



Humber Refinery

Environmental Permit Variation Application
Appendix D - Air Impact Assessment

Phillips 66 Limited

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Quality information

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Table of Contents

1.	Introduction	1
2.	Assessment Criteria	2
	2.1 Air Quality Legislation	2
	2.1.1 Human Health	2
	2.1.2 Ecological	3
	2.2 Environmental Permitting Regulations	4
	2.2.1 Human Health Significance Criteria	5
	2.2.2 Ecological Significance Criteria	6
3.	Receptors and Baseline Air Quality	7
	3.1 Receptors	7
	3.1.1 Human Health Receptors	7
	3.1.2 Ecological Receptors	7
	3.2 Baseline Air Quality	8
	3.2.1 Human Health Background Concentrations	9
	3.2.2 Ecological Receptors Background Concentrations	11
4.	Dispersion Model Parameters	14
	4.1 Emissions Inventory	14
	4.1.1 Baseline Assessment	14
	4.1.2 Future Assessment	16
	4.2 Meteorological Data	19
	4.3 Buildings and Terrain	20
	4.4 NO _x to NO ₂ Conversion	21
	4.5 Calculation of Deposition at Sensitive Ecological Receptors	21
	4.6 Specialised Model Treatments	22
5.	Assessment of Amine Degradation Products	23
	5.1 Introduction	23
	5.2 Discussion of Amines and N-Amines	23
	5.2.1 Toxicity of N-Amines	23
	5.2.2 N-Amine Emissions from Carbon Capture Processes	25
	5.3 N-Amines Assessment Methodology	27
	5.3.1 Model Selection	27
	5.3.2 Dispersion Model Input Parameters	28
6.	Results and Conclusions	31
	6.1 Baseline Assessment	31
	6.1.1 Human Health Receptor Results	31
	6.1.2 Ecological Receptor Results	32
	6.2 Future Assessment	37
	6.2.1 Human Health Receptor Results	37
	6.2.2 Ecological Receptor Results	40
	6.3 N-Amines Assessment Results	45
	6.3.1 Total N-Amine 1 Impacts from Amine 1 and N-amine 1 Emissions	45
	6.3.2 Total N-Amine 2 Impacts from Amine 2 and N-amine 2 Emissions	45
	6.3.3 Total N-Amine Impacts	46
	6.3.4 N-Amine Assessment Limitations and Assumptions	47
	Annex A - Supporting Toxicological Information for Amines and N-Amines in the Solvent	49
	Annex B- Figures	63
	Annex C – Model Sensitivity	71
	Annex D - Stack Height Assessment	73
	Annex E – Visible Plumes	75

Tables

Table 2.1: National Air Quality Strategy (NAQS) objectives – Protection of Human Health	2
Table 2.2: Critical Levels (CL) – Protection of Vegetation and Ecosystems	3
Table 2.3: Environmental Assessment Levels (EAL) – Human Health	5
Table 3.1: Human Receptor Locations for Air Quality Assessment	7
Table 3.2: Ecological Receptor Locations in the Vicinity of the Installation	8
Table 3.3: NLC Annual Mean Automatic Monitoring Data for Killingholme School CM6	9
Table 3.4: NLC Annual Mean NO ₂ Diffusion Tube Monitoring Data	10
Table 3.5: Defra Background Air Quality Data (Annual Mean) (1km ² grid average).....	10
Table 3.6: Baseline Concentrations for Human Health Receptors Used in Assessment.....	11
Table 3.7: Baseline Data for Ecological Receptors (APIS Background).....	11
Table 3.8: Baseline Deposition Data (APIS Background)	12
Table 4.1: Stack Emission Parameters for Baseline Emission Sources	15
Table 4.2: Assessed Stack Emission Parameters for Future Emission Sources	18
Table 4.3: Buildings Incorporated into the Modelling Assessment.....	20
Table 4.4: Deposition Conversion Rates Ecological Receptors.....	21
Table 5.1: Amine Branching Ratios	26
Table 5.2: Amine Information for ADMS Model Set-Up	28
Table 5.3: Amines Chemistry Module Model Set-Up	29
Table 6.1: Baseline – Maximum Human Health Impacts at Any Receptor	31
Table 6.2: Baseline – Ecological Impacts of NO _x	33
Table 6.3: Baseline – Annual Average Ecological Impacts of SO ₂	34
Table 6.4: Baseline – Annual Average Ecological Impacts of NH ₃	34
Table 6.5: Baseline – Nitrogen Deposition at Ecological Receptors	35
Table 6.6: Baseline – Acid Deposition at Ecological Receptors.....	36
Table 6.7: Future – Maximum Human Health Impacts at Any Receptor	38
Table 6.8: Future – Ecological Impacts of NO _x	41
Table 6.9: Future – Annual Ecological Impacts of SO ₂	42
Table 6.10: Future – Annual Ecological Impacts of NH ₃	42
Table 6.11: Future – Nitrogen Deposition at Ecological Receptors.....	43
Table 6.12: Future – Acid Deposition at Ecological Receptors	44
Table 6.13: Future - Annual Average N-Amine 1 Concentrations as a Result of Amine 1 and N-Amine 1 Emissions	45
Table 6.14: Future - Annual Average Indirect N-Amine 2 Concentrations as a Result of Amine 2 and N- amine 2 Emissions	45
Table 6.15: Future – Total Annual Average N-Amine Concentrations.....	46
Table C1: Dispersion Model Sensitivity Analysis –Future Assessment	71
Table E1: Visible Plumes from the PCC Plant Stack	75

1. Introduction

This Air Impact Assessment has been prepared on behalf of Phillips 66 Limited ('Phillips 66'), to support a substantial Environmental Permit variation application for the Humber Refinery (the 'Installation') for the retrofit of a Post-combustion Carbon Capture (PCC) plant on to the existing Fluid Catalytic Cracker (FCC) Unit at the Installation.

The Air Impact Assessment carried out for the Environmental Permit variation application considers the current impacts of the emissions from the FCC Stack (i.e. 'the Baseline Assessment') and compares these to the future operation of the FCC flue gas undergoing CO₂ removal through the PCC Plant ('the Future Assessment').

The assessment aims to demonstrate that the emissions from the operation of the PCC Plant would not lead to the exceedance of any Air Quality Standards objectives, Environmental Assessment Levels, Critical Levels and Critical Loads, as appropriate.

The assessment has been carried out in accordance with the following guidance:

- Environment Agency (EA). Risk Assessments for Specific Activities: Environmental Permits guidance (Defra and EA, 2016) (the 'EA's Risk Assessment guidance')¹; and,
- EA (Air Quality Modelling and Assessment Unit (AQMAU)) (2021). AQMAU recommendations for the regulation of impacts to air quality from amine-based post-combustion carbon capture plant' AQMAU-C2025-RP01² (the 'EA's Amine Modelling guidance').
- EA (Air Quality Modelling and Assessment Unit (AQMAU)) (2023). Developing Environmental Assessment Levels (EALs) for new carbon capture and storage compounds – Briefing on EALs for carbon capture activities that use amine-based solvents. Issues to the Carbon Capture and Storage Association (the 'EA's Amine EAL Briefing Note').

The dispersion of emissions from both existing and future emission sources has been predicted using the latest version of the atmospheric dispersion model ADMS (currently version 6) supplied by Cambridge Environmental Research Consultants Limited (CERC).

¹ [Air emissions risk assessment for your environmental permit - GOV.UK \(www.gov.uk\)](https://www.gov.uk/guidance/air-emissions-risk-assessment-for-your-environmental-permit)

² [AQMAU-C2025-RP01.pdf \(ukccsrc.ac.uk\)](https://ukccsrc.ac.uk/aqmau-c2025-rp01.pdf)

2. Assessment Criteria

2.1 Air Quality Legislation

2.1.1 Human Health

The principal air quality legislation within the United Kingdom (UK) is the Air Quality Standards Regulations 2010, which transposes the requirements of the European Ambient Air Quality Directive 2008³ and the 2004 fourth Air Quality Daughter Directive⁴. The Air Quality Standards Regulations 2010⁵ set air quality limits for a number of major air pollutants that have the potential to impact public health, such as nitrogen dioxide (NO₂), carbon monoxide (CO), sulphur dioxide (SO₂) and particulates.

The Environment Act 2021⁶ amends the Environment Act 1995⁷, transposing the requirement for local authorities to review air quality within their district or borough, in order to determine where pollutant levels identified in the National Air Quality Standard objectives may be exceeded. The Environment Act 2021 requires the UK Government to update the National Air Quality Strategy (NAQS)⁸, last reviewed in 2007, containing air quality objectives and timescales to meet those objectives. The objectives apply to outdoor locations where people are regularly present and do not apply to occupational, indoor or in-vehicle exposure.

The current objectives applicable to this assessment for the protection of human health are presented in Table 2.1.

Table 2.1: National Air Quality Strategy (NAQS) objectives – Protection of Human Health

Pollutant	Source	Concentration (µg/m ³)	Measured as
Nitrogen dioxide (NO ₂)	EU air quality limit value	40	Annual mean
		200	1-hour mean, not to be exceeded more than 18 times a year
Sulphur dioxide (SO ₂)	UK Air Quality Strategy Objective	266	15-minute mean, not to be exceeded more than 35 times a year
	EU Air Quality Limit Values	350	1-hour mean, not to be exceeded more than 24 hours a year
	EU Air Quality Limit Values	125	24-hour mean, not to be exceeded more than 3 times a year
Particulate matter (PM ₁₀)	EU air quality limit value	40	Annual mean
		50	24-hour mean, not to be exceeded more than 35 times a year
Particulate matter (PM _{2.5})	EU air quality target value	25	Annual mean
Carbon monoxide (CO)	EU air quality limit value	10,000	Maximum daily running 8-hour mean

³ Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe' (2008) *Official Journal* L152, P.1

⁴ 'Directive 2004/107/EC of the European Parliament and of the Council of 15 December 2004 relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air' (2004) *Official Journal* L23, P.3

⁵ The Air Quality Standards Regulations 2010 (SI 2010/1001). London: The Stationery Office.

⁶ [Environment Act 2021 \(legislation.gov.uk\)](https://www.legislation.gov.uk)

⁷ The Environment Act 1995 (c. 25). London: The Stationery Office.

⁸ Department for Environment, Food and Rural Affairs (2007). The Air Quality Strategy for England, Scotland, Wales and Northern Ireland. London: The Stationery Office.

The Environment Act 2021 also requires local authorities to undertake an assessment of local air quality to establish whether the objectives are being achieved, and to designate air quality management areas (AQMA) if improvements are necessary to meet the objectives. Where an AQMA has been designated, the local authority must draw up an Air Quality Action Plan (AQAP) describing the measures that will be put in place to assist in achieving the objectives. Defra has responsibility for coordinating assessments and AQAPs for the UK as a whole.

2.1.2 Ecological

The impact of emissions from the PCC Plant on sensitive ecological receptors are quantified within this assessment in two ways:

- as direct impacts arising due to increases in atmospheric pollutant concentrations, assessed against defined ‘Critical Levels’; and
- as indirect impacts arising through deposition of acids and nutrient nitrogen to the ground surface, assessed against defined ‘Critical Loads’.

The Critical Levels for the protection of vegetation and ecosystems are defined as “concentrations of pollutants in the atmosphere above which direct adverse effects on...plants [and] ecosystems...may occur according to present knowledge,” and critical loads are defined as “a quantitative estimate of exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge”⁹.

Critical Levels for the protection of vegetation and ecosystems have been adopted by, amongst others, the European Union and the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (CLRTAP). The annual average Critical Level for oxides of nitrogen (NO_x) has been transposed in the Air Quality Standards Regulations 2010. Additional values for daily NO_x and ammonia (NH₃) are also generally used as regulatory standards, although these have not been formally adopted.

The Critical Levels applied in this assessment are set out in Table 2.2 and apply regardless of the habitat type present at the habitat receptor. In the cases of SO₂ and NH₃, the greater sensitivity of lichens and bryophytes to this pollutant is reflected in the application of two Critical Levels, with a stricter Critical Level to be applied to locations where such species are present.

Table 2.2: Critical Levels (CL) – Protection of Vegetation and Ecosystems

Pollutant	Source	Concentration (µg/m ³)	Measured as
Oxides of nitrogen (NO _x)	EU air quality limit value	30	Annual mean
	UK target value	75	Daily mean
Sulphur dioxide (SO ₂)	EA Risk Assessment guidance	20	Annual mean, for sensitive lichen communities & bryophytes and ecosystems where lichens and bryophytes are an important part of the ecosystem’s integrity
		10	Annual mean, for all higher plants (all other ecosystems)
Ammonia (NH ₃)	UK Target Value	1	Annual mean, for sensitive lichen communities & bryophytes and ecosystems where lichens and bryophytes are an important part of the ecosystem’s integrity
		3	Annual mean, for all higher plants (all other ecosystems)

⁹ [Critical Loads and Critical Levels - a guide to the data provided in APIS | Air Pollution Information System](#)

Critical Load criteria for the deposition of nutrient nitrogen and acidifying species are dependent on the habitat type and species present and are specific to the sensitive receptors considered within the assessment. The relevant Critical Loads for the ecological receptors considered in this assessment are defined on the Centre for Ecology and Hydrology Air Pollution Information System (APIS) website¹⁰ and are detailed in Section 3.2.2.

2.2 Environmental Permitting Regulations

Where legislative ambient air quality limits or objectives are not specified for the pollutant species potentially released from the activities carried out under the Environmental Permitting (England and Wales) Regulations 2016 (as amended) ('EP Regulations'), Environmental Assessment Levels (EALs), published in the EA's Risk Assessment guidance¹¹ can be used to assess potential health effects on the general population. This includes an EAL for hourly concentrations of CO which can result from both the Baseline and Future operation of the FCC Unit and PCC Plant.

As well as the combustion emissions from the existing FCC Unit, emissions of amines and their breakdown (oxidation) products could occur directly from the PCC Plant to be retrofitted on the FCC Unit. In addition, amines and some of the breakdown products could further degrade in the atmosphere following release. Due to carbon capture being an emerging technology, there are limit EALs available in the latest version of the EA's Risk Assessment guidance; however, the EA has recently derived an EAL for one amine species, Mono-ethanolamine (MEA). It is understood that the EA are due to publish 8 further amine and degradation product EALs in the near future, however these were not available at the time of submission of this Environmental Permit variation.

The carbon capture plant licensor has reviewed the toxicological data available for the amine species within their Cansolv DC-103 solvent, proposed to be used in the carbon capture plant, in order to determine suitable EALs for the assessment of potential impacts from the amines and their degradation products potentially present in the PCC Plant emissions. The terms Amine 1, Amine 2 and Amine 3 have been used throughout this report and in the Main Supporting Document for ease of reference to the different amines species, to avoid confusion with the complicated naming of the individual amines species.

Information on the specific amine species and the supporting toxicological information is provided in Annex A and demonstrates that two of the amine species (Amine 1 and Amine 3) present in the emission are likely to be less toxic than MEA. For these species therefore it is proposed to use the published MEA EAL as a proxy to ensure that a conservative assessment is carried out.

Toxicological information for Amine 2 indicates that a more stringent EAL than that for MEA would be more appropriate, and therefore a species specific EAL has been proposed to ensure that a conservative assessment is carried out.

It is also known that some amines can potentially degrade (chemically react with oxygen) and form nitrosamines and nitramines (collectively referred to as N-amines) both during the carbon capture process itself and also in the environment, following release to the atmosphere. Therefore, the impacts of both directly released N-amines and the N-amines produced through atmospheric degradation of released amines have also been considered in the assessment.

The EA has adopted an EAL for N-nitrosodimethylamine (NDMA), of 0.2 nanograms (ng)/m³. It is understood that NDMA has been used for the EAL because this is considered to be one of the most toxic nitrosamines, and therefore results in a conservative EAL. Due to the limited information available on the toxicology of other N-amines, the EA have recently issued a briefing paper to the Carbon Capture and Storage Association (CCSA) (the EA's Amine EAL Briefing Note), recommending that the total N-amine concentration from PCC plant emissions should be compared with the NDMA EAL as a proxy, although it should be recognised that some of the degradation products will be less harmful, and therefore this is a very conservative assumption. This approach has been adopted in this assessment.

Other degradation products, such as ammonia, amides, formaldehyde and acetaldehyde may also result from the PCC Plant, and therefore these have also been included in the assessment. The EALs applicable for this assessment for the protection of human health are presented in Table 2.3.

¹⁰ www.apis.ac.uk

¹¹ [Air emissions risk assessment for your environmental permit - GOV.UK \(www.gov.uk\)](http://Air%20emissions%20risk%20assessment%20for%20your%20environmental%20permit%20-%20GOV.UK%20(www.gov.uk))

Table 2.3: Environmental Assessment Levels (EAL) – Human Health

Pollutant	Concentration (µg/m ³)	Measured as	Source of EAL
CO	30,000	Hourly mean	
Ammonia (NH ₃)	180	Annual mean	EA Risk Assessment guidance.
	2,500	Hourly mean	
Amine 1 and 3	400	Hourly mean	MEA EALs used as a proxy, with supporting information provided in Annex A.
	100	Daily mean	
Amine 2	75	Hourly mean	Amine specific EALs proposed based on supporting information provided in Annex A.
	17	Daily mean	
Total Nitrosamines	0.2ng/m ³	Annual mean	NDMA used as a proxy – based on the EA's Amine EAL Briefing Note.
Formaldehyde	100	30-minute mean	
	5	Annual mean	
Acetaldehyde	9,200	Hourly mean	EA Risk Assessment guidance.
	370	Annual mean	
Amide ¹	18	Hourly mean	
	0.6	Annual mean	

¹ EAL for Acrylamide used, as the lowest EAL of any amide listed in the EA Risk Assessment guidance, therefore ensuring a conservative assessment.

Throughout the remainder of this Appendix, NAQS objectives, Critical Levels and EALs are collectively referred to as Air Quality Assessment Levels (AQAL).

