cutting fluid containing DEA (Piipari et al., 1998). Bronchial provocation tests were performed with the cutting fluid and DEA aerosol at two different concentrations below the ACGIH threshold limit value of 2 mg/m^3 (ACGIH, 2022). DEA was found to cause asthmatic airway obstruction at both concentrations; however, IgE-antibodies for DEA were not found.

DEA replaces choline in phospholipids, interfering with lipid metabolism (Blum et al., 1972). By blocking choline uptake and competing for utilisation in the CDP-choline pathway, DEA reversibly inhibits phosphatidylcholine synthesis (Lehman-McKeeman and Gamsky, 1999). These effects can cause systemic toxicity to occur in various tissues including the nervous system, liver, kidney and blood system (OEHHA, 2008).

The National Toxicology Program (1992) conducted toxicology studies of DEA on Fischer 344 rats and B6C3F1 mice[1] of both sexes to compare the effects of oral and dermal exposure. Rats and mice were given drinking water containing DEA in concentrations up to 10,000 ppm for durations of either 2 or 13 weeks. Rats and mice of both sexes in the 10,000 ppm group died before the end of the two-week study, with female rats also dying but at a lower concentration of 5,000 ppm. Rats receiving DEA developed poorly regenerative, microcytic anaemia in both studies, and depressed weight gains in the higher concentration groups. In the two week study, male and female rats showed renal tubular cell necrosis and decreased renal function, whilst in the 13-week study, rats also showed increased incidences and severity of nephropathy, tubular necrosis, mineralisation and demyelination in the medulla oblongata and spinal cord. In mice, dose-dependent increases in liver weight were observed in the 2-week study, as well as cytologic alternation and necrosis of individual hepatocytes in the highest dose group. Other conditions were observed in the 13-week study, including degeneration of cardiac myocytes and hepatocellular necrosis.

The same report (NTP, 1992) discussed 2 and 13-week dermal studies of rats and mice. Doses of DEA were administered in 95% ethanol in concentrations up to 2,500 mg/kg, five days per week. Early deaths of all rodents occurred in the two week study at the highest dose groups, and body weight gains were also reduced in the higher dermal dose groups. The symptoms shown by the rats and mice were largely comparable to those observed in the oral studies, however rats in the dermal

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[1] These are common inbred rats and hybrid strains of mice which are available commercially for use in toxicological studies.

studies also exhibited ulcerative skin lesions at the site of application, accompanied by inflammatory cell infiltration, hyperkeratosis and acanthosis of the epidermis. Ulceration was also observed in mice at the site of application, and where mice had been given lower doses of DEA, acanthosis without ulceration or inflammatory cell infiltration was observed.

There is very limited research on the neurotoxicity of DEA. In a study of the inhalation toxicity of DEA, Wistar rats were exposed to a liquid aerosol of DEA at concentrations up to 400 mg/m^3 for six hours daily over a course of 90 days (Gamer et al., 2008). There were a few isolated differences in motor activity between the treated animals and the control group, however, the authors considered these incidental. They concluded that no neurotoxic effects were induced by DEA in the study.

Evidence for developmental and reproductive effects in humans from DEA has not been reported (IARC, 2000). Marty et al. (1999) painted an aqueous solution of DEA on the skin of rats on days 6 – 15 of gestation at doses of 0, 150, 500 and 1,500 mg/kg body weight (bw) per day. The two higher dose levels caused severe skin irritation, but there was no effect on foetal weight, and no external, visceral or skeletal abnormalities were induced. However, at the highest dose level, delayed ossification of the axial skeleton and distal appendages were observed in foetuses. Degeneration of seminiferous tubules and reduced sperm count was observed in a 13-week subchronic study where male rats were given drinking water with a DEA concentration of 2500 ppm (Melnick et al., 1994).

6.1 Genotoxicity and carcinogenicity

DEA was tested for mutagenicity in several in vivo and in vitro studies. Male and female mice were administered DEA once per day to the uncovered skin in concentrations up to 600 mg/ml for 13 weeks. No induction of micronuclei was noted at any dose level (NTP, 1999). No sister chromatid exchanges or chromosomal aberrations were observed in cultured Chinese hamster ovary cells exposed to DEA at concentrations from 150 – 1,500 µg/ml (Loveday, 1989). In a study of the effects of DEA in bacterial mutation assays, no mutagenic effect was observed in Salmonella typhimurium or Escherichia coli (Dean et al., 1985).