2.2.1 Human Health Significance Criteria

The EA's Risk Assessment guidance identifies a two-stage process for determining the impact of emissions to air from a process. The stage one screening criteria compares the process contribution (PC) (i.e. the modelled ground level pollutant concentration) with the relevant AQALs. The criteria states that an emission may be considered to have an insignificant impact where:

- Short term PC ≤10% of the AQAL; and,
- Long term PC ≤1% of the AQAL.

If both criteria are met, no further assessment is required, but if they are not met, the second stage of screening is applied.

The second stage of screening considers the PCs in the context of the existing background pollutant concentrations; the predicted environmental concentration (PEC) is considered acceptable where:

- Short term PC <20% of the short term AQAL minus twice the long-term background concentration; and
- Long term PEC (PC + background concentration) <70% of the AQAL.

The EA's Risk Assessment guidance indicates that where AQALs are likely to be breached as a result of contributions from an installation, or where installation releases constitute a major proportion of the AQAL, such releases are likely to be considered unacceptable.

Where the PEC is not predicted to exceed the AQAL and the proposed emissions comply with the BAT-AEL (or equivalent requirements) the emissions may be considered acceptable by the EA.

2.2.2 Ecological Significance Criteria

For European sites (Special Protection Areas (SPA), Special Areas of Conservation (SAC) or Ramsar sites) an assessment is made as to whether the emissions from an installation are *“likely to have a significant effect”*, and whether this could lead to an *“adverse effect on site integrity”*. This also includes Sites of Special Scientific Interest (SSSIs).

The EA's Risk Assessment guidance states that PCs may be considered to have an insignificant impact at the first stage of screening on these sites where:

- Short term PC $\leq 10\%$ of the AQAL; and,
- Long term PC $\leq 1\%$ of the AQAL.

If these requirements are not met for short term impacts, further assessment is required. For long term impacts, the PEC must be calculated and if it is less than 70% of the AQAL, the impacts are considered insignificant.

For SPAs, SACs and Ramsar sites, there is also a requirement to consider the ‘in combination’ (combined) impact of all permissions, plans or projects that affect the site. A cumulative assessment of impacts in-combination with the adjacent VPI Immingham LLP Combined Heat and Power Plant proposed PCC plants is provided in the Environmental Statement accompanying the Planning Applications for the PCC Plant, which is provided in Appendix B of the Main Supporting Document (see Volume 2, Appendix 6B).

For local nature sites, the assessment needs to determine whether the emissions are *“likely to damage”* the site. The EA's Risk Assessment guidance screening criteria states that where PCs are less than 100% of the short or long term AQAL, the impact of emissions is insignificant at these sites.

The impact of point source emissions on ecological receptors, through deposition of nutrient nitrogen or acidity, has been evaluated using the EA's and Natural England's guidance insignificance criterion of 1% of the long-term objective. Depositional impacts that are over 1% are not necessarily significant, but further assessment of the potential for impacts to occur on the relevant habitat type needs to be considered.

3. Receptors and Baseline Air Quality

3.1 Receptors

3.1.1 Human Health Receptors

Receptors potentially affected by the emissions from the Installation, including local residential and amenity receptors, have been identified through site knowledge and desk study of local mapping. Isoleth figures of pollutant dispersion have been examined to identify the receptors that will receive the highest point source contributions and these receptors have been included in the model set up as discrete receptors.

The receptors are selected to be representative of residential dwellings and recreational areas around the Installation and are shown in Table 3.1, and illustrated in Figure 3.1 (Annex B).

Table 3.1: Human Receptor Locations for Air Quality Assessment

Receptor I.D	Receptor	NGR Grid Reference	Approximate Distance and Direction from Installation
R1	Hazel Dene, Marsh Lane	517330, 417311	790m east
R2 ¹	Station House, Station Road	517333, 418345	1.6km northeast
R3	Fairfield House, North Garth	514687, 418769	1.9km northwest
R4	Old Vicarage, North Garth	514428, 418197	1.5km northwest
R5	Manor Farm, North Killingholme	514515, 417653	1.0km northwest
R6	Church Lane, North Killingholme	514763, 417331	635m northwest
R7	Westfield Farm, North Killingholme	514708, 416785	680m west
R8	Melrose, South Killingholme	515115, 416417	460m west
R9	Town St/ Humber Road, South Killingholme	515516, 416120	240m west
R10	South Killingholme Primary School	514880, 416120	760m west
R11	East End Farm	515935, 415730	100m west
R12	Immingham	517765, 415255	950m southeast

¹ R2 is currently understood to be an unoccupied residence owned by Able Humber Ports Limited, which is proposed to be demolished as part of Able Marine Energy Park enabling works

3.1.2 Ecological Receptors

The EA Risk Assessment guidance requires that the effects of stack emissions on designated ecological sites be assessed where they fall within set distances of the source, up to 10km (or 15km for large emitters) for European designated sites and up to 2km for nationally designated sites.

Statutory designated sites have been identified through a desk study of the Defra Magic mapping¹² website, which identifies SPAs, SACs, Ramsar sites, and SSSIs. In addition, non-statutory designated receptors have also been identified, including Local Wildlife Sites (LWSs) and Sites of Importance for

¹² Defra Magic mapping accessed at <http://magic.defra.gov.uk/MagicMap.aspx>

Nature Conservation (SINC). The relevant sites are listed below in Table 3.2 and shown in Figure 3.2 Annex B).

Table 3.2: Ecological Receptor Locations in the Vicinity of the Installation

Receptor I.D	Receptor	Designation	NGR Grid Reference		Approximate Distance and Direction from Installation
E1	Humber Estuary	SAC, SPA, Ramsar, SSSI	517235 - 517868	419385 - 418379	1.9m northeast
E2	North Killingholme Haven Pits	SSSI	516875	419530	2.6km north
E3	Swallow Wold	SSSI	516950	404990	10.7km south
E4	Wrawby Moor	SSSI	503350	411120	13.3km southwest
E5	Eastfield Road Railway Embankment	LWS	515313	417108	100m northwest
E6	Burkinshaws Covert	LWS	516432	417874	910m north
E7	Rosper Road Pools	LWS	517224	416937	500m east
E8	Chase Hill Wood	LWS	515702	418875	1.9km north
E9	Mayflower Wood Meadow	LWS	516000	415920	10m east
E10	Homestead Park Pond	LWS/ SINC	517935	415625	900m southeast
E11	Eastfield Road Pit	SINC	515350	417040	100m northwest

There are three additional SSSI within 15km of the Installation (Kirmington Pits, Kelsey Hill Gravel Pits and South Ferriby Chalk Pit) which are designated due to their geological features. It is therefore considered that these sites will not be affected by emissions from the Installation, as the Critical Levels and Critical Loads assigned to such sites are for the protection of vegetation and ecosystems only, and therefore they have been screened from further assessment.

In addition, it is understood that the Station Road Fields LWS that was located approximately 900m east of the Installation, has been lost due to the Able Marine Energy Park (AMEP) development.

3.2 Baseline Air Quality

No AQMAs have been declared for the Installation or surrounding nearby areas. There is a single AQMA designated for 24-hour mean PM₁₀ within the administrative boundary of North Lincolnshire Council (NLC). However, the AQMA is approximately 21km west of the Installation and covers an area surrounding the steelworks to the east of Scunthorpe. Given the prevailing wind direction in the vicinity of the Installation (i.e. from the south-west), it is considered unlikely that the emissions from the Installation would affect this AQMA.

The neighbouring council area to NLC (North East Lincolnshire (NELC)) has the nearest AQMA to the Installation, approximately 13km to the southeast in Grimsby, and is designated for the exceedance of the annual mean NO₂ concentration. Again, given the distance from the Installation, and the prevailing wind direction in the area, it is considered unlikely that this would be affected by emissions from the Installation.

Based on Defra forecast models and local authority monitoring data, no exceedances of the AQS standards have been identified in the vicinity of the Installation.

Existing air quality conditions in the vicinity of the Installation have been evaluated through a review of local authority air quality management reports, Defra published data and other sources. The key pollutants of concern resulting from Baseline and Future operation of the Installation for which monitoring data is available are NO_x, NO₂, CO, SO₂ and particulates, therefore the assessment of

baseline conditions considers these pollutants only. In addition, baseline NH₃ concentrations have been derived from the APIS website.

It should be noted that as the FCC Unit is an existing emission source, the background concentrations applied in the assessment will include the contribution of this source to the baseline conditions. The assessment therefore includes some double counting of the emissions from the Installation in both the Baseline and Future Assessment, therefore represents very much a worst case.

There is no background monitoring data for the other trace species emitted from the Future operation of the Installation (amines, N-amines, amides). N-amine levels are likely to be below the limit of detection of any monitoring technique currently available for these species.

3.2.1 Human Health Background Concentrations

Under the requirements of Part IV of the Environment Act, NLC and NELC have a duty to undertake the periodic review and assessment of local air quality within their administrative areas. As previously stated, there are no AQMAs declared within 10km of the Installation, and therefore it is considered unlikely that the Installation will result in significant impact at any AQMA.

The 2021 Air Quality Annual Status Report, available from NLC, stated that during 2020 there were no recorded exceedances of the relevant air quality objectives for NO₂, particulate or SO₂ within the area. The review and assessment process has not identified any air quality issues in the vicinity of the Installation, nor the air quality study area surrounding it.

Automatic monitoring for NO₂ is undertaken by NLC at three locations within the borough, with one of the monitoring sites located within 2km of the Installation (CM6 Killingholme School monitoring site located in South Killingholme). The monitoring site is classified as being at an urban industrial background location.

Typically, annual mean concentrations of NO₂ and PM₁₀ at the automatic monitoring site have shown a reduction in NO₂ concentrations since 2014. Summaries of the monitoring data from 2016 are presented in Table 3.3.

Table 3.3: NLC Annual Mean Automatic Monitoring Data for Killingholme School CM6

Monitoring Site	2016 (µg/m ³)	2017 (µg/m ³)	2018 (µg/m ³)	2019 (µg/m ³)	2020 (µg/m ³)	2021 (µg/m ³)	2022 (µg/m ³)
NO ₂ Concentrations	17.0	16.0	18.0	15.0	13.0	14.0	13.8
PM ₁₀ Concentrations	18	18	19	19	15	9	14.9
SO ₂ Concentrations	3.3	2.8	3.7	3.4	3.9	3.6	3.4

NLC also operates a number of NO₂ diffusion tubes within the borough including background, roadside and kerbside locations. The closest tubes to the Installation are located within South Killingholme. Summary monitoring data is presented in Table 3.4.

Table 3.4: NLC Annual Mean NO₂ Diffusion Tube Monitoring Data

Monitoring Site	Distance to Site (km)	Monitor Type	2016 (µg/m ³)	2017 (µg/m ³)	2018 (µg/m ³)	2019 (µg/m ³)	2020 (µg/m ³)	2021 (µg/m ³)
DT13 Ulceby Road, Killingholme	2.5	Roadside	31	20	17	17	18.2	17.4
DT14 Killingholme NOx Analyser	2.3	Roadside	31	27	28	29	26.4	28.4
DT15 Humber Road, Chip Shop	1.7	Urban Background	21	19	20	18	16.6	17.9
DT16 Humber Road, LP 695	1.8	Roadside	26	25	26	25	23.4	22.0

Background data has also been obtained from Defra published maps for the locations of likely maximum impact from point source emissions from the Installation, and at identified sensitive receptor locations. Background mapping data for 2018 (based on 2018 background maps) is conservatively assumed to be representative of the background concentrations when the Installation becomes operational (assumed to be 2027 at the earliest); as general trends are showing a reduction in both NO₂ and PM₁₀ concentrations over time this is considered to be a conservative assumption. Background data assumed for the maximum impact location from the point source emissions is provided in Table 3.5 and indicates NO₂ and CO concentrations within the vicinity of the Installation are consistently well below the NAQS annual mean objectives.

Table 3.5: Defra Background Air Quality Data (Annual Mean) (1km² grid average)

Location	Pollutant	2018 (µg/m ³)
Maximum Impact Location (down-wind of the Installation Site at 517500, 418500)	NO ₂	14.4
	CO ¹	114
	PM ₁₀	15.0
	PM _{2.5}	8.7
	SO ₂	9.8

¹ Defra background mapping from 2001 (with appropriate adjustment factor applied for 2018)

It can be seen from Table 3.5 that the Defra NO₂ background mapping data is lower than the automatic monitoring data at Killingholme School for 2018 - 2019. The PM₁₀ values for 2019 – 2021 for the Killingholme School monitoring site range between 9 - 19µg/m³ between 2019 and 2022, with the Defra data being in the middle of this range. SO₂ concentrations at the Killingholme School monitoring site are much lower than those from the Defra mapping, and it is considered that this is due to the fact that the Defra SO₂ backgrounds have not been updated since 2001.

The 2018 Defra background maps have also been consulted for each identified human health receptor location, with NO₂ concentrations ranging from 11.2 – 14.4µg/m³, therefore in order to carry out a conservative assessment, the concentrations measured during 2019 at the Killingholme School automatic monitoring station (15µg/m³) have been assumed to be representative of all human health receptors in the immediate vicinity of the Installation. The data from 2020 and 2021 is not going to be used due to the temporary impact of COVID-19 on NO₂ concentrations, and thus might not be representative of air quality trends.

Data used in the assessment, and its source is provided in Table 3.6.

Table 3.6: Baseline Concentrations for Human Health Receptors Used in Assessment

Pollutant	Background Concentration used for Assessment ($\mu\text{g}/\text{m}^3$)	Source of Data
NO ₂	15.0	Killingholme School Automatic Monitor 2019.
CO	118	Defra background mapping from 2001 (with appropriate adjustment factor applied for 2018). Maximum concentration at all receptor locations.
SO ₂	3.4	Killingholme School Urban Industrial (Automatic) Monitor 2019.
Particulates (PM ₁₀)	19	Killingholme School Automatic Monitor 2019.
Particulates (PM _{2.5})	11.8	Defra background mapping from 2018 (with no future adjustment applied). Maximum concentration at all receptor locations.
NH ₃	1.6	APIS website 2019 – 2021. Maximum concentration at all receptor locations.
Amines	No background data available	

Short-term (hourly) background concentrations have been calculated by multiplying the selected annual mean background concentration by a factor of two, in accordance with the EA Risk Assessment guidance.

In addition to the background concentrations used to determine the Predicted Environmental Concentrations of pollutants released, hourly background concentrations of NO_x, NO₂ and ozone (O₃) for the meteorological years used within the dispersion model are required for input into the Amines Chemistry Module. NO_x and NO₂ background concentrations are available from the Killingholme School automatic monitoring site in South Killingholme, whereas O₃ concentrations have been taken from the Automatic Urban and Rural Network (AURN) monitor at Hull Freetown, being the closest site with O₃ monitoring data available.

3.2.2 Ecological Receptors Background Concentrations

The background concentrations for ecological receptors have been obtained from the APIS website and are shown in Table 3.7 and Table 3.8.

Table 3.7: Baseline Data for Ecological Receptors (APIS Background)

Receptor I.D.	Ecology Site	NO _x ($\mu\text{g}/\text{m}^3$)	SO ₂ ($\mu\text{g}/\text{m}^3$)	NH ₃ ($\mu\text{g}/\text{m}^3$)
E1	Humber Estuary – worst case location	20.0	3.2	1.7
E2	North Killingholme Haven Pits	18.0	3.4	1.8
E3	Swallow Wold	10.3	1.0	1.5
E4	Wrawby Moor	11.0	1.6	2.3
E5	Eastfield Road Railway Embankment	14.4	3.3	1.7
E6	Burkinshaws Covert	14.8	3.0	1.6
E7	Rosper Road Pools	15.8	3.1	1.6
E8	Chase Hill Wood	16.3	3.2	1.8

Receptor I.D.	Ecology Site	NOx (µg/m ³)	SO ₂ (µg/m ³)	NH ₃ (µg/m ³)
E9	Mayflower Wood Meadow	13.2	2.9	1.6
E10	Homestead Park Pond	14.5	3.1	1.6
E11	Eastfield Road Pit	14.4	3.3	1.7

Short-term (daily) background concentrations for NOx have been calculated by multiplying the selected annual mean background concentration by a factor of 1.5, as advised by the EA on previous projects.

Table 3.8: Baseline Deposition Data (APIS Background)

Receptor I.D.	Ecology Site	Habitat Type and Location	Grid Reference x, y	N-Deposition (kg N/Ha/Yr)	Acid Deposition	
					Keq N/Ha/Yr)	Keq S/Ha/Yr)
E1a		Coastal stable dunes grasslands - acid type – Cleethorpes	533500, 405590	13.5	0.60	0.15
E1b		Coastal stable dunes grasslands - calcareous type – Spurn Point	539700, 411020	11.9	0.85	0.14
E1c	Humber Estuary	Shifting coastal dunes – Saltfleet	546535, 392760	13.2	0.93	0.11
E1d		Wetland and Reedbeds – North Killingholme Pits	516875, 419530	17.0	1.21	0.28
E1e		Pioneer, low, saltmarshes	517353, 419059	17.0	1.21	0.28
E1e		Low and medium altitude hay meadows	513431, 423906	16.8	1.20	0.19
E2	North Killingholme Haven Pits	Mid upper saltmarshes	516875, 419530	17.0	1.21	0.28
E3	Swallow Wold	Sub-atlantic semi-dry calcareous grassland	516950, 404990	16.1	1.15	0.15
E4a	Wrawby Moor	Non-mediterranean dry acid and neutral closed grassland	503305, 410990	19.6	1.78	0.19
E4b		Meso- and eutrophic Quercus woodland	503280, 411180	33.1	2.36	0.21
E5	Eastfield Road Railway Embankment	Neutral grassland	515313, 417108	16.9	1.46	0.38
E6	Burkinshaws Covert	Broadleaved woodland	516432, 417874	27.9	2.44	0.45
E7	Rosper Road Pools	Wetland and reedbeds	517224, 416937	16.3	1.46	0.38

Receptor I.D.	Ecology Site	Habitat Type and Location	Grid Reference x, y	N-Deposition (kg N/Ha/Yr)	Acid Deposition	
					Keq N/Ha/Yr)	Keq S/Ha/Yr)
E8	Chase Hill Wood	Broadleaved woodland	515702, 418875	28.3	2.44	0.45
E9	Mayflower Wood Meadow	Neutral grassland	516000, 415920	16.3	1.46	0.38
E10	Homestead Park Pond	Standing open water and neutral grassland	517935, 415625	16.1	1.46	0.38
E11	Eastfield Road Pit	Calcareous grassland	515350, 417040	16.9	1.46	0.38

Data on APIS is only pertinent to statutory ecological sites, however advice from the project ecologists has provided the lowest appropriate critical load for the non-statutory sites included in the assessment (E5 - E11). There are no equivalent values for acid deposition, therefore acid deposition data presented in this report is limited to statutory ecological sites only.

4. Dispersion Model Parameters

4.1 Emissions Inventory

There will be no change to the emissions from any other source at the Humber Refinery as a result of this Permit variation and therefore only the sources that currently release from the FCC stack are considered in the assessment. All existing sources at the Installation are considered to already have been taken into account in the existing background concentrations used for the assessment.

4.1.1 Baseline Assessment

The Baseline Assessment has considered the impact of the existing combustion emissions from the 115m high FCC Unit stack (Emission Point A6) on local air quality under normal operating conditions, assumed to be operating for 8,760 hours per year, as this represents the worst-case for annual average impacts.

Emission Point A6 comprises emissions from a number of sources; the FCC Feed Heater and the Isostripper reboiler (Emission Point A6a) and also the FCC Regenerator (Emission Point A6b). The existing emissions of all sources venting to the FCC Unit stack have been modelled, to determine the impact associated with the current emissions from this source (i.e. the 'Baseline Assessment'). Emissions from the FCC Unit stack have been modelled at the current emission levels for A6a and A6b, as detailed in the Environmental Permit for the Installation. Only monthly mean emission limits values are specified for the FCC Unit stack within the Permit and therefore for the purpose of assessment, these have been used for all averaging periods (i.e. annual averages, daily averages and hourly averages).

There is no separate airflow monitoring for A6a and A6b, and therefore the combined airflow has been used to calculate the release rates for each source. It is recognised that this will lead to a slight overprediction of the existing impacts.

For the modelled emissions the release rates have been summed for the combined A6 source.

The modelled emissions for the Baseline Assessment are provided in Table 4.1.

Table 4.1: Stack Emission Parameters for Baseline Emission Sources

Emission Point Ref.	Emission Source	Location (x, y)	Stack Height (m)	Flue Diameter (m)	Release Temp (°C)	Flue Airflow (actual) Am ³ /s	Flue H ₂ O Content (%)	Flue O ₂ content (dry) (%)	Flue flow at reference conditions (Nm ³ /s) ¹	Flue gas exit velocity (m/s)	Pollutant	Existing Emission Limits Assessed	
												Emission Conc ² (mg/Nm ³)	Release Rate (g/s)
A6a	FCC Feed Heater and the Isostripper reboiler										NOx	150	7.0
											CO	100	4.7
											Particulates	5	0.2
											SO ₂	35	1.6
A6b	FCC Regenerator	515712, 416838	115	2.8	273	102	9.8	2.8	46.5	16.6	NOx	300	14.0
											CO	200	9.3
											Particulates	50	2.3
											SO ₂	800	37.2
											NH ₃	15	0.7
A6	FCC Unit Combined										NOx	-	21.0
											CO	-	14.0
											Particulates	-	2.6
											SO ₂	-	38.8
											NH ₃	-	0.7

¹ Normalised conditions to 0°C, 101.325 kPa, dry and ref O₂ (reference O₂ 3%)

4.1.2 Future Assessment

The existing FCC Regenerator emission will vent to the new PCC Plant via a new Selective Catalytic Reduction (SCR) plant and a new Wet Gas Scrubber (WGS) and Wet Electric Precipitator (Wet ESP), which will reduce the combustion emissions of NO₂, SO₂ and particulates from the FCC Regenerator in order to optimise the PCC Plant process, as detailed in the Main Supporting Document.

There may be times when the PCC Plant is not operational, specifically when the WGS is first commissioned, as this will be prior to the PCC Plant becoming operational, and also potentially before the T&S Network is available. Therefore, the emissions occurring continuously from either the WGS or the PCC Plant have both been assessed for the Future Assessment. Emissions will only ever occur from one of these sources at once, with the WGS stack only venting emissions when the PCC Plant is not operational.

Only the emissions from the FCC Regenerator will be directed to the PCC Plant, and the FCC Feed Heater and the Isostripper reboiler will continue to release from the existing FCC Unit stack. As such, the emissions from the existing FCC Feed Heater and the Isostripper reboiler have been modelled from the existing FCC Unit stack at the existing release parameters, based on design data produced by the project engineers.

For the Future Assessment, due to the addition of the SCR plant and the WGS to reduce the FCC combustion emissions, the concentrations of these pollutants will be lower than the current emission values for the FCC Unit Stack. As such, new annual emission limits for NO_x, SO₂, particulates and ammonia have been proposed in the Main Supporting Document, and these have been used for the assessment of annual average impacts.

The Main Supporting Document also details how the emission limits for NO_x and SO₂ for the FCC stack also form part of the Humber Refinery's Integrated Emissions Management Technique (IMET). The Humber Refinery employs the IMET (or "BRef Bubble"), as detailed in their existing Environmental Permit, to manage the overall performance of the Refinery's emission sources on a monthly concentration basis in accordance with the Refineries BAT conclusions.

The FCC Unit Regenerator contributes a large proportion of both the NO_x and SO₂ BRef Bubble ELVs, as it is the largest single flue gas flow source at the Humber Refinery. As such, in order to not adversely impact the operation of the Refinery as a whole, it is proposed that the WGS and PCC Plant stacks also has higher monthly ELVs, which will be applied for the BRef Bubble calculations within the Environment Permit. Whilst emissions from the WGS stack or PCC Plant stack would never actually occur at these higher ELVs, they have been used to assess short term impacts in this assessment, at the request of the Environment Agency during pre-application discussions.

BAT-AELs are defined in the Refining of Mineral Oil and Gas BAT BRef (Refineries BRef) (European Commission, 2015) for NO_x, SO₂, particulates, CO and NH₃ emissions from catalytic crackers, and therefore where appropriate these values have been applied in the assessment of the future emissions from the WGS/ PCC Plant stacks, as described in the Main Supporting Document. Whilst it is proposed that the monthly NO_x limit of 300mg/Nm³ for the FCC stack is retained for the WGS/ PCC Plant stacks, it is proposed that the SO₂ monthly limit is reduced from 800 to 600mg/Nm³. As discussed in the Main Supporting Document, it may be that lower monthly ELVs for NO_x and SO₂ can be achieved, however this is currently being investigated by the Refinery and will be resolved during the Environmental Permit determination. To ensure a worst-case assessment is carried out, these higher values have been applied.

The stack conditions for the WGS and PCC Plant are based on design data, produced by the project engineers.

Particulate emissions are in part present due to combustion and also due to carryover of the catalyst fines into the flue gas. The WGS will reduce particulate emissions from the FCC Unit considerably over currently emission concentrations (from 50mg/Nm³ to a proposed 10mg/Nm³), as such the metals potentially present in the catalyst fines (nickel, vanadium and antimony) will in turn be lower than current emission concentrations. The current Environmental Permit does not contain an ELV for metals, however it does require that metals are monitored every 6 months.

The emission of metals has been assessed using the Environment Agency's H1 screening tool and can be screened as being insignificant. As such, metals have not been considered in the dispersion model. The H1 assessment carried out is detailed in the Main Supporting Document.

In addition, emissions of amines present within the Cansolv DC-103 solvent used within the PCC Plant, and their potential degradation products may also be present. There are currently no BAT-AELs relating to PCC processes, and although the EA has provided BAT guidance for PCC plants, the guidance does not propose any specific ELVs at this time, as it is intended that these will be developed once PCC plants become operational in the UK, and collated monitoring data can confirm suitable levels for which the BAT-AELs should be set.

Emissions from the PCC Plant are therefore based on levels that have been advised by the solvent supplier, as achievable emissions from their PCC process. Shell have developed a proprietary amine emissions model, which predicts the emissions of the three amines species and their nitrosamine emissions and accounts for both vapor phase and liquid entrainment emissions. Vapor phase emissions are calculated based on volatilities and activity coefficients determined experimentally, and the gas-liquid equilibrium in the wash sections at the top of the absorber.

Emissions due to entrainment are calculated based on known entrainment rates from the standard internals used in the absorber, as well as droplets capture efficiencies of the wash and demister sections at the top of the absorber. Potential aerosol-induced entrainment are also accounted for based on the inlet gas composition and application aerosol risk profile.

Operational data gathered from pilot, demonstration and commercial units (mainly the Boundary Dam plant, which performs regular emissions sampling and analysis of amine and nitrosamine emissions) has been used to develop and improve the Shell model. The model is reviewed and improved as new data is gathered (use of on-line monitoring and lower quantification limits with improved analytical methods).

Amine 3 is a minor component of the solvent, with low volatility, and thus accounts for a negligible fraction of the emitted amines, usually not being detected in the stack gas. However, recent improvements in the sensitivity of the analytical methods used to analyse extractive (impinger set) gas samples, to ppbv or sub-ppbv levels, have allowed detection of Amine 3 in a few samples from a 2023 test campaign performed at Technology Centre Mongstad, although at concentrations not exceeding 0.4% of the total Amine 1 emission. For this reason, and as the proposed proxy EALs for Amine 1 and 3 are the same, Amine 1 and Amine 3 have been grouped together for the assessment of impact.

Only two N-amine species (N-amine 1 and N-amine 2) are shown to occur as a direct emission from the PCC Plant's stack, which are the degradation products of Amine 1 and Amine 2 respectively. Amine 3 is a tertiary amine that does not form stable nitrosamines (as described in Section 5.3.2) and therefore there is no N-amine 3 present in the emission.

At the current time, the final stack height for the WGS and CO₂ Absorber has not been confirmed and will only be finalised following detailed design. The current design shows the height to be 65 – 70m above ground level. A height of 65m has been assumed for the dispersion modelling assessment as this will lead to the worst-case impacts. A higher stack would improve dispersion and therefore result in lower impacts.

The data provided in Table 4.2 represents the anticipated emissions from the PCC Plant and WGS, as based on the current PCC Plant design.

Table 4.2: Assessed Stack Emission Parameters for Future Emission Sources

Emission Point Ref.	Emission Source	Location (x, y)	Stack Height (m)	Flue Diameter (m)	Release Temp (°C)	Airflow (actual) Am ³ /s	H ₂ O (%)	O ₂ (dry) (%)	Airflow (reference) (Nm ³ /s) ¹	Exit velocity (m/s)	Pollutant	Annual Emissions		Monthly Emissions	
												Emission Conc ² (mg/Nm ³)	Release Rate (g/s)	Emission Conc ² (mg/Nm ³)	Release Rate (g/s)
A6a	FCC Feed Heater and the Isostripper reboiler	515712, 416838	115	2.8	380	33.4	11.0	9.4	7.7	5.4	NOx	150	1.15	-	-
											CO	100	0.77	-	-
											Particulates	5	0.04	-	-
											SO ₂	35	0.27	-	-
New Emission Point A6c	PCC Plant	515598, 416841	65	2.0	49	74.4	7.7	5.4	50.4	23.7	NOx	50	2.52	300	15.1
											CO	100	5.04	-	-
											Particulates	10	0.50	-	-
											SO ₂	50	2.52	600	30.3
											NH ₃	5	0.25	-	-
											Amine 1 & 3	1.0	0.050	-	-
											Amine 2	0.11	0.0055	-	-
											N-amine 1	0.0019	0.0001	-	-
											N-amine 2	0.0010	0.00005	-	-
											Amide	0.032	0.0016	-	-
Formaldehyde	0.067	0.0034	-	-											
Acetaldehyde	0.20	0.0099	-	-											
New Emission Point A6d ²	WGS Stack	515604, 416816	65	3.1	42	80.4	4.8	4.0	62.6	11.0	NOx	50	3.13	300	18.8
											CO	100	6.26	-	-
											Particulates	10	0.63	-	-
											SO ₂	50	3.13	600	37.6
											NH ₃	5	0.31	-	-

¹ Normalised conditions to 0°C, 101.325 kPa, dry and ref O₂ (reference O₂ 3%)

² Emissions will only vent via this Emission Point when the PCC Plant is not operational

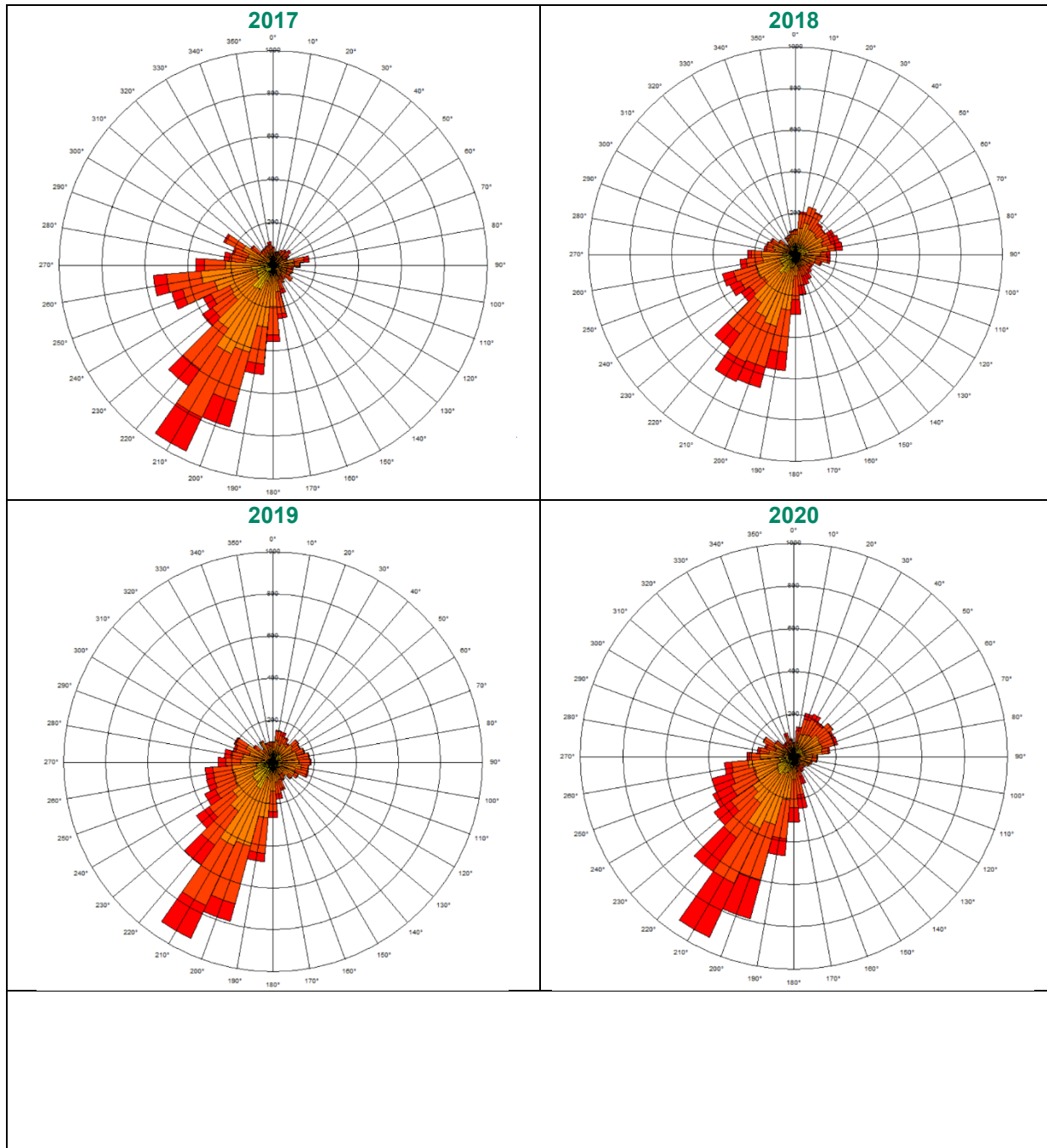
4.2 Meteorological Data

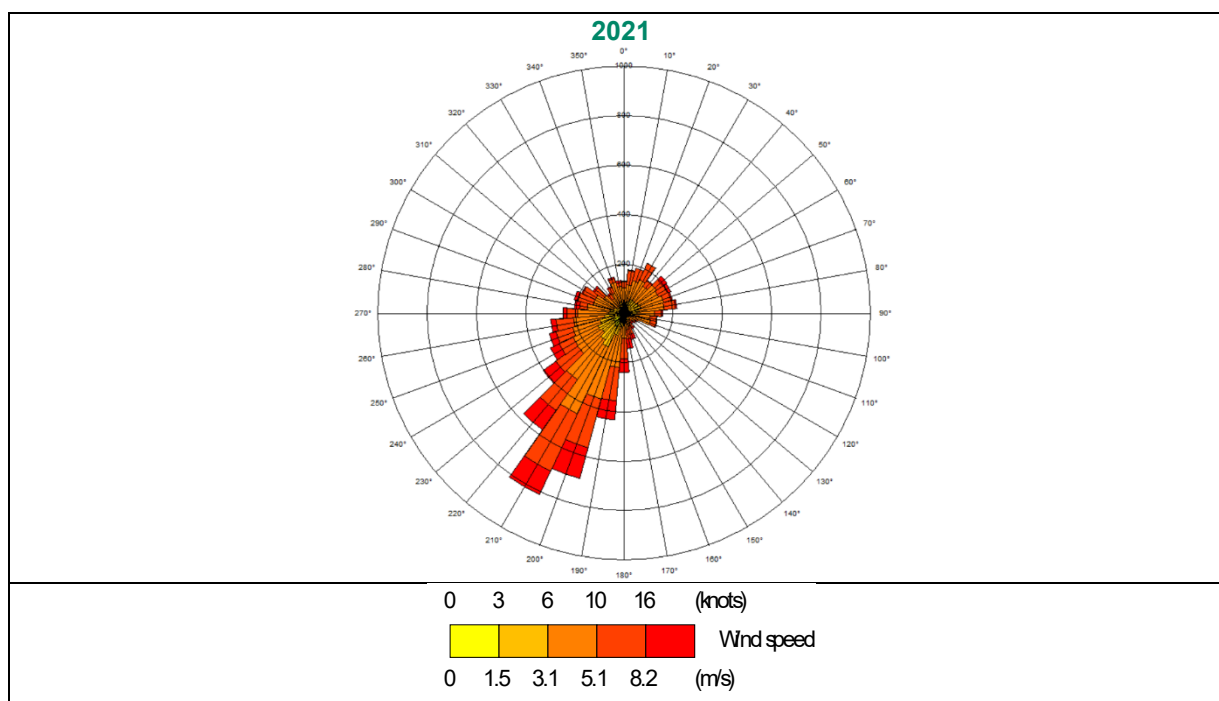
Actual measured hourly-sequential meteorological data is available for input into dispersion models, and it is important to select data as representative as possible for the site that is modelled. This is usually achieved by selecting a meteorological station as close to the site as possible, although other stations may be used if the local terrain and conditions vary considerably, or if the station does not provide sufficient data.

The meteorological site that was selected for the assessment is Humberside Airport, located approximately 9.5km south-west of the Installation, at a flat airfield in a principally agricultural area, and therefore a surface roughness of 0.2m (representative of minimum agricultural areas) has been selected for the meteorological site.

The modelling for this assessment has utilised five years of meteorological data for the period 2017 - 2021, and the worst-case impacts from all years modelled has been used in the assessment. The sensitivity of the results to different years' data is discussed in Annex C. The wind roses for Humberside Airport for 2017 to 2021 are provided in Figure 4.1.

Figure 4.1: Wind Rose, Humberside Airport 2017 - 2021





4.3 Buildings and Terrain

The presence of buildings or structures near to the emission points can have a significant effect on the dispersion of emissions. The wind field can become entrained into the wake of buildings, which causes the wind to be directed to ground level more rapidly than in the absence of a building. If an emission is entrained into this deviated wind field, this can give rise to elevated ground-level concentrations. Building effects are typically considered where a structure of height greater than 40% of the stack height is situated within 8 - 10 stack heights of the emissions source.

Buildings associated with the Installation (and the surrounding area) that are considered to be of sufficient height and volume to potentially impact on the dispersion of emissions from the stacks have been included in the dispersion model.

Parameters representing the buildings included in the model are shown in Table 4.3 and are illustrated in Figure 4.2 (Annex B).

Table 4.3: Buildings Incorporated into the Modelling Assessment

Building	Building Centre		Height (m) ¹	Length (m)	Width (m)
	x	y			
Wet Gas Scrubber	515604	416816	47	6.6	circular
CO ₂ Absorber	515598	416841	51	7.8	circular
CO ₂ Stripper	515588	416882	50	5.4	circular

The local area upwind and downwind of the Installation is flat, and predominantly industrial to the east, residential to the west and agricultural to the north and south. A surface roughness of 0.5m, corresponding to Parkland and Open Suburbia, has therefore been selected to represent the local terrain. The sensitivity of the model results to surface roughness is provided in Annex C.

Emissions from the Installation’s stacks have been modelled on a receptor grid that is 7km by 7km centred on the Installation. The grid spacing is 81m, which is considered appropriate for the height of the stacks included in the assessment.

In addition, the receptors detailed in Table 3.1 and Table 3.2 have been included as specified points within the model and therefore the predicted PCs at these locations are unaffected by grid spacing.

Site-specific terrain data has not been used in the model, as typically terrain data will only have a marked effect on predicted concentrations where hills with gradient of more than 1 in 10 are present in the vicinity of the source, which is not the case at the Installation.

4.4 NO_x to NO₂ Conversion

Emissions of NO_x from industrial point sources are typically dominated by nitric oxide (NO), with emissions from combustion sources typically in the ratio of NO to NO₂ of 9:1. However, it is NO₂ that has specified environmental standards due to its potential impact on human health. In the ambient air, NO is oxidised to NO₂ by the ozone present, and the rate of oxidation is dependent on the relative concentrations of NO and ozone in the ambient air.

For the purposes of detailed modelling, and in accordance with EA technical guidance, it is assumed that 70% of NO emitted from the stack is oxidised to NO₂ in the long term and 35% of the emitted NO is oxidised to NO₂ in the local vicinity of the Installation in the short-term.

4.5 Calculation of Deposition at Sensitive Ecological Receptors

The deposition of nutrient nitrogen and acid at sensitive ecological receptors has been calculated using the modelled PCs predicted at the relevant receptor points. The deposition rates are determined using conversion rates and factors contained within guidance published by the Institute of Air Quality Management (IAQM)¹³, which takes into account variations in the deposition mechanisms for different types of habitat.

The conversion rates and factors used in the assessment are shown in Table 4.4.

Table 4.4: Deposition Conversion Rates Ecological Receptors

Pollutant	Deposition Velocity Grasslands (m/s)	Deposition Velocity Woodlands (m/s)	Deposition Conversion Factors	
			Nutrient Nitrogen (µg/m ³ /s to kg/ha/yr)	Acid (µg/m ³ /s to keq/ha/yr)
NO _x as NO ₂	0.0015	0.003	95.9	6.84
NH ₃	0.02	0.03	259.7	18.5
Amines	0.02	0.03	259.7	18.5
SO ₂	0.012	0.024	-	9.84

The Environment Agency's AQMAU have recently issued for consultation a draft paper on the assessment of amines and their degradation products on nutrient nitrogen deposition¹⁴.

For the purpose of assessment, and from advice from the EA on other similar projects, the deposition of amine species has been assumed to be equivalent to that of NH₃. The conversion factor from µg/m³/s to kg N/ha/yr however relates to the nitrogen (N) that is available for deposition, which is calculated by dividing the molecular mass of N (i.e. 14) by the molecular mass of the species.

The AQMAU paper details conversion factors for MEA and DMA and their nitrosamines and nitramines. For MEA for example the conversion factor is calculated as 14/61 = 0.23, which then equates to a deposition conversion factor of 72. This is considerably lower than the conversion factor for NH₃ of 260. The other amine conversion factors detailed in the AQMAU paper range from 42 – 98.

¹³ Institute of Air Quality Management (2020). A Guide to the Assessment of Air Quality Impacts on Designated Nature Conservation Sites, Version 1.1 (Online). Available at: <https://iaqm.co.uk/text/guidance/air-quality-impacts-on-nature-sites-2020.pdf>

¹⁴ AQMAU (October 2023). Proposed assessment method to include amines and degradation products in nutrient nitrogen deposition estimations at ecological sites. Ref. AQMAU-C2600-RP01

However, as the AQMAU paper is currently in draft, for the purpose of this assessment it is considered that using the conversion factor for NH₃ for the amines in the emission will provide a very conservative assessment, at this stage. As the actual contribution to nitrogen deposition from the PCC Plant is dominated by an NH₃ emission of 5mg/Nm³ compared to the amine emission of 1.0mg/Nm³ it is considered that the contribution of amines to nitrogen deposition is minimal in any case.

4.6 Specialised Model Treatments

Emissions have been modelled such that they are not subject to dry and wet deposition or depleted through chemical reactions (except in the case of the amines and N-amines specific modelling). The assumption of continuity of mass is likely to result in an over-estimation of impacts at receptors, and therefore is considered to be conservative.

5. Assessment of Amine Degradation Products

5.1 Introduction

An assessment of amine degradation products has also been undertaken to determine the potential impact on human health from these species as a result of the emissions from the Future operation of the PCC Plant.

Whilst the assessment methodology of amines and other known potential degradation products (e.g. ammonia, amide, formaldehyde and acetaldehyde) has been covered in Section 4, the assessment method for assessing the atmospheric reactions that occur in amines, nitrosamines and nitramines (collectively referred to as N-amines) degradation products post release is more complex.

When the FCC Regenerator is operating with carbon capture, an amine-based solvent will be utilised as the scrubbing medium within the PCC Plant, to remove the carbon dioxide (CO₂) within the flue gas streams. 'Amine slip' can occur during the carbon capture process, resulting in direct emission of amines from the PCC Plant Absorber stack. Over time, the amine solvent used in the PCC Plant can degrade, through for example, reaction with nitrogen dioxide (NO₂) within the flue gases, which can result in the generation of N-amines within the amine solvent. Degradation is minimised through continuous solvent replenishment, monitoring and process control, as will be required under the Environmental Permit. Nevertheless, the amine slip emission from the PCC Plant is likely to include a very small fraction of N-amines.

Potentially of more significance is the subsequent atmospheric degradation of the amines released from the PCC Plant's Absorber stack.

The atmospheric chemistry of amines and N-amines is complex, dependent on atmospheric ozone and NO₂ concentrations, and with the generation of hydroxyl (OH) radical intermediates and other unstable intermediate species in UV light, however the principal mechanisms are understood and many studies have been made of the primary reaction rates and subsequent interactions between degradation products and these atmospheric species.

This section details the amine chemistry mechanisms likely to occur following release of amines and N-amines from the PCC Plant Absorber stack, and the specific parameters used for the modelling assessment for N-amines impacts from the Installation.

The assessment of N-amine emissions has been undertaken using the ADMS dispersion model. CERC have developed an Amine Chemistry module to simulate the atmospheric chemistry of amines and N-amines following their release from stacks. The chemistry scheme is based on the reactions initiated by the attack of an emitted gaseous amine or N-amine by a hydroxyl radical, and predicts the subsequent formation of nitrosamine and nitramines.

5.2 Discussion of Amines and N-Amines

The AQAL for NDMA is the only AQAL that has been derived to date for N-amine species. NDMA is the nitrosamine formed from dimethyl amine (DMA) degradation, and is the most widely studied nitrosamine, due to its known toxicity and carcinogenicity. As such, the AQAL proposed by the EA for the assessment of N-amines in the UK has been derived for NDMA. In the absence of other published values for N-amines, and in order to ensure a conservative assessment, the AQAL for NDMA has been applied to all N-amines in this assessment.

5.2.1 Toxicity of N-Amines

Many nitrosamines and nitramines are known or potential carcinogens. Whilst there is toxicity data available for a few of the more generally researched substances (e.g. NDMA and Nitrosodiethanolamine (NDELA)), the environmental toxicity of many of the other individual compounds is not well

understood¹⁵. NDMA is understood to be the most mutagenic (having the ability to cause a permanent change in an organism's genes) of the nitrosamines tested¹⁶.

The World Health Organisation (WHO) has published a Concise International Chemical Assessment Document on NDMA¹⁷, which states that laboratory studies have shown that exposure to NDMA results in tumours in all species examined; it is metabolised (in the body turned into new cells, energy and waste products by chemical processes) and does not bioaccumulate (build up within the tissues of an organism).

NDMA can be produced during water treatment processes involving chlorination and is also found in low levels in some pharmaceutical products, cured meat, fish, beer and tobacco smoke.

There is less information available on the toxicity of nitramines, which include nitro (-NO₂) compounds of the amine, such as dimethylnitramine (DMNA), however it is generally considered that they are of lower toxicity than nitrosamines. Although they are suspected carcinogens, none are classified as such by the International Agency for Research on Cancer (IARC). Animal carcinogenicity studies have indicated that DMNA is at least 6 times less toxic than NDMA¹⁸. This paper goes on to state that further quantitative evaluation of relevant nitramines is required to rank them against nitrosamine toxicity, in order that more refined and less conservative assessments, where currently all N-amines are assumed to be as toxic as the most toxic nitrosamine, can be carried out.

Detailed toxicology data is not currently available for the N-amines that may be formed by the degradation of the amines within the Cansolv DC-103 solvent, in terms of animal testing to derive of No Adverse Effect Levels (NOAEL). This testing is scheduled to be carried out once there is certainty that the PCC Plant project will be moving into construction and then commissioning. Once complete, the results of this testing can be used to derive species specific AQALs for the Cansolv N-amines to provide assurance that the predicted level of impacts are acceptable to protect human health.

That said, a bacterial reverse mutation assay (or Ames test) has been carried for the Cansolv N-amines. Such tests are widely employed as an initial screening to determine the mutagenic potential of new chemicals and drugs. In the test, bacterial cells are exposed to the test chemical in the presence and absence of metabolic activation. Mutations are determined by scoring bacterial growth (revertant colonies) on selective agar plates lacking the essential amino acid.

Tests carried out for the N-amines potentially formed by degradation of the Cansolv DC-103 solvent amines compared their mutagenic potential with the mutagenic potency of NDMA. The tests concluded that the toxicity of the N-amines potentially formed from Cansolv DC-103 is significantly lower than NDMA. The report detailing these conclusions is provided in Annex A and the results are summarised here. The nitrosamines formed from the use of the proposed Cansolv DC-103 solvent are named as 'Cansolv N-1' and 'Cansolv N-3' (which correspond to N-amine 1 and N-amine 2 in this assessment) in the report, a further N-amine 'Cansolv N-2' is also referenced, however this is not formed from the Cansolv DC-103 solvent and therefore is not relevant to this application.

The study found that NDMA was an exceedingly potent mutagen. Cansolv N-3 (N-amine 2) was found to be a clear mutagen, but approximately 50 times less potent than NDMA. Cansolv N-1 (N-amine 1) was found to be a very weak mutagen with a mutagenic potency approximately 2,000 times less than that of NDMA (Plew report provided in Annex A). N-amine 1 is the main nitrosamine formed from the Cansolv DC-103 formulation, with N-amine 2 being formed in lower amounts.

However, in order to ensure that a worst-case assessment is carried out, it has been assumed that N-amine emissions occurs solely as NDMA and therefore comparison of the predicted process contributions to the NDMA AQAL is considered to be very conservative.

¹⁵ Scottish Environmental Protection Agency (SEPA) (2015). Review of amine emissions from carbon capture systems, Version 2.01. 2015

¹⁶ Wagner, Osiol, Mitch and Plewa (2014). Comparative in Vitro Toxicity of Nitrosamines and Nitramines Associated with Amine-based Carbon Capture and Storage.

¹⁷ World Health Organisation. (2002). Concise International Chemical Assessment Document 38, N-Nitrosodimethylamine.

¹⁸ Gjernes E, Helgesen L I, Maree Y (2013) Health and environmental impact of amine based post combustion CO₂ capture.

5.2.2 N-Amine Emissions from Carbon Capture Processes

5.2.2.1 Direct N-Amine Emissions

The amine solvent used in the PCC Plant will be contained and recycled within the plant. Within the process, the amine solvent can degrade to N-amines through oxidation, thermal degradation and acid gas/ trace impurity reactions. Losses via the PCC Plant Absorber stack can therefore occur through entrainment of the solvent within the exhaust gas.

The main cause of degradation of the amine solvent is understood to be thermal degradation and therefore this can be reduced by ensuring that the maximum operating temperature of the re-boiler and CO₂ Stripper in the PCC Plant is carefully controlled.

Acid gas reactions can occur due to the other trace pollutant species present in the emission, in particular NO₂ and SO₂ within the exhaust gases FCC Regenerator. High concentrations of these species in the exhaust gas increases the rate of amine degradation to N-amines, and therefore the lower the overall pollutant release, the less N-amines will be generated by this mechanism. This is the driver for the installation of SCR abatement to reduce NO_x emissions, and the WGS to reduce SO₂ emissions, as described in the Main Supporting Document.

The solvent inventory will be managed to minimise the formation and release of degradation products through continuous bleed and regeneration of solvent within the process.

It is therefore considered that through best practice storage and management measures for the amine solvent, that its degradation within the PCC Plant can be minimised, and this requirement will be managed through the Environmental Permit. As a result, the direct emissions of N-amines into the atmosphere from the PCC Plant Absorber stack, are expected to be at very low levels (i.e. in the parts per billion (ppb) range).

5.2.2.2 Indirect N-Amine Emissions

The majority of N-amines resulting from releases from the carbon capture process are considered to form through reactions in the atmosphere post release. These atmospheric reactions are complex, and the rate of N-amine formation and subsequent destruction depends upon a range of factors.

The amine and N-amine degradation process in the atmosphere requires the presence of either an OH or a nitrate (NO₃) radical. The primary method for formation of N-amines in the atmosphere is a two-step process:

- an OH radical (daytime) or an NO₃ radical (night-time) removes a single hydrogen atom in the amine molecule to form a highly unstable amine radical; then
- the amine radical reacts with either an NO group to form a nitrosamine, or an NO₂ group to form a nitramine.

A variety of competing reactions can also take place, preventing the formation of N-amines:

- the amine can degrade to other radical species via removal of a non-amine hydrogen, or methyl group (this potential is known as the branching ratio);
- the amine radical can undergo competing reactions, with NO₂ and O₂ to form an imine (stable, and not toxic¹⁹); and
- the nitrosamine or nitramine can undergo further degradation or reverse reaction to the radical.

During daylight hours, atmospheric amine degradation is initiated by reaction with the OH radical (generated by photolysis of water (H₂O) by the action of ultraviolet (UV) light from sunlight). At night, in the absence of UV light, no OH radical is generated. Night-time reactions instead proceed by the much slower pathway of NO with ozone (O₃) to form NO₂ and subsequent reaction of NO₂ with O₃ to form the NO₃ radical; amine degradation is then initiated by reaction with the NO₃ radical to form N-amines. The nitrate radical is rapidly photolyzed (decomposed or separated by the action of light) in daylight and does not represent a likely reaction pathway during the daytime.

¹⁹ Helgesen/ Gjernes (2016). A way of qualifying Amine Based Capture Technologies with respect to Health and Environmental Properties.

The concentration of NO_x and O₃ available in the atmosphere therefore influences the reaction of amine to N-amines. The night-time reactions are slower than the daytime reactions as a result of the intermediate reaction step, therefore a higher rate of formation of N-amines results from daytime reactions.

The steady state concentration of N-amines can be calculated using reaction rate constants, usually derived through experimental studies. Such studies have indicated that not all amines released would convert to N-amines in the atmosphere, and the conversion of those amines that would degrade in the atmosphere to N-amines can take many hours to occur. Typical conversion rates are <1% although chamber experiments show a range of between 0 and 10%.

The ratio of reaction coefficients in the formation of (1) the amine radical (that can proceed to N-amine formation) or (2) an alternative species radical (that does not form N-amine) is described as the branching ratio; and for several amine species these have been published, although values range between published sources. The higher the branching ratio of the amine, the more likely it is to form N-amines. Known branching ratios are detailed in Table 5.1.

Table 5.1: Amine Branching Ratios

Amine Species	Branching Ratio	Source
Monoethanolamine (MEA)	0.05 – 0.15	CERC ²⁰ and Karl ²¹
Monomethylamine (MMA)	0.25	Nielson <i>et al</i> ²²
Dimethylamine (DMA)	0.38 - 0.42	CERC 2012

As can be seen in Table 5.1, the branching ratios for the primary amines MEA and MMA are lower than that for the secondary amine, DMA, therefore secondary amines are more likely to form N-amines. Tertiary amines must first degrade to a primary or secondary amine, through elimination of a hydrocarbon group, before further reaction to N-amine or other species can occur. Therefore, as other competing reactions may also occur, the likelihood of a tertiary amine forming an N-amine must also be lower than for a secondary amine; however, there is limited published data for tertiary amine reaction constants.

The Cansolv DC-103 supplier has provided specific branching ratios for the amines within their solvent (as detailed in Table 5.3), which have been determined by Professor Claus Nielson of the University of Oslo, the leading authority on amine atmospheric chemistry, through comparison of the characteristics of the amines within the Cansolv DC-103 solvent with published data for other amine species with similar characteristics. The branching ratio derived for the Amine 1 is similar to that of DMA, whereas the branching ratio for Amine 2 is lower.

In addition to the branching ratios, the concentration of ambient NO_x also influences the generation of N-amines from amines. From laboratory tests, it is known that when more NO_x is present, more amines are converted into N-amines. This function is called the ‘amino radical/ NO₂ reaction rate constant [k₄]’.

In the flue gas emitted from the PCC Plant, the NO_x is composed of around 90-95% NO to 5-10% NO₂. Once in the atmosphere, the NO will react with OH to form NO₂. The reaction of OH is preferential to NO rather than the amine as NO is more reactive. Therefore, as NO concentrations decrease spatially due to reaction with OH, there becomes more available OH radicals to react with the amines, so amine reaction will occur at greater distance from the stack. The details of this process are too uncertain to be accurately represented in the ADMS amines chemistry model and therefore the model does not include this time-delay in the initiation of the amine degradation reaction, assuming that this occurs

²⁰ Cambridge Environmental Research Consultants (2012). Contract number 257430174: Atmospheric Chemistry Modelling. Activity 1: Gaseous Phase Chemistry Modelling (initiated by hydroxyl radical). Prepared for CO₂ Capture Mongstad Project Gassnova SF.

²¹ Karl M, Herckes P, Mitch W and da Silva E F (2012). Atmospheric chemistry - Aqueous phase chemistry. Project 257430193: D6 Final report. SINTEF Materials and Chemistry. Process Technology 2012-05-25.

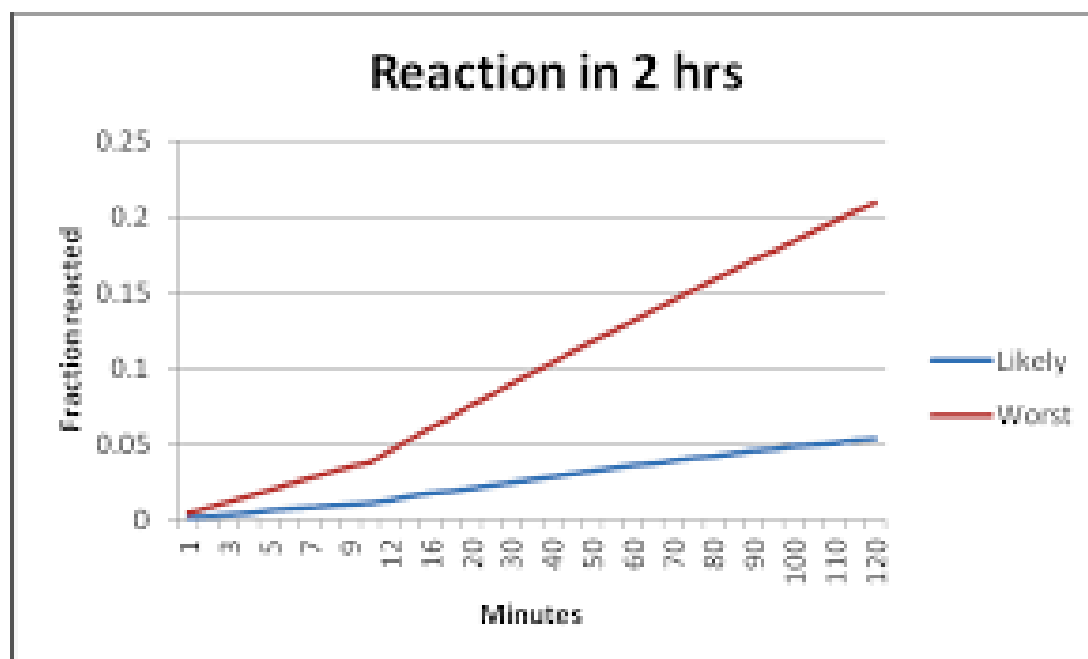
²² Nielsen C J, D’Anna B, Karl M, Aursnes M, Boreave A, Bossi R, Bunkan A J C, Glasius M, Hallquist M, Hansen A M K, Kristensen K, Mikoviny T, Maguta M M, Müller, M, Nguyen Q, Westerlund J, Salo K, Skov H, Stenstrøm Y, Wisthaler A (2011). Atmospheric Degradation of Amines (ADA). Summary report: Photo-oxidation of methylamine, dimethylamine and trimethylamine. CLIMIT project no. 201604. Kjeller, NILU.

instantly on release, therefore potentially resulting in higher concentrations in close proximity to the release stack.

The time delay of the amine reaction is described by the work carried out by Tonnesen²³, which demonstrated that less than 5% of the amines that would convert to N-amines would have done so in the first 10 minutes after release. After 2 hours, only 20% of the amines that would convert to N-amine would have done so. The work then goes on to estimate that it would take in the order of 10 hours for 100% conversion to occur. A graph showing this process is provided in Figure 5.1.

The fact that this time-delay is not taken into account in the ADMS amines chemistry module therefore is considered to result in an over-prediction in the process contributions at receptor locations predicted by the model. As such, the model results should be considered to be conservative.

Figure 5.1: Conversion of Amines to N-Amine in the Atmosphere Over Time



At night-time the NO_3 radical is formed from the reaction of O_3 with NO , and then NO_2 . Therefore, the reaction of NO to NO_2 is likely to be preferential to the reaction of NO_2 to NO_3 or NO_3 reacting with amines, which again will slow down the formation of N-amines. These details again are too uncertain to be accurately represented in the amines chemistry module and therefore are not included.

Only a proportion of the N-amines released or generated will remain as N-amines, as during daylight hours, N-amines are degraded to more basic amines, amides, ethanoic acid, ketones and simple nitrogen compounds in the presence of sunlight. At night no destruction of N-amines occurs.

5.3 N-Amines Assessment Methodology

5.3.1 Model Selection

ADMS is a modern dispersion model that has an extensive published validation history for use in the UK. This model has been extensively used throughout the UK to demonstrate regulatory compliance.

CERC has generated a specific amine chemistry module for use with the ADMS software, for the assessment of emissions of amines and their atmospheric degradation products. The model calculates the rate of amine degradation taking into account the reaction of amines with other species present in the exhaust gas (i.e. NO_2) and also with OH radicals in the atmosphere.

The ADMS Amines chemistry module is currently the only commercially available modelling software for evaluating the potential impacts of amines and amine degradation products. Whilst the ADMS model

²³ Tonnesen. (2011). Update and improvement of dispersion calculations for emissions to air from TCMs amine plant Part II – Likely case nitrosamines, nitramines and formaldehyde.

itself has been validated, the specific amines module has not been, and therefore the results should be regarded as indicative rather than definitive.

The module is based on established science considering published research on mechanisms of formation of toxic compounds. Although the module has not been validated, the ADMS air dispersion modelling algorithms are continually validated against real world situations, field campaigns and wind tunnel experiments.

The Environment Agency's AQMAU recognise in their evaluation of the module, provided in the EA's Amine Modelling guidance, state that *"There are various aspects of the current version of the module that suggest the estimation of toxic products might be conservative, however, the level of uncertainties in other input parameters can counteract this."*

Within the ADMS amines chemistry module, it is necessary to specify the amine, nitrosamine, nitramines and radical species that are being modelled. The module also requires the amine-specific branching ratio and the kinetic constants, k values (specific to each subsequent reaction rate). The rates of reaction may be derived through scientific research through experimental observation, for the more stable intermediate reaction species, or through theoretical computational calculations such as Transition State Theory.

Specific k values for Amine 1 within the Cansolv DC-103 solvent have been determined by Professor Claus Nielson of the University of Oslo through comparison of the characteristic of Amine 1 with published data for other amine species with similar characteristics (report provided in Annex A). The specific k values for Amine 2 have been sourced from literature for the specific amine species^{24 25}.

Amine 3 is a tertiary amine which Shell have found to not always be present in the emission. As a tertiary amine, it does not form stable nitrosamines and therefore there is no N-amine 3 present in the emission.

Due to the minute quantities of Amine 3 potentially present in the emission, and the fact that it does not form nitrosamines, the assessment only considers atmospheric processes concerning Amine 1 and 2.

5.3.2 Dispersion Model Input Parameters

As discussed above, the treatment of chemistry within the ADMS amines model requires a suite of reaction rate parameters derived from laboratory studies and other sources. The parameters required by the model in order to simulate amine chemistry for a specific amine(s) are detailed in Table 5.2.

Table 5.2: Amine Information for ADMS Model Set-Up

Parameter	Units	Notes
Amines Release	g/s	Emission concentrations as provided in Table 4.2
Direct N-amine Release	g/s	Emission concentrations as provided in Table 4.2.
Ratio of NO _x to NO ₂ in the exhaust gas	%	Sensitivity tested at 5% and 10%.
k1 = Amine/OH radical reaction rate constant	ppb/s	Rate constant provided by the solvent provider for the reaction of the amine with the hydroxyl radical ('•') (OH•).
k2 = Amino radical/O ₂ reaction rate constant	ppb/s	Rate constant provided by the solvent provider for the reaction of the amine• with O ₂ (to form imine).
k3 = Rate constant for formation of nitrosamine	ppb/s	Rate constant provided by the solvent provider for formation of nitrosamine from amine• and NO.
k4a = Rate constant for formation of nitramine	ppb/s	Rate constant provided by the solvent provider for formation of nitramine from amine• and NO ₂

²⁴ Wen Tan, Liang Zhu, Tomas Mikoviny, Claus J. Nielsen, Armin Wisthaler, Barbara D'Anna, Simen Antonsen, Yngve Stenstrøm, Naomi J. Farren, Jacqueline F. Hamilton, Graham A. Boustead, Alexander D. Brennan, Trevor Ingham, and Dwayne E. Heard. (2021). Experimental and Theoretical Study of the OH-Initiated Degradation of Piperazine under Simulated Atmospheric Conditions. The Journal of Physical Chemistry 125 (1), 411-422

²⁵ Nielson, C, Herrmann, H and Weller, C. (2012). Atmospheric chemistry and environmental impact of the use of amines in carbon capture and storage (CCS). Chem. Soc. Rev., 2012, 41, 6684–6704

Parameter	Units	Notes
k4 = Amino radical/NO ₂ reaction rate constant	ppb/s	Rate constant provided by the solvent provider for the reaction of the amine• with NO ₂ (to form imine or nitramine).
Branching Ratio	dimensionless	Branching ratio provided by the solvent provider for the amine/ OH• reaction – representing the reaction split, in formation of amine radical (amine• which further reacts to nitrosamine/ nitramine) and alternative hydrocarbaryl radical species.
Ratio of J (nitrosamine) to NO ₂	dimensionless	The ratio of the photolysis rate constants for the nitrosamine and NO ₂ - representing the relative atmospheric fluctuations of NO ₂ and nitrosamine formation as a result of UV light action.
c = OH concentration constant	s	OH concentration constant, derived for typical daytime atmosphere for the Installations's location. Site specific value calculated following the derivation of J (NO ₂).
Atmospheric oxygen concentration	ppb	Representing 21% O ₂ in air.
NO _x baseline	µg/m ³	Hourly values obtained for South Killingholme automatic monitor for the years of meteorological data used in the model.
NO ₂ baseline	µg/m ³	
Ozone Baseline	µg/m ³	Hourly values obtained for Hull Freetown automatic monitor (being the closest site with O ₃ data available) for the years of meteorological data used in the model

These parameters are entered into an ADMS Additional Input (.aai) file, which characterises the amine chemistry for the amine or N-amine species being assessed.

The specific input parameters used in the model are detailed in Table 5.3.

Table 5.3: Amines Chemistry Module Model Set-Up

Parameter	Units	Amine 1	Amine 2
Amines	mg/Nm ³	1.0	0.11
	g/s	0.050	0.0055
Direct N-amine (assumed to be NDMA, as a worst case)	mg/Nm ³	0.0019	0.0010
	g/s	0.0001	0.00005
Ratio of NO _x to NO ₂ in the exhaust gas	%	5 – 10%	5 – 10%
k1 = Amine/OH radical reaction rate constant	ppb/s	6.15 ²²	6.89 ²³
k2 = Amino radical/O ₂ reaction rate constant	ppb/s	1.33e-9 ²²	1.33e-9 ²⁴
k3 = Rate constant for formation of nitrosamine	ppb/s	0.00524 ²²	0.00235 ²⁴
k4a = Rate constant for formation of nitramine	ppb/s	7.82e-3 ¹⁸	7.82e-3 ¹⁸
k4 = Amino radical/NO ₂ reaction rate constant	ppb/s	0.009 ²²	0.0102 ²⁴
Branching Ratio	dimensionless	0.37 ²²	0.18 ²³
Ratio of J (nitrosamine) to NO ₂	dimensionless	0.34 ²²	0.34 ²⁴
OH concentration constant c ¹	Seconds	0.00101	0.00101

¹ Specifically derived for the Installation's location following CERC methodology. Based on the average of the 5 years of meteorological used in the assessment.

The model includes an option to take into account the effects of dilution of pollutant species and the entrainment of background pollutants. This 'dilution and entrainment' effect can be switched on and off, however it is recommended that it is switched on for all model runs involving amine chemistry. This is employed in the ADMS chemistry module (and recommended by CERC for low concentration plumes for the amines module) to represent slower mixing of the ambient air within the plume – rather than instantaneous mixing with an ambient air 'parcel' at plume release. The use of the dilution and entrainment option leads to a higher process contribution (as shown in Annex C). The dilution and entrainment option has therefore been included for the main assessment for conservatism.

In addition, the amine module includes an option for modelling unstable nitrosamines, which can be employed when modelling primary amines that do not form stable nitrosamines. In effect, this means that the model results generated when this option is selected include no nitrosamine component, with only nitramines being predicted to form. This option has not been included in the assessment, as it is not considered to be appropriate for the amines present within the solvent, as advised by the solvent provider.

The stack parameters, meteorology and structural parameters used in the dispersion modelling of N-amines are the same as those for other pollutants emitted from the PCC Plant.

5.3.2.1 Direct N-Amine Emissions

Direct N-amine emissions have been assumed to occur at the concentration provided by the solvent provider for the Installation, as detailed in Table 5.3. The Amines chemistry module has been used to determine the predicted process contributions of the Direct N-Amine emissions, taking account the atmospheric process that will occur to the N-amines following their release.

5.3.2.2 Indirect N-Amine Emissions

Indirect N-amine emissions have been modelled as an amine release from the PCC Plant, as detailed in Table 5.3.

6. Results and Conclusions

6.1 Baseline Assessment

6.1.1 Human Health Receptor Results

The baseline impacts of the existing emissions from the FFC Unit stack have been modelled at the emission parameters detailed in Table 4.1. The results at the worst-case identified receptor are shown in Table 6.1.

The modelled PCs have been compared to the AQALs for each pollutant released. The background concentrations (BC) have then been added to the modelled PCs to determine the Predicted Environmental Concentrations (PECs), which is again then compared to the AQAL.

As the existing source is already operational, the impact will already be presented within the BCs derived for the assessment and therefore there will be some degree of double counting of the FCC Unit emissions in the PECs.

Isopleths of the PCs for annual mean and hourly NO₂ concentrations are provided in Figure 6.1 and Figure 6.2 (Annex B).

Table 6.1: Baseline – Maximum Human Health Impacts at Any Receptor

Pollutant	Averaging Period	AQAL (µg/m ³)	PC (µg/m ³)	PC/ AQAL %	BC (µg/m ³)	PEC (µg/m ³)	PEC/ AQAL %
NO ₂	Annual mean	40	0.33	0.8%	15.0	15.3	38%
	1-hour mean (as the 99.79 th %ile of hourly averages)	200	3.9	2.0%	30.0	33.9	17%
CO	1-hour mean (as the 100 th %ile of hourly averages)	30,000	11.4	<0.1%	236.6	248.0	1%
	Maximum daily running 8-hour mean	10,000	7.2	0.1%	236.6	243.9	2%
PM ₁₀	Annual mean	40	0.06	0.1%	19.0	19.1	59%
	24-hour mean (as the 90.41 th %ile of hourly averages)	50	0.20	0.4%	38.0	38.2	76%
PM _{2.5}	Annual mean	20	0.06	0.3%	11.8	11.8	59%
	15-minute mean (as the 99.9 th %ile)	266	24.2	9.1%	6.7	30.9	12%
SO ₂	1-hour mean (as the 99.73 th %ile)	350	20.2	5.8%	6.7	26.9	8%
	24-hour mean (as the 99.18 th %ile)	125	6.5	5.2%	3.4	9.8	8%
NH ₃	Annual mean	180	0.02	<0.1%	2.2	2.2	1%
	1-hour mean (as the 100 th %ile of hourly averages)	2,500	0.6	<0.1%	4.4	5.0	0.2%

The annual average PCs at the worst-case human health receptor are less than 1% of the relevant AQAL, and therefore below EA's threshold for determining insignificance.

Likewise, all the short-term PC impacts are all less than the 10% of the relevant AQALs and therefore below the short-term screening threshold to demonstrate insignificance.

6.1.2 Ecological Receptor Results

The results of the dispersion modelling of predicted impacts of the Baseline emissions on sensitive ecological receptors are presented in Table 6.2 to Table 6.4. These tables set out the predicted PC compared to the atmospheric concentrations of NO_x, SO₂ and NH₃.

For all receptors, except E1, E2, E6 and E7 the predicted annual average NO_x concentrations are below 1% of the AQAL and therefore are considered insignificant. The PEC is under the 70% threshold for all sites, and therefore can be considered to be not significant. The background concentrations already include the contribution from the Installation, and therefore the actual PECs will be below these values.

The daily mean NO_x concentrations are less than 10% of the AQAL at all receptors, and therefore existing impacts are insignificant.

The annual average SO₂ impacts at E1, E2, E6, E7, E8 and E10 are all over the 1% threshold for insignificance, however the PECs are all well below 70% of the AQAL. Given that the background concentrations already include the contribution from the Installation, it is considered highly unlikely that the SO₂ AQAL would be exceeded as a result of the existing operation.

For all receptors the predicted annual average NH₃ concentrations are below the 1% screening threshold to demonstrate insignificance.

Depositional impacts of nutrient nitrogen and acid deposition are shown in Table 6.5 and Table 6.6 respectively. The Baseline nitrogen deposition results show that, on the whole, the existing impacts are less than the 1% threshold to demonstrate insignificance. Nitrogen deposition impacts at E1d, E7 and E8 are only slightly over the 1% threshold. Guidance from the IAQM clarifies that the 1% threshold is not intended to be precise to a set number of decimal places but to the nearest whole number, and therefore where an increase is shown to be 1.4%, as in the case of nitrogen deposition at Receptor E1d, for example, this can be rounded down to 1% for the purpose of assessment and therefore the impacts can be considered to still be insignificant.

The acid depositional impacts at receptor E4 is over the 1% screening threshold for insignificance. The background acid deposition at this habitat sites is already exceeding the relevant critical loads, and will already include the contribution from the existing Installation sources.

Table 6.2: Baseline – Ecological Impacts of NOx

Receptor ID	Annual Average Impacts						24-hour Average Impacts					
	AQAL (µg/m ³)	PC (µg/m ³)	PC/ AQAL %	BC (µg/m ³)	PEC (µg/m ³)	PEC/ AQAL %	AQAL (µg/m ³)	PC (µg/m ³)	PC/ AQAL %	BC (µg/m ³)	PEC (µg/m ³)	PEC/ AQAL %
E1		0.48	1.6%	20.0	20.5	68%		3.1	4%	30.0	33.1	44%
E2		0.50	1.7%	18.0	15.8	62%		3.3	4%	27.0	30.3	40%
E3		0.03	0.1%	10.3	10.3	34%		0.7	1%	15.5	16.1	22%
E4		0.04	0.1%	11.0	11.0	37%		0.6	1%	16.5	17.1	23%
E5		0.02	0.1%	14.4	14.4	48%		2.2	3%	21.6	23.6	31%
E6	30	0.68	2.3%	14.8	15.5	52%	75	5.3	7%	22.2	27.5	37%
E7		0.42	1.4%	15.8	16.2	54%		3.9	5%	23.7	27.6	37%
E8		0.31	1.0%	16.3	16.6	55%		3.6	4%	24.5	28.1	37%
E9		0.08	0.3%	13.2	13.3	44%		2.9	5%	19.8	22.7	30%
E10		0.16	0.5%	14.5	14.7	49%		2.7	4%	21.8	24.5	33%
E11		0.02	0.1%	14.4	14.4	48%		1.8	2%	21.6	23.4	31%

Table 6.3: Baseline – Annual Average Ecological Impacts of SO₂

Receptor ID	AQAL (µg/m ³)	PC (µg/m ³)	PC/ AQAL %	BC (µg/m ³)	PEC (µg/m ³)	PEC/ AQAL %
E1		0.90	4.5%	3.2	4.1	20%
E2		0.92	4.6%	3.4	4.3	22%
E3		0.05	0.3%	1.0	1.1	5%
E4		0.07	0.3%	1.6	1.7	8%
E5		0.04	0.2%	3.3	3.3	17%
E6	20	1.27	6.3%	3.0	4.3	21%
E7		0.79	3.9%	3.1	3.9	19%
E8		0.57	2.8%	3.2	3.8	19%
E9		0.15	0.8%	2.9	3.1	15%
E10		0.30	1.5%	3.1	3.4	17%
E11		0.03	0.2%	3.3	3.3	17%

Table 6.4: Baseline – Annual Average Ecological Impacts of NH₃

Receptor ID	AQAL (µg/m ³)	PC (µg/m ³)	PC/ AQAL %	BC (µg/m ³)	PEC (µg/m ³)	PEC/ AQAL %
E1	3	0.016	0.5%	1.7	1.72	57%
E2	3	0.017	0.6%	1.8	1.82	61%
E3	3	0.001	<0.1%	1.5	1.50	50%
E4	1	0.001	0.1%	2.3	2.30	230%
E5	3	0.001	<0.1%	1.7	1.70	57%
E6	3	0.023	0.8%	1.6	1.62	54%
E7	3	0.014	0.5%	1.6	1.61	54%
E8	3	0.010	0.3%	1.8	1.81	60%
E9	3	0.003	0.1%	1.6	1.60	53%
E10	3	0.005	0.2%	1.6	1.61	54%
E11	3	0.001	<0.1%	1.7	1.70	57%

Table 6.5: Baseline – Nitrogen Deposition at Ecological Receptors

Receptor ID	Most Stringent Critical Load Class for the Site	Background Nitrogen Deposition (kg N/ha/yr)	Lower value of Critical Load Range	PC (kg N/ha/yr)	PC% Critical Load	PEC (kg N/ha/yr)	PEC% Critical Load
E1a	Coastal stable dunes grasslands - acid type	13.5	8	0.006	0.1%	13.5	169%
E1b	Coastal stable dunes grasslands - calcareous type	11.9	10	0.006	0.1%	11.9	119%
E1c	Shifting coastal dunes	13.2	10	0.003	0.03%	13.2	132%
E1d	Wetland and reedbed	17.0	10	0.136	1.4%	17.4	171%
E1e	Pioneer, low-mid saltmarshes	17.0	20	0.123	0.6%	17.1	86%
E1f	Low and medium altitude hay meadows	16.8	20	0.015	0.1%	16.8	84%
E2	Upper saltmarshes	17.0	10	0.136	1.4%	17.1	171%
E3	Sub-Atlantic semi-dry calcareous grassland	16.1	15	0.008	0.1%	16.1	107%
E4a	Non-Mediterranean dry acid and neutral closed grassland	19.6	10	0.010	0.1%	19.6	196%
E4b	Meso- and eutrophic <i>Quercus</i> woodland	33.1	15	0.017	0.1%	33.1	221%
E5	Neutral grassland	16.9	10	0.007	0.1%	16.9	169%
E6	Broadleaved woodland	27.9	10	0.316	3.2%	28.2	282%
E7	Wetland and reedbed	16.3	10	0.116	1.2%	16.4	164%
E8	Broadleaved woodland	28.3	10	0.141	1.4%	28.4	284%
E9	Neutral grassland	16.3	10	0.023	0.2%	16.3	163%
E10	Standing open water and neutral grassland	16.1	10	0.045	0.4%	16.1	161%
E11	Calcareous grassland	16.9	15	0.005	0.0%	16.9	113%

Table 6.6: Baseline – Acid Deposition at Ecological Receptors

Receptor ID	Most Stringent Critical Load Class for the Site	Background Deposition (keq ha/yr)	Relevant Critical Load (keq ha/yr)	Background % of Critical Load	PC (keq N/ha/yr)	PC% Critical Load	PEC% Critical Load
E1		No critical load assigned in APIS					
E2		No critical load assigned in APIS					
E3	Calcareous grassland	N: 1.16 S: 0.15	MinNMinN: 0.856 MinCLMaxS: 4.00 MinCLMaxN: 4.856	27.0%	N: 0.0006 S: 0.0064	0.1%	27.1%
E4a	Unmanaged broadleaved/ coniferous woodland	N: 2.36 S: 0.21	MinNMinN: 0.285 MinCLMaxS: 0.748 MinCLMaxN: 1.033	248.8%	N: 0.0012 S: 0.0163	1.7%	250.5%
E5		No critical load assigned in APIS					

6.2 Future Assessment

6.2.1 Human Health Receptor Results

The Future results for the Installation are shown for the worst-case receptor location in Table 6.7.

The results for modelling of the WGS future emission result in worst case impacts of NO_x, SO₂, CO, PM and NH₃, compared to the modelling of the Future PCC Plant Absorber emissions, and therefore these are the reported results in Table 6.7. Presented impacts of amines and degradation products are from the PCC Plant Absorber emission, as these species are only released from this Future source.

Due to the reduction in emission concentrations of some species (NO₂ and SO₂ particularly), the annual average impacts at some receptors are actually slightly lower than those reported in the Baseline Assessment.

Due to modelling the NO_x and SO₂ impacts at the monthly BRef Bubble ELVs for short term impacts, there is a predicted increase in these impacts. However, the FCC cannot operate without the WGS and SCR being operational, and therefore these higher emission concentrations will never actually occur in practice. Even at these higher emission concentrations, the predicted impacts at human health receptors are insignificant in the case of NO_x, or not predicted to result in an exceedance of the AQS in the case of SO₂.

All other impacts are still considered to be insignificant.

Isopleths of the PCs for annual mean and hourly NO₂ concentrations are provided in Figure 6.3 and Figure 6.4 (Annex B).

Table 6.7: Future – Maximum Human Health Impacts at Any Receptor

Pollutant	Averaging Period	AQAL (µg/m ³)	PC (µg/m ³)	PC/ AQAL %	BC (µg/m ³)	PEC (µg/m ³)	PEC/ AQAL %	Change in PC over Baseline Assessment
NO ₂	Annual mean	40	0.20	0.5%	15.0	15.2	38%	- 0.3%
	1-hour mean (as the 99.79 th %ile of hourly averages)	200	18.6	9.3%	30.0	48.6	24%	+ 7.3%
CO	1-hour mean (as the 100 th %ile of hourly averages)	30,000	21.9	0.1%	236.6	258.5	1%	0%
	Maximum daily running 8-hour mean	10,000	15.1	0.2%	236.6	251.7	3%	+ 0.1%
PM ₁₀	Annual mean	40	0.05	0.1%	19.0	19.1	48%	0%
	24-hour mean (as the 90.41 th %ile of hourly averages)	50	0.23	0.5%	38.0	38.2	76%	+ 0.1%
PM _{2.5}	Annual mean	20	0.05	0.3%	11.8	11.8	59%	0%
	15-minute mean (as the 99.9 th %ile)	266	124.6	47%	6.7	131.3	49%	+ 37.7%
	1-hour mean (as the 99.73 th %ile)	350	106.2	30%	6.7	112.9	32%	+ 24.5%
SO ₂	24-hour mean (as the 99.18 th %ile)	125	38.3	31%	3.4	41.7	33%	+ 25.5%
	Annual mean	180	0.03	<0.1%	2.2	2.2	1%	0%
	1-hour mean (as the 100 th %ile of hourly averages)	2,500	1.0	<0.1%	4.4	5.5	0.2%	0%
Amine 1 and 3s	Daily mean (as the 100 th %ile of daily averages)	100	0.051	0.1%	-	0.051	0.1%	+ 0.1%
	Hourly Mean (as the 100 th %ile of hourly averages)	400	0.16	<0.1%	-	0.16	<0.1%	+ <0.1%
Amine 2	Daily mean (as the 100 th %ile of daily averages)	17	0.0062	<0.1%	-	0.0062	<0.1%	<0.1%
	Hourly Mean (as the 100 th %ile of hourly averages)	75	0.018	<0.1%	-	0.018	<0.1%	<0.1%
Amide	Annual mean	0.6	0.00011	<0.1%	-	0.00011	<0.1%	+ <0.1%
	1-hour mean (as the 100 th %ile of hourly averages)	18	0.0047	<0.1%	-	0.0047	<0.1%	+ <0.1%

Pollutant	Averaging Period	AQAL (µg/m ³)	PC (µg/m ³)	PC/ AQAL %	BC (µg/m ³)	PEC (µg/m ³)	PEC/ AQAL %	Change in PC over Baseline Assessment
Formaldehyde	Annual mean	5	0.00024	<0.1%	-	0.00024	<0.1%	<0.1%
	30-minute mean (as the 100 th %ile)	100	0.011	<0.1%	-	0.011	<0.1%	<0.1%
Acetaldehyde	Annual mean	370	0.00069	<0.1%	-	0.00069	<0.1%	<0.1%
	Hourly Mean (as the 100 th %ile of hourly averages)	9,200	0.029	<0.1%	-	0.029	<0.1%	<0.1%

6.2.2 Ecological Receptor Results

The results in Table 6.8 are shown for the worst-case WGS future emissions of NO_x, SO₂, NH₃, as these are slightly higher than the modelling of the future PCC Absorber emission and therefore result in a worst-case conservative assessment.

The results at nearly all receptors show a decrease in the annual average NO_x impacts of the Future Assessment against those reported for the Baseline Assessment, due to the reduction in the NO_x emission concentrations as a result of the SCR abatement. Annual average NO_x impacts typically show a decrease of 0.9% or less. As the daily NO_x impacts have been assessed at the higher monthly BRef Bubble ELV, the Future assessment shows an increase at all the receptors, although there are no exceedances predicted. As stated previously, the new SCR will ensure that NO_x emissions are never actually released at this concentration, and in reality, a slight decrease in the daily NO_x impacts is likely at the ecological receptors.

SO₂ impacts in Table 6.9 show decreases of up to 4.3% or less at all receptors.

The results in Table 6.10 show very slight increases (<0.5%) NH₃ emissions at all sites, however as these increases are so small, and as the background concentrations already include the PC from the FCC Unit stack, it is considered unlikely that the change in operation would result in an exceedance of the AQAL at any habitat site.

It should be noted that a cumulative assessment of impacts in-combination with the adjacent VPI Immingham LLP Combined Heat and Power Plant proposed PCC plants is provided in the Environmental Statement accompanying the Planning Applications for the PCC plants, which is provided in Appendix B of the Main Supporting Document (see Volume II, Appendix 6B).

Table 6.8: Future – Ecological Impacts of NOx

Rec ID	Annual Average Impacts							24-hour Average						
	AQAL (µg/m ³)	PC (µg/m ³)	PC/ AQAL %	BC (µg/m ³)	PEC (µg/m ³)	PEC/ AQAL %	Change in PC over Baseline Assessment	AQAL (µg/m ³)	PC (µg/m ³)	PC/ AQAL %	BC (µg/m ³)	PEC (µg/m ³)	PEC/ AQAL %	Change in PC over Baseline Assessment
E1		0.22	0.7%	20.0	20.2	67%	- 0.9%		6.1	8.1%	30.0	36.1	48%	+ 4.2%
E2		0.25	0.8%	18.0	18.2	61%	- 0.8%		6.5	8.6%	27.0	33.5	45%	+ 4.3%
E3		0.01	<0.1%	10.3	10.3	34%	- 0.1%		1.0	1.3%	15.5	16.4	22%	+ 0.4%
E4		0.01	<0.1%	11.0	11.0	37%	- 0.1%		1.0	1.4%	16.5	17.5	23%	+ 0.5%
E5		0.07	0.2%	14.4	14.5	48%	+ 0.2%		12.8	17%	21.6	34.4	46%	+ 14.4%
E6	30	0.45	1.5%	14.8	15.3	51%	- 0.8%	75	14.3	19%	22.2	36.5	49%	+ 12.1%
E7		0.25	0.8%	15.8	16.0	53%	- 0.6%		12.1	16%	23.7	35.8	48%	+ 10.9%
E8		0.21	0.7%	16.3	16.5	55%	- 0.3%		9.4	12%	24.5	33.8	45%	+ 7.7%
E9		0.11	0.4%	13.2	13.3	44%	+ 0.1%		18.1	24%	19.8	37.9	50%	+ 20.2%
E10		0.08	0.3%	14.5	14.6	49%	- 0.3%		5.8	8%	21.8	27.6	37%	+ 4.1%
E11		0.05	0.2%	14.4	14.5	48%	+ 0.1%		11.2	15%	21.6	32.8	44%	+ 12.6%

Table 6.9: Future – Annual Ecological Impacts of SO₂

Receptor ID	AQAL (µg/m ³)	PC (µg/m ³)	PC/AQAL %	BC (µg/m ³)	PEC (µg/m ³)	PEC/AQAL %	Change in PC over Baseline
E1		0.19	1.0%	3.2	3.4	17%	- 3.5%
E2		0.22	1.1%	3.4	3.6	18%	- 3.5%
E3		0.01	<0.1%	1.0	1.0	5%	- 0.2%
E4		0.01	<0.1%	1.6	1.6	8%	- 0.3%
E5		0.07	0.4%	3.3	3.4	17%	+ 0.1%
E6	20	0.41	2.0%	3.0	3.4	17%	- 4.3%
E7		0.22	1.1%	3.1	3.3	17%	- 2.8%
E8		0.19	0.9%	3.2	3.4	17%	- 1.9%
E9		0.11	0.5%	2.9	3.0	15%	- 0.2%
E10		0.07	0.4%	3.1	3.2	16%	- 1.1%
E11		0.08	0.3%	3.3	3.4	17%	+ 0.1%

Table 6.10: Future – Annual Ecological Impacts of NH₃

Receptor ID	AQAL (µg/m ³)	PC (µg/m ³)	PC/AQAL %	BC (µg/m ³)	PEC (µg/m ³)	PEC/AQAL %	Change in PC over Baseline
E1	3	0.018	0.6%	1.7	1.72	57%	+ 0.1%
E2	3	0.020	0.7%	1.8	1.82	61%	+ 0.1%
E3	3	0.001	<0.1%	1.5	1.50	50%	0.0%
E4	1	0.001	0.1%	2.3	2.30	230%	0.0%
E5	3	0.007	0.2%	1.7	1.71	57%	+ 0.2%
E6	3	0.039	1.3%	1.6	1.64	55%	+ 0.5%
E7	3	0.021	0.7%	1.6	1.62	54%	+ 0.2%
E8	3	0.018	0.6%	1.8	1.82	61%	+ 0.3%
E9	3	0.010	0.3%	1.6	1.61	54%	+ 0.3%
E10	3	0.007	0.2%	1.6	1.61	54%	0.0%
E11	3	0.005	0.2%	1.7	1.71	57%	+ 0.2%

The changes in the depositional impacts due to the Future operation shown in Table 6.11 and Table 6.12 are either below the 1% threshold for insignificance defined by the Environment Agency and Natural England or indicate a reduction in the impact over the Baseline Assessment.

Table 6.11: Future – Nitrogen Deposition at Ecological Receptors

Receptor ID	Most Stringent Critical Load Class for the Site	Background Nitrogen Deposition (kg N/ha/yr)	Lower value of Critical Load Range	PC (kg N/ha/yr)	PC% Critical Load	PEC (kg N/ha/yr)	PEC% Critical Load	Change in PC over Baseline Assessment
E1a	Coastal stable dunes grasslands - acid type	13.5	8	0.003	<0.1%	13.5	169%	0%
E1b	Coastal stable dunes grasslands - calcareous type	11.9	10	0.003	<0.1%	11.9	119%	0%
E1c	Shifting coastal dunes	13.2	10	0.001	<0.1%	13.2	132%	0%
E1d	Reedbeds	17.0	10	0.13	1.3%	17.1	171%	- 0.1%
E1e	Pioneer, low, mid saltmarshes	17.0	20	0.12	0.6%	17.1	86%	0%
E1f	Low and medium altitude hay meadows	16.8	20	0.01	<0.1%	16.8	84%	- 0.6%
E2	Mmid upper saltmarshes	17.0	10	0.13	1.3%	17.1	171%	- 0.1%
E3	Sub-Atlantic semi-dry calcareous grassland	16.1	15	0.005	<0.1%	16.1	107%	0%
E4a	Non-Mediterranean dry acid and neutral closed grassland	19.6	10	0.006	<0.1%	19.6	196%	0%
E4b	Meso- and eutrophic <i>Quercus</i> woodland	33.1	15	0.01	<0.1%	33.1	221%	0%
E5	Neutral grassland	16.9	10	0.05	0.5%	16.9	169%	+ 0.4%
E6	Broadleaved woodland	27.9	10	0.43	4.3%	28.3	283%	+ 1.2%
E7	Wetland and reedbed	16.3	10	0.14	1.4%	16.4	164%	+ 0.3%
E8	Broadleaved woodland	28.3	10	0.20	2.0%	28.5	285%	+ 0.6%
E9	Neutral grassland	16.3	10	0.07	0.7%	16.4	164%	+ 0.5%
E10	Standing open water and neutral grassland	16.1	10	0.05	0.5%	16.1	161%	0%
E11	Calcareous grassland	16.9	15	0.03	0.2%	16.9	113%	+ 0.2%

Table 6.12: Future – Acid Deposition at Ecological Receptors

Receptor ID	Most Stringent Critical Load Class for the Site	Background Deposition (keq ha/yr)	Relevant Critical Load (keq ha/yr)	Background % of Critical Load	PC (keq N/ha/yr)	PC% Critical Load	PEC% Critical Load	Change in PC over Baseline Assessment
E1			No critical load assigned in APIS					
E2			No critical load assigned in APIS					
E3	Calcareous grassland	N: 1.16 S: 0.15	MinNMinN: 0.856 MinCLMaxS: 4.00 MinCLMaxN: 4.856	27.0%	N: 0.0004 S: 0.001	0.2%	27.2%	+ 0.1%
E4a	Unmanaged broadleaved/ coniferous woodland	N: 2.36 S: 0.21	MinNMinN: 0.285 MinCLMaxS: 0.748 MinCLMaxN: 1.033	248.8%	N: 0.0007 S: 0.002	0.3%	249.1%	-1.4 %
E5			No critical load assigned in APIS					

6.3 N-Amines Assessment Results

6.3.1 Total N-Amine 1 Impacts from Amine 1 and N-amine 1 Emissions

The results of modelling the atmospheric process involved with the emissions of Amine 1 and N-amine 1 release are shown in Table 6.13. The results at the worst-case receptor are shown in **bold** type.

Table 6.13: Future - Annual Average N-Amine 1 Concentrations as a Result of Amine 1 and N-Amine 1 Emissions

Receptor	AQAL (ng/m ³)	Nitrosamine 1 PC (ng/m ³)	Nitramine 1 PC (ng/m ³)	Total N-Amines 1 PC (ng/m ³)	PC/AQAL %
R1	0.2	0.015	0.023	0.038	19%
R2		0.009	0.018	0.027	13%
R3		0.003	0.009	0.012	6%
R4		0.003	0.007	0.010	5%
R5		0.005	0.009	0.014	7%
R6		0.008	0.012	0.020	10%
R7		0.019	0.030	0.049	25%
R8		0.023	0.030	0.053	26%
R9		0.016	0.019	0.035	18%
R10		0.017	0.029	0.046	23%
R11		0.007	0.011	0.017	9%
R12		0.003	0.007	0.010	5%

The results for the total Amine 1 and N-amine1 emissions for the Future Assessment indicates that PCs at receptor locations are well within the very conservative AQAL for NDMA. The worst-case impacts are experienced at receptor OR8 and represent 26% of the NDMA AQAL applied to the assessment.

As stated in Section 5.2.1, testing has shown that N-amine 1 is approximately 2,000 times less toxic than NDMA. Although insufficient information is currently available to derive a specific AQAL for N-amine 1 at this time, the testing carried out to date indicates that a significantly higher AQAL would be appropriate to ensure there would be no impact to human health. If an arbitrary factor of times 2 was applied to the NDMA AQAL, which would still be considered to be very conservative based on the information currently available, the impacts at the worst-case receptor would be reduced to 13% of the AQAL, showing that impacts were well below such an AQAL.

6.3.2 Total N-Amine 2 Impacts from Amine 2 and N-amine 2 Emissions

The predicted modelling results of the atmospheric processes involved with the release of Amine 2 and N-amine 2 from the PCC Plant are shown in Table 6.14.

Table 6.14: Future - Annual Average Indirect N-Amine 2 Concentrations as a Result of Amine 2 and N-amine 2 Emissions

Receptor	AQAL (ng/m ³)	Nitrosamine 2 PC (ng/m ³)	Nitramine 2 PC (ng/m ³)	Total N-Amine 2 PC (ng/m ³)	PC/AQAL %
R1	0.2	0.003	0.002	0.006	3%
R2		0.002	0.002	0.004	2%
R3		0.001	0.001	0.002	1%

Receptor	AQAL (ng/m ³)	Nitrosamine 2 PC (ng/m ³)	Nitramine 2 PC (ng/m ³)	Total N-Amine 2 PC (ng/m ³)	PC/AQAL %
R4		0.001	0.001	0.001	1%
R5		0.001	0.001	0.002	1%
R6		0.001	0.001	0.003	1%
R7		0.003	0.003	0.006	3%
R8		0.004	0.003	0.007	3%
R9		0.003	0.002	0.005	2%
R10		0.003	0.003	0.006	3%
R11		0.001	0.001	0.002	1%
R12		0.001	0.001	0.001	1%

The results for the total N-amine 2 impacts for Installation’s Future operation indicates that PCs at receptor locations are well within the conservative AQAL for NDMA. The impacts at worst case receptor occur at R8 and represented 3% of the NDMA AQAL.

As stated in Section 5.2.1, testing has shown that N-amine 2 is approximately 50 times less toxic than NDMA. Although insufficient information is currently available to derive a specific AQAL for N-amine 2 at this time, the testing carried out to date indicates that a higher AQAL would be appropriate to still ensure there would be no impact to human health. Given that N-amine 2 has been shown to be more toxic than N-amine 1 however, it is not proposed to apply an arbitrary factor to the NDMA AQAL to ensure a conservative assessment is carried out.

6.3.3 Total N-Amine Impacts

the direct N-amine releases are shown in Table 6.15 and compared against the very conservative AQAL for NDMA, as recommended by the EA.

Table 6.15: Future – Total Annual Average N-Amine Concentrations

Receptor	AQAL (ng/m ³)	Nitrosamine PC (ng/m ³)	Nitramine PC (ng/m ³)	Total N-Amines PC (ng/m ³)	PC/AQAL %
R1		0.019	0.025	0.044	22%
R2		0.011	0.020	0.031	15%
R3		0.004	0.009	0.013	7%
R4		0.004	0.008	0.011	6%
R5		0.006	0.010	0.015	8%
R6		0.010	0.014	0.023	12%
R7	0.2	0.022	0.033	0.055	28%
R8		0.027	0.033	0.060	30%
R9		0.019	0.021	0.040	20%
R10		0.020	0.032	0.052	26%
R11		0.008	0.012	0.020	10%
R12		0.004	0.007	0.011	6%

The results for the total N-amine impacts for the future operation of the Installation indicates that PCs at receptor locations are within the conservative AQAL for NDMA. The impacts at the worst-case receptor (R8), represent 30% of the NDMA AQAL. If the arbitrary factor of times 2 was applied to the NDMA AQAL for N-amine 1 impacts, then the total N-amine PC/AQAL at R2 would reduce to 16%.

Given the conservative assumptions used in the assessment, and that information currently available indicates that the Cansolv N-amines are less toxic than NDMA, the assessment carried out indicates that the N-amine PCs predicted at the receptor locations are unlikely to result in impacts to human health.

6.3.4 N-Amine Assessment Limitations and Assumptions

This section outlines the potential limitations associated with the dispersion modelling assessment. Where assumptions have been made, this is also detailed here.

The greatest uncertainty associated with any air quality modelling assessment arises through the inherent uncertainty of the dispersion modelling process itself. The use of dispersion modelling is nevertheless a useful and widely applied and accepted approach for the prediction of impacts from industrial sources.

The EA recognises that the level of uncertainty within the ADMS amines chemistry model is high, however, as the only commercially available model, recognises that it follows first principles and considers available knowledge on the mechanisms of formation of toxic pollutants from amine emissions in ambient air. The main model uncertainties are set out below.

6.3.4.1 No Time-Delay in N-amine Formation

As previously detailed, the amines chemistry module does not account for the time delay in the initiation of the amine degradation. This time delay indicates that only around 15% of the amines that react to form N-amines would have done so within 1 hour, as a worst-case. The ADMS model assumes that a 'steady state' is achieved within 1 hour (N-amine formation/ destruction). The time taken for the peak concentration to reach a receptor at 1km from the source is between 1 - 30 minutes. The model only calculates spatial dispersion, not temporal change. In the real world, as the plume travels further from the source, the amine concentration reduces but the OH concentration may increase (less NO_x for the preferential reaction to occur) leading to higher potential N-amine formation, but when balanced against N-amine and amine dispersion, the result is a lower N-amine concentration with distance. The model has to assume reaction completion at the point of calculation, and therefore it is considered that this is overly conservative.

6.3.4.2 No Interaction Between Different Amine Species

The amines chemistry module does not allow for any interactions between different amines/ degradation species as only one amine species can be modelled at a time. This could result in missing N-amine removal pathways and therefore result in higher predicted results.

6.3.4.3 No Consideration of Other Potential Radical Species Present

Other reactions with chlorine atoms, nitrate radicals are not taken into account, although these are considered to be less significant.

6.3.4.4 No Further Degradation Assumed after the Initial Reactions

The amines chemistry module also does not account for further amine degradation, for example the primary amine MEA can degrade to the secondary amine DEA (which could subsequently degrade into NDMA). This could result in an increase in N-amine formation but over longer time periods, which could be counterbalanced by the destruction of N-amine over time, as discussed above.

6.3.4.5 Only Daytime Reactions are Considered

The amines chemistry module accounts for diurnal variation in the photolysis (OH) reaction but does not account for the slower NO₂ degradation reaction that occurs during night-time.

6.3.4.6 No Consideration of Phase Partitioning

Once emitted to the air, amines, nitrosamines and nitramines undergo multiphase chemistry, i.e. gas, aqueous (aerosols, cloud droplets, fog and rain) and particle phase (aerosol). Therefore, the mass of starting amine may be partitioned (e.g. gas or aqueous phase). The current assessment is only concerned with the gaseous phase, however it is considered that the solubility of amines will put them out of the gas phase (Nielsen et al. 2012), therefore decreasing the amount of amines in the ambient air.

In order to ensure a conservative assessment, and therefore to minimise the likelihood of under-estimating the impacts of N-amines from the CO₂ Absorber stack, the following conservative assumptions have been made within the assessment:

- the operational Installation have been assumed to operate on a continuous basis i.e. for 8,760 hours per year, although in practice the plant would require routine maintenance periods;
- the modelling predictions are based on the use of five full years of meteorological data from Humberside Airport meteorological station for the years 2017 to 2021 inclusive, with the highest result being reported for all years assessed; and,
- all N-amines have been assessed against the AQAL for NDMA, when there will be different N-amine species present in the PC, and all of which are considered to be less toxic than NDMA, as discussed in Section 5.2.1..

Annex A - Supporting Toxicological Information for Amines and N-Amines in the Solvent

This Annex sets out:

- The DC-103 solvent composition, chemistry and list of components generated/ emitted to atmosphere.
- The proposed methodology to derive indicative EALs for the amines emitted from the carbon capture plant. Amines and nitrosamines/ nitramines (collectively referred to as N-amines) are considered separately.

1- Solvent Composition and Chemistry

1-1 Virgin (starting) Solvent Amine Components

The DC-103 solvent is used as a 50%wt amine aqueous solution, comprising the amine components shown in Table A1.

Table A1: DC-103 Solvent Amine Components

Component	Chemical name	CAS number
Amine 1	1-Piperazineethanol	103-76-4
Amine 2	Piperazine	110-85-0
Amine 3	1,4-Piperazinediethanol	122-96-3

1-2 Chemistry and Degradation Products

The solvent chemistry leading to the formation of degradation compounds potentially emitted to the atmosphere involves mainly the following processes:

- Oxidative degradation:
 - o Oxidation of amine or hydroxyl functionalities, leading primarily to low molecular weight organic acids and ammonia.
 - o Formation of heavier molecular weight species by reaction with oxygen, free radicals or organic acids, leading to non-alkaline compounds such as formamides or ketone-type species such as amides.
- Formation of nitrosamines by reaction with NO₂- (nitrite).

Note tertiary amines will not form nitrosamines, and therefore there is no nitrosamine associated with Amine 3.

The full list of potential degradation products is provided in Table A2.

Table A2: DC-103 Potential Solvent Degradation Products

Status	Type	Components	Chemical name ⁽²⁾	CAS number ⁽²⁾
Confirmed degradation products	-	N-amine 1	4-Nitroso-1-piperazineethanol	48121-20-6
		N-amine 2	1-nitrosopiperazine	5632-47-3
		Amide 1	4-(2-Hydroxyethyl) piperazin-2-one	23936-04-1
		Formamide 1	1-formyl-4-(2-hydroxyethyl) piperazine	25209-64-7
		Amide 2	Piperazin-2-one	5625-67-2
		Formamide 2	1-formylpiperazine	7755-92-2
		Ammonia	-	-
	Organic acids	Formate	-	-
		Glycolate	-	-
		Oxalate	-	-
		Acetate	-	-
		Sulfamate	-	-
	Possible degradation products ⁽¹⁾	-	Formaldehyde	-
Acetonitrile			-	-
Acetaldehyde			-	-
Ethanol			-	-
Acetone			-	-
MEA			Mono Ethanol Amine	141-43-5

Note 1: compounds not linked to an established degradation pathway but detected in some instances in the Absorber treated gas in amounts that indicate at least a partial origin in solvent chemistry.

Note 2: For DC-103 specific components.

1-3 Emissions to Atmosphere

The solvent components and degradation compounds detailed in Table A1 and A2 above will have a zero vapor pressure over the solvent if they are ionized. This will be the case for the organic acids.

The other components have the potential to be present in the emissions from the CO₂ Absorber, and water and acid wash systems can be used to control the amounts emitted to the atmosphere to low levels.

In the case of the Cansolv DC-103 system, the oxidative degradation pathways favour the formation of heavier compounds that will have a low vapor pressure which have been shown to be effectively controlled with a single stage water-wash (as demonstrated in the operating units of Boundary Dam and Brothers CISA, and in further pilot campaigns). The low amounts of lighter products, in particular ammonia, are also well controlled with this water wash system and usually do not mandate the addition of an acid wash stage.

Monitoring of the emissions of the Boundary Dam unit has included the amine and nitrosamine emissions, relevant to the concern of nitrosamine levels in the environment.

An advanced PTR-TOF-MS instrument, with full spectrum analysis capabilities, has been used on several pilot and demonstration scale campaigns, has been used to detect the confirmed and suspected degradation products mentioned in Table A2 in the treated gas (instrument installation, calibration, maintenance and data analysis performed by specialists at the University of Oslo, also owner of the PTR-TOF-MS instrument).

Concurrent extractive sampling with impinger trains followed by LCMS analysis has been used to confirm emission levels for targeted components.

Table A3 summarizes components known to be potentially emitted to atmosphere, which includes the solvent components (Table A1) as well as the degradation products (Table A1, with the exception of organic acids that are not volatile in their ionized form).

Table A3: Components Potentially Emitted to Atmosphere

Status	Components
Solvent components	Amine 1
	Amine 2
	Amine 3
Confirmed degradation products	N-amine 1
	N-amine 2
	Amide 1
	Formamide 1
	Amide 2
	Formamide 2
	Ammonia
Possible degradation products ⁽¹⁾	Formaldehyde
	Acetonitrile
	Acetaldehyde
	Ethanol
	Acetone
	MEA

Note 1: compounds not linked to an established degradation pathway but detected in some instances in the Absorber treated gas in amounts that indicate at least a partial origin in solvent chemistry.

2- EAL Derivation Methodology for Amines and Nitrosamines

Among the components that can be released from the Absorber stack, amines and nitrosamines are of special interest, due to the potential carcinogenicity of nitrosamines. These can be emitted directly or formed in the atmosphere from the emitted amines.

This section describes the proposed methodology to derive indicative EALs for the amines and nitrosamines emitted from a carbon capture plant using the Cansolv DC-103 solvent. Amines and nitrosamines/ nitramines (N-amines) are considered separately.

2-1 Amines

2-1-1 Reference: Monoethanol amine (MEA)

The Environment Agency (EA) have derived an EAL for monoethanol amine (MEA):

- 1-hour: 400 $\mu\text{g}/\text{m}^3$
- 24-hour: 100 $\mu\text{g}/\text{m}^3$

This is based upon a No Observed Adverse Effect Concentration (NOAEC) value of 10 mg/m^3 (Environment Agency, 2020). To derive the EAL, a safety factor of 25 has been applied to derive the 1-hour EAL, and a safety factor of 100 has been applied to derive the 24-hour EAL.

MEA is a strong respiratory, ocular, and skin irritant, there are equivocal indications that MEA could have skin and respiratory sensitizing properties, but MEA is currently not classified for these endpoints (ECHA Registration Dossier MEA).

For derivation of the short-term EAL, the critical effect considered is localized respiratory irritation. The pivotal study for derivation of a short-term EAL is the sub-acute duration rodent study submitted as evidence in support of an application under REACH (HSE 2016) with a No Observed Adverse Effect Concentration (NOAEC) of 10 mg/m^3 . No correction for continuous exposure was applied because irritation is considered a concentration-dependent effect.

For derivation of the EALs, the critical health effects from long-term inhalation exposure are considered to be respiratory irritation and neurobehavioral toxicity. The pivotal study for derivation of a long-term EAL is the same sub-acute rodent study used for the short-term EAL (HSE 2016). No Uncertainty Factor (UF) for sub-acute to chronic duration is required because irritation is considered a concentration-based effect. An additional UF was included to take account of uncertainty over long-term effects.

The monoethanol amine REACH dossier also contains Derived No Effect Levels for the general population for local and systemic effects, and these are 280 and 180 $\mu\text{g}/\text{m}^3$, respectively. These are in the same order of magnitude as the EA's derived EALs.

2-1-1 Cansolv DC-103 Amines

Section 1-1 describes the amines used in the Cansolv DC-103 solvent. These amines are structural analogues, consisting of a heterocyclic di-amine (Amine 2), with an alkanol group substitution on one (Amine 1) or both (Amine 3) amine functions.

Amine 1 has low vapor pressure and is considered to be a strong ocular and skin irritant. Available data are summarized in Appendix 1 and Table A4 below.

Amine 2 has low vapor pressure and is considered to be a strong ocular and skin irritant. It is classified for respiratory sensitization and reproductive toxicity. Available data are summarized in Appendix 2 and Table A4 below.

Amine 3 is a minor component of the DC-103 solvent with low volatility and is generally not detected at stack. DC-103 amine 3 is an amine with low vapor pressure, and is considered to be a strong ocular and skin irritant. Available data are summarized in Appendix 3 and Table A4 below.

Evaluation

Due to their common active group (the amine group), the overall toxicity of all aliphatic amines is similar, with some potency differences depending on the aliphatic parts. Based on a review of the toxicological properties of alkanol-amines, cyclic amines and aliphatic amines, supplemented with modelling of the structure-activity relationship, the following can be summarized regarding the toxicity of these compounds in the human body:

- Amines are metabolized by oxidation into the corresponding aldehydes, a process accompanied by the release of ammonia. The aldehydes are then metabolized into carboxylic acids and, ultimately, into CO_2 (that is subsequently exhaled).
- Aliphatic amines and alkanolamines are of relatively low acute toxicity, with LD50 levels (Lethal Dose for 50% of the test animals) in the order of grams per kilogram bodyweight. The cyclic

amines have a lower threshold of toxicity (LD50 levels in the order of 100s of milligrams per kilogram bodyweight), but are still of relatively low acute toxicity.

- Except for tertiary amines, the range of aliphatic amines, alkanolamines, as well as cyclic amines are to some degree corrosive or highly irritating to the skin, eyes and/or respiratory tract.
- With the exception of piperazine, amines are no skin or respiratory sensitizers.
- Overall, amines are not mutagenic or carcinogenic and, with exception of piperazine, amines are not expected to affect human development or reproduction.

Overall, amines will pose minimal risk to members of the general public. However, due to their corrosive properties risk management measures need to be in place for workers.

The main amine present in the Absorber emission is Amine 1. Based on available data, as well as modeling data (see Appendix 1), all DC-103 amines are expected to be of low systemic toxicity with no alerts for carcinogenicity, mutagenicity or reproductive toxicity. Like MEA, the main effect would be local irritation.

It should be noted that all chemicals imported to the UK are subject to the UK REACH regulation. It is anticipated that additional information will be generated for the REACH registration of Amine 1. This will include longer-term repeated dose studies that will confirm a NOAEL and can be used to substantiate the current EAL derivation. The current EAL derivation however is considered to be conservative, and based on inhalation effects from MEA. Due to the low vapor pressure of Amine 1 compared to MEA, exposure levels are estimated to be well below the EAL, and this has been demonstrated by the dispersion modelling carried out for the project.

Analysis of the No Observed Adverse Effect Levels (NOAEL) of the DC-103 amines and MEA, support that there is no concern for systemic toxicity from the DC-103 amines. The NOAELs for Amine 2 and Amine 3 are 627 and 1,000 mg/kg bw/d for systemic effects, which is above the systemic NOAEL of MEA of 300 mg/kg bw/d.

To date, a NOAEL has not been derived for Amine 1, however based on structural similarity with Amine 2 and Amine 3, Amine 1 is expected to have a systemic NOAEL of the same order of magnitude. Given that the NOAELs for Amine 2 and 3 are higher than that derived for MEA, it is reasonable to assume that for systemic effects, the EAL derived for MEA would represent a worst-case, and that the EAL protective for systemic effects from exposure to MEA, should also be protective for systemic effects of all three of the DC-103 amines.

For short-term, local effects, all DC-103 amines are ocular and skin irritants. In addition, Amine 2 is classified as a respiratory sensitizer. However, based on its REACH registration dossier, the substance could be considered an asthmagen (causing asthma by non-immunological mechanism) rather than a respiratory allergen (causing asthma by an immunological mechanism). Amines 1 and 3 have the same local irritating effects as MEA. It is therefore reasonable to assume that the EAL protective for local irritating effects from exposure to MEA, should also be protective for local irritating effects of DC-103 amines.

The worker Derived No Effect Level (DNELs) derived for Amine 2, based on the critical effect of respiratory sensitization are $100 \mu\text{g}/\text{m}^3$ and $300 \mu\text{g}/\text{m}^3$ for long-term and short-term exposure, respectively. Translating these values for the general population, a correction is made for the long-term DNEL by adjusting exposure from 8 hours per day to 24 hours per day, and from working life exposure (40 years) to life-time exposure (80 years).

The outcome is $100 / 3 / 2 = 17 \mu\text{g}/\text{m}^3$

The worker DNEL for short-term exposure is adjusted from $300 \mu\text{g}/\text{m}^3$ for 15 minutes to $300/4 = 75 \mu\text{g}/\text{m}^3$ for the 1-hour EAL.

Table A4 provides a summary of the available toxicity data available for MEA and the DC-103 amines.

Table A4: Summarized toxicity data for MEA and DC-103 amines

Amine	Irritation	Sensitization	Geno-toxicity	NOAEL (mg/kg bw/day)	NOAEC (mg/m ³)	STEL (mg/m ³)	OEL or DNEL (mg/m ³)
Mono-ethanol Amine (MEA)	H314	Not classified	Negative	300	10	7.6	2.5 0.28* 0.18**
Amine 1	H315 H318 No clinical signs after exposure to saturated vapors	Not classified	Negative	N/A	***	N/A	N/A
Amine 2	H314	H334 H317	Negative	627	N/A	0.3	0.1
Amine 3	H318	N/A	Negative	1000	***	N/A	N/A

* General population DNEL local effects

** General population DNEL systemic effects

*** Due to the low vapor pressure it is unlikely that the substance will be available as a vapor.

STEL – Short-term Exposure Limit, OEL = Occupational Exposure Limit

Summary EALs Amines

In summary, based on the absence of significant systemic toxicity and similar local effects (irritation) the proposed EALs for the DC-103 amines are similar to those of MEA, which is 400 µg/m³ and 100 µg/m³ for short-term and long-term exposure, respectively. For Amine 2 however, a more stringent EAL of 17 µg/m³ is proposed for long term impacts, and 75 µg/m³ for the 1-hour EAL.

The DC-103 amine EALs are summarized in Table A5.

Table A5: Environmental Assessment Level (EAL) for MEA and DC-13 amines

Amine	1-hour EAL (µg/m ³)	24-hour EAL (µg/m ³)
Mono ethanol amine	400	100
Amine 1	400	100
Amine 2	75	17
Amine 3	400	100

2-2 Nitrosamines

The carbon capture process can emit N-amine 1 and N-amine 2.

The EA have derived an EAL for N-nitrosodimethylamine (NDMA) (see Appendix 5):

- Annual mean: 0.0002 µg/m³

This is based on a Dose Level (BMDL10) of 0.023 mg/m³. The EA also state: "NDMA is one of the most potent nitrosamines [in terms of carcinogenic potential]" and also state that NDMA is one of the most widely studied of the nitrosamines, recognizing that toxicology data for other nitrosamines is scarce, particularly for carcinogenic potential.

N-amine 1 has no carcinogenic data currently available. N-amine 2 has been studied for carcinogenic potential and it has been demonstrated to be 45 times less potent than NDMA (Buist (2013)).

Mutagenic potency of N-amine 1, N-amine 2 and NDMA (as a positive control) have been investigated in a modified Ames test (Plewa et al. University of Illinois 2013), using bacterial strains sensitive to nitrosamines. The mutagenic potency of N-amine 1 was found to be 2,000 times less than that of NDMA, and the mutagenic potency of N-amine 2 was found to be 50 times less than that of NDMA. An overview of data is presented in Table A6.

Table A6: Mutagenic and carcinogenic potency of NDMA and DC-103 nitrosamines

Nitrosamine	Mutagenic potency (µmol) ⁻¹	Carcinogenic potency based on animal data (mmol/m ³) ⁻¹	EAL (ng/m ³) annual mean
NDMA	1	300	0.2
DC-103 nitrosamine 1	0.043	N/A	0.2 proposed
DC-103 nitrosamine 2	0.001	6.6	0.2 proposed

Evaluation and summary

NDMA is one of the best-studied nitrosamines, and also one of the nitrosamines with the highest carcinogenic potential. Based on the available data, EA have derived an EAL of 0.2 ng/m³ (annual mean). Based on available data on the mutagenic and carcinogenic potency of DC-103 nitrosamines and NDMA, it is expected that NDMA is the most potent mutagen and carcinogen. Hence, the EAL for NDMA of 0.2 ng/m³ (annual mean) would serve as a very conservative EAL for DC-103 nitrosamines.

Appendix 1 - Substance Information Amine 1

Data are obtained from the REACH registration dossier: <https://echa.europa.eu/nl/registration-dossier/-/registered-dossier/19699/7/2/1>

Classification

H315: Causes skin irritation.

H318: Causes serious eye damage.

Acute Toxicity

Based on an acute oral toxicity in rats equivalent to OECD TG 401, the LD50 was ca. 4,244 mg/kg bw for male and female animals.

In an acute inhalation hazard test equivalent to OECD TG 403 male and female rats (strain not specified) were exposed to saturated vapors of the test substance in air (concentration not determined) for a period of 8 hours. No mortality occurred and no clinical signs were observed. To verify the results, the test was repeated once with new groups of animals. Necropsy of all animals was performed. No mortality occurred and no clinical signs were observed. Only one animal showed chronic bronchitis and bronchiectasis in the right lobe of the lung. No LC50 was determined. In an acute dermal toxicity study conducted in rats the LD50 value was found to be greater than 5,000 mg/kg bw.

Irritation

The substance was concluded to be irritating to skin. In an eye irritation study in rabbits, the test substance was shown to be severely irritating and led to irreversible effects.

Sensitization

Based on the results of the DPRA and LuSENS assays, the substance is not peptide reactive and does not activate keratinocytes in vitro. Applying the evaluation criteria, the substance is predicted not to be a skin sensitizer based on the in vitro testing strategy. These results are supported by the results of a Guinea Pig Maximization Test according to Magnusson that demonstrate that the substance does not meet criteria for classification and is therefore not classified as a skin sensitizer in vivo.

Genetic Toxicity

The substance was tested negative in the Ames test, the HPRT test, and the Chromosome aberration assay.

Repeated dose toxicity

No repeated dose toxicity studies are available.

Results from QSAR modeling (OECD Toolbox)

The OECD Toolbox was used to perform Quantitative Structure-Activity Relationship (QSAR) modelling of Cansolv DC103 Amine 1. The results are show in the table below.

Endpoint	QSAR prediction	Experimental data
Acute toxicity (oral)	LD50 = 1,500 – 3,000 mg/kg	LD 50 = ~4,244 mg/kg
Acute toxicity (inhalation)	Not Available	No mortality at saturated vapors
Acute toxicity (dermal)	Not Available	LD 50 > 5000 mg/kg
Skin irritation/corrosion	Positive	Skin irritant Cat 2
eye irritation/corrosion	Undefined	eye irritant Cat 1
Respiratory irritation	Negative *	No data
skin sensitization	No alert found	Negative
Respiratory sensitization	No alert found	No data

Endpoint	QSAR prediction	Experimental data
Repeated dose toxicity (oral)	Not categorized	No data
Repeated dose toxicity (inhalation)	Not categorized	No data
Repeated dose toxicity (dermal)	Not categorized	No data
Genetic toxicity	Negative	Negative
Carcinogenicity	Negative	No data, expect to be negative
Toxicity to reproduction	Negative	No data
Developmental toxicity	Negative	No data

* the prediction came from the latest developed QSAR tools: link
<https://respiratox.item.fraunhofer.de/index.php>

Appendix 2 - Substance Information Amine 2

Data are obtained from the REACH registration dossier: <https://echa.europa.eu/mt/registration-dossier/-/registered-dossier/14941>

Classification

H361: Suspected of damaging fertility or the unborn child <state specific effect if known> <state route of exposure if it is conclusively proven that no other routes of exposure cause the hazard>.

H314: Causes severe skin burns and eye damage.

H334: May cause allergy or asthma symptoms or breathing difficulties if inhaled.

H317: May cause an allergic skin reaction

Acute Toxicity

The substance has low toxicity in acute oral and dermal toxicity tests: LD50 oral, rat = 2,600 mg/kg bw and LD50 dermal, rabbit = 8,300 mg/kg bw. In acute inhalation toxicity tests (inhalation hazard tests) rats were exposed to the vapor; no LC50 was determined. At 1.61 mg/l exposure for 7 h slight mucosal irritation was noted. No clinical signs were noted at inhalation exposure of 0.57 mg/l for 7 h.

Irritation

Based on skin irritation study in rabbits, the substance is classified as Skin Corr. Cat. 1B (H314).

The classification for skin corrosion also leads to a classification of serious eye damage (Eye Dam. 1; H318) according to Regulation (EC) No 1272/2008 (CLP Regulation).

Sensitization

Based on the results of a Guinea Pig maximization test and an LLNA test in mice, the substance was concluded to be a weak skin sensitizer.

In an additional study in mice, cytokine production (IFN- γ) was demonstrated, supporting that the substance possesses contact allergenic potential in mice. In the same study, the substance failed to provoke production of IL-4 and IL-10, which are markers of respiratory tract allergens. In studies with exposed workers the substance has been shown to cause occupational asthma, but as the substance failed to provoke production of IL-4 and IL-10 (markers of respiratory allergens - vide supra), the substance could be considered an asthmagen (causing asthma by non-immunological mechanism) rather than a respiratory allergen (causing asthma by an immunological mechanism).

Genetic Toxicity

Based on the available genotoxicity data in vitro and in vivo it can be concluded that the substance is not genotoxic.

Repeated dose toxicity

Based on a subchronic study in rats, the NOAEL was established at 627 mg/kg bw/day.

Reproductive toxicity

Developmental effects have been observed in rabbits but in the presence of overt maternal toxicity, and in view of the absence of developmental toxicity in rats and mice, the substance is classified as developmental toxicant cat. 2

Occupational exposure limits

Based on local effects (respiratory sensitization) Derived No Exposure Levels are 300 $\mu\text{g}/\text{m}^3$ for short-term exposure and 100 $\mu\text{g}/\text{m}^3$ for long-term exposure.

Appendix 3 - Substance Information Amine 3

Data