In a rodent oncogenicity study by the National Toxicology Program (1999), where ethanolic DEA solutions were received topically by rats and mice in concentrations up to 64 mg/kg bw and 160 mg/kg bw, respectively, no evidence of carcinogenic activity of diethanolamine in male or female rats was found after the 2-year dermal study. However, for both male and female mice, the incidences of hepatocellular adenoma and carcinoma were significantly higher in dosed groups compared to the control. Renal tubule adenoma was also observed in male mice at the high dose level at a low incidence. The liver tumours were considered to be directly related to the increase in cellular proliferation rate due to enzyme induction, weak peroxisome proliferation and choline depletion. Based on the increased S-phase synthesis observed in the kidney, it is suggested that a non-genotoxic mode of action involving choline deficiency is responsible for the benign kidney tumours (ECHA Dossier). B6C3F1 mice are highly sensitive to non-genotoxic effects and have shown a high incidence of spontaneous liver tumours. Short term tests on the carcinogenicity of DEA found no carcinogenic effects in mice (Spalding et al., 2000). Mechanistic research on DEA indicates that the mechanism by which DEA can potentially induce tumours in mice is not relevant to humans, and therefore, based on the available data, DEA is not considered carcinogenic for humans (ECHA Dossier).

6.2 Pivotal studies

The Gamer et al. (1996) study was summarised by California Environmental Protection Agency's Office of Environmental Health Hazard Assessment (OEHHA) in their 2008 Technical Supporting Document for Non cancer RELs Appendix D3. The Gamer et al. (1996) study was used as the basis for the OEHHA chronic reference exposure limit (REL) to DEA of 0.003 mg/m^3.

In their study, Gamer et al. (1996) exposed groups of 26 Wistar rats (13 per sex) to a liquid aerosol of DEA for six hours daily, five days a week, for 90 days at concentrations of 15 mg/m^3, 100 mg/m^3 and 400 mg/m^3. There was no functional or morphological evidence of neurotoxicity.

Body weight gain reduction was observed in males exposed to the highest dose. At low doses, no systemic effects were evident, while the high concentration dose group displayed systemic effects in the liver, kidney, male reproductive system, and red blood cells. In the mid-dose group, mild effects on the liver and kidney were observed. Both the high and mid-dose groups exhibited local irritation of the larynx and trachea, with laryngeal irritation also noted in the low dose group. According to this study, 15 mg/m^3 represents a NOAEL for liver and kidney effects, and a LOAEL for laryngeal irritation.

The Gamer et al. (2008) study was used as the basis for the United States Environmental Protection Agency's (US EPA) 2012 chronic inhalation provisional reference concentration (p-RfC) of 0.0002 mg/m^3. In their 2008 work, two separate nose-only inhalation experiments took place. In the first study, groups of 26 Wistar rats (13 per sex) were exposed to a liquid aerosol of DEA for 6-hours a day, 5-days a week, for 90 days at concentrations of 0 mg/m^3, 15 mg/m^3, 150 mg/m^3 and 400 mg/m^3. In the second, groups of 20 Wistar rats (10 per sex) were exposed to aerosolised DEA at concentrations of 0 mg/m^3, 1.5 mg/m^3, 3 mg/m^3 and 8 mg/m^3 for 6 hours a day, 5-days a week for 90 days.

In the first study, systemic toxicity was induced at 150 mg/m^3 and 400 mg/m^3. Body and organ weight changes were observed, as well as histopathological changes suggesting mild blood, liver, kidney and testicular effects. At all concentrations, metaplasia at the base of the epiglottis was observed. At 150 mg/m^3 and 400 mg/m^3 concentration-dependent increase in squamous laryngeal hyperplasia was observed, and increased incidence and severity of inflammation in the larynx and trachea.

In the second study, respiratory irritation was observed at concentrations at and above 3 mg/m^3. This was demonstrated by reversible metaplasia at the base of the epiglottis and inflammation extending into the trachea. No treatment related histopathological changes in the larynx were observed at 1.5 mg/m^3 exposure, making this concentration the no adverse effect concentration (NOAEC) for local irritation.

In both the Gamer et al. (2008) studies, no evidence of neurotoxicity was present.

7 Health based guidance values (HBGVs) for short-term exposure

There are no appropriate known HBGVs for short-term exposure to DEA. The European Chemicals Agency (ECHA) dossier does not derive a short-term derived no effect level (DNEL) for short-term exposure stating that there is "low hazard". The justification for this statement is unclear.

8 HBGVs for long-term exposure

The ECHA dossier, US EPA (2012) and California Environmental Protection Agency's Office of Environmental Health Hazard Assessment (OEHHA) (2001) have proposed HBGVs for long-term exposure to DEA.

8.1 ECHA chemical dossier

ECHA chemical dossier has stated a long term DNEL for the general population of 0.125 mg/m^3 for inhalation exposure to DEA. This is based on an unnamed study conducted in 2002 submitted under the REACH application for DEA. In the 2002 90-day sub-chronic study, a NOAEC of 3 mg/m^3 was observed for DEA exposure six hours daily, five days a week (65 exposures in the 90-day period).

The REACH DNEL for the general population was calculated by adjusting a DNEL for local effects already derived for workers. The workers DNEL of 0.5 mg/m^3 was derived by applying an uncertainty factor (UF) of 6 to the NOAEC of 3 mg/m^3: 2 for extrapolation of sub-chronic to chronic duration of exposure and 3 for intraspecies differences. This DNEL was based on local effects of respiratory tract irritation. The calculation of the DNEL for the general population from the workers DNEL was as follows:

$$0.5\,mg/m^3 \times \frac{10\,m^3}{20\,m^3} \times \frac{5}{10} = 0.125\,mg/m^3.$$

The 10 m^3/ 20 m^3 factor was due to the assumption that the respiratory volume of workers over an 8-hour period would be 10 m^3 while the respiratory volume of the general population would be 20 m^3 over 24-hours. The ECHA chemical dossier states that the 5/10 factor was used because an UF of 5 was applied for intraspecies differences in the workers calculation, whereas an UF of 10 would be applied for intraspecies differences in the general population. However, it appears that the factor applied for intraspecies differences in the workers calculation was actually 3.

It is possible that the DNEL for the general population was meant to be calculated based on the systemic DNEL for workers which was 0.75 mg/m^3 (instead of the DNEL for local effects). In the derivation for the systemic DNEL for workers, the intraspecies portion of the UF was 5, which supports this theory. In this case, applying the same calculation as above to the 0.75 mg/m^3 value would result in a DNEL of 0.188 mg/m^3. However, there is not enough evidence to be confident in this.

8.2 California Environmental Protection Agency's Office of Environmental Health Hazard Assessment (OEHHA)

OEHHA (2001) proposed a chronic inhalation reference exposure limit (REL) of 0.003 mg/m^3 based on laryngeal lesions in Wistar rats in a sub-chronic study (Gamer et al., 1996). Gamer et al. (1996) observed a lowest adverse effect (LOAEC) of 15 mg/m^3 for exposure to DEA 6 hours / day, 5 days / week for 90 days. The OEHHA (2001) corrected the observed LOAEC for equivalent continuous exposure, to obtain 2.7 mg/m^3 $(15\,mg/m^3 \times \frac{6\,hours}{24\,hours} \times \frac{5\,days}{7\,days} = 2.7\,mg/m^3)$. The OEHHA then applied an UF[2] of 1000 based on: 3 for use of LOAEC instead of NOAEC, 3 for subchronic length of study, 10 for interspecies uncertainty and 10 for intraspecies uncertainty. The OEHHA remarked

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[2] Uncertainty factors (UFs), also known as safety factors or assessment factors, are numerical factors used to account for uncertainty when extrapolating data to derive HBGVs. When setting an UF, consideration is usually given to interspecies variability, intraspecies variability, point of departure used to derive the HBGV, completeness of the database, and steepness of the dose response curve. See page 13 for further detail.

that the use of a sub-chronic study was due to the absence of chronic inhalation studies in the peer-reviewed literature.

8.3 United States Environmental Protection Agency (US EPA)

The US EPA (2012) has issued a p-RfC for inhalation exposure to DEA of 0.0002 mg/m^3. The p-RfC is based on a sub-chronic rat inhalation study performed by Gamer et al., (2008). There were no chronic inhalation studies available to consider. In the 90-day Gamer et al. (2008) study, a NOAEC of 1.5 mg/m^3 was observed for 6-hour exposure on 65 days.

Using the incidence data from the Gamer et al. (2008) study, the US EPA (2012) performed a benchmark concentration (BMC) analysis. To do this, each concentration used in the study (0 mg/m^3, 1.5 mg/m^3, 3.0 mg/m^3, 8.0 mg/m^3) was corrected for continuous exposure. Following this, dosimetric adjustment factors (DAFs) were calculated to obtain the human equivalent concentration (HEC). These are factors that account for the regional deposited dose ratio (RDDR) for particles in various regions of the respiratory tract. The DAFs were calculated using the EPA's RDDR software. For each concentration, a DAF was calculated for males and females separately, and for both respiratory (in the tracheobronchial region) and extra-respiratory effects (such as increases in relative liver weight). This meant that for each concentration, 4 DAFs were calculated.

Each DAF was then multiplied by the appropriate adjusted concentration, which generated the HECs. All HECs, for all concentrations tested, both sexes, and for both respiratory and extra-respiratory effects, were then used as inputs to the BMC analysis using EPA BMDS (version 2.1.1) (U.S. EPA, 2011). For both respiratory and extra-respiratory effects, models were fitted to the data to produce benchmark concentrations for the lower confidence limit at 10% extra risk ($BMCL_{10HEC}$) and benchmark concentrations at 10% extra risk (BMC_{10HEC}).

Based on respiratory and extra-respiratory effects of the BMDS modelling output, a $BMCL_{10HEC}$ of 0.63 mg/m^3 from respiratory effects in male rats was selected as the point of departure for derivation of the chronic p-RfC. This was lower than the $BMCL_{10HEC}$ of 2.03 mg/m^3 from extra respiratory effects. The $BMCL_{10HEC}$ of 0.63 mg/m^3 would therefore be protective for both respiratory and extra-respiratory effects in both sexes (US EPA, 2012).

To derive the chronic p-RfC, the US EPA (2012) applied an UF of 3000 to the $BMCL_{10HEC}$ of 0.63 mg/m^3 (3 for the toxicodynamic portion of interspecies differences not addressed by use of DAFs, 10 for intraspecies differences, 10 for extrapolation from a sub-chronic duration of study, and 10 for lack of data in the toxicological database). The resultant value was 0.0002 mg/m^3.

9 Summary

Although the overall toxicological database is small, several authoritative organisations have proposed HBGVs for long term exposure to DEA.

Long-term chronic exposure guidelines have been proposed by the ECHA dossier, the OEHHA (2001) and the US EPA (2012) based on respiratory tract irritation in rats. Table 1 shows a summary of these guidance values.

Table 1: Summary of HBGVs for long-term exposures

Guideline	Value (mg/m^3)	Duration	Critical effect	Pivotal reference(s)
Current EAL	None	-	-	-
REACH DNEL general population	0.125	24 hours	Respiratory tract irritation	Unnamed 2002 study
OEHHA REL	0.003	24 hours	Respiratory tract irritation	Gamer et al. 1996
US EPA p-RfC	0.0002	24 hours	Respiratory tract irritation	Gamer et al. 2008

10 Recommendations

10.1 Short-term EAL

No short-term EAL is proposed due to insufficient evidence.

10.2 Long-term EAL

The critical health effect from long-term inhalation exposure to DEA is considered to be respiratory tract irritation. The proposed EAL of 0.0002 mg/m^3 is based on the US EPA chronic p-RfC for inhalation exposure to DEA. The pivotal study used to derive the p-RfC was Gamer et al. (2008). In the relevant portion of this study, groups of 20 Wistar rats (10 per sex) were exposed to aerosolised DEA at concentrations of 0 mg/m^3, 1.5 mg/m^3, 3 mg/m^3 and 8 mg/m^3 for six hours daily, five days a week for 90 days. In this study, a NOAEC of 1.5 mg/m^3 was observed for irritation to the respiratory tract.

The US EPA (2012) applied BMC analysis to derive the point of departure for the p-RfC, which was the $BMCL_{10HEC}$ of 0.63 mg/m^3 from respiratory effects in male rats. The UF of 3000 was then applied to derive the p-RfC. This UF is in line with EA guidance on use of UFs, as described in Appendix A. This HBGV was selected in preference to the OEHHA (2001) REL of 0.003 mg/m^3, because the Gamer et al. (2008) study tested lower concentrations of DEA exposure and derived the NOAEC of 1.5 mg/m^3, while the OEHHA REL was based on the Gamer et al. (1996) LOAEC of 15 mg/m^3. Additionally, BMC analysis was confirmed by the European Food Safety Authority (EFSA) Scientific Committee to be a scientifically more advanced approach than applying NOAECs. This is because it makes extended use of the dose–response data and accounts for statistical limitations in the data (EFSA, 2017).

The REACH DNEL of 0.125 mg/m^3 was not considered for the long-term EAL due to insufficient information on the study from which it was derived and inconsistencies in the calculation.

10.3 Summary

Table 2: Recommended EALs for DMA

Short-term EAL	None (insufficient evidence)
Long-term EAL	0.0002 mg/m^3 as a 24-hour mean

Source: Fichtner

Appendices

A Uncertainty factors

Uncertainty factors, also known as safety factors or assessment factors, are numerical factors used to account for uncertainty when extrapolating data to derive health-based guidance values (HBGVs). There are differences in the approach to the application of the uncertainty factors among groups that derive HBGVs.

Table 3 provides examples of the typical uncertainty factors used in chemical risk assessment, highlighted in the Environment Agency's 2009 guidance on assessment of contaminants in soil (Environment Agency, 2009).

Table 3: Examples of uncertainty factors used in chemical risk assessment

Consideration	Typical uncertainty factor applied
Interspecies variability	A 10-fold factor is normally used to account for variability in species susceptibility between humans and the animal species in which the chemical was tested.
Intraspecies variability	A 10-fold factor is normally used to account for variability of responses in human populations which may not be present in the inbred strains of animals used for toxicity testing.
LOAEL to NOAEL	A 10-fold factor may be used when a LOAEL instead of a NOAEL is used in the derivation. For a minimal LOAEL, an intermediate factor of three may be used. It is inappropriate to use a LOAEL if the NOAEL is likely to be more than 10 times less than the NOAEL.
Data gaps	A factor, usually 3- to 10-fold, may be used for "incomplete" databases (with missing studies, such as no chronic bioassays or no reproductive toxicity data). It accounts for the inability of any study to consider all toxic endpoints.
Steep dose-response curve	Where the dose-response curve is steep and a small error in the extrapolation would have dramatic consequences, an additional factor may be applied.

Source: Environment Agency (2009)

B Abbreviations and definitions

ACGIH - American Conference of Governmental Industrial Hygienists

BMC - Benchmark concentration

BMC_{10HEC} - Benchmark concentration at 10% extra risk, human equivalent concentration

$BMCL_{10HEC}$ - Benchmark concentration for the lower confidence limit at 10% extra risk, human equivalent concentration

CDP-choline - Cytidine 5'-diphosphocholine

DAF - Dosimetric adjustment factors

DEA - Diethanolamine

DNEL - Derived no effect level

EA - Environment Agency

EAL - Environmental assessment level

ECHA - European Chemicals Agency

EFSA - European Food Safety Authority

HBGV - Health-based guidance value

IARC - International Agency for Research on Cancer

IgE - Immunoglobulin E

LOAEC - Lowest adverse effect concentration

NOAEC - No adverse effect concentration

N-MDEA - N-methyldiethanolamine

N,N-DMDEA - N,N-dimethyldiethanolamine

NTP - National Toxicology Program

OEHHA - (California) Office of Environmental Health Hazard Assessment

Ppm - Parts per million

REACH - Registration, evaluation, authorisation and restriction of chemicals

REL - Reference exposure limit

UF - Uncertainty factor

US EPA - United States Environmental Protection Agency

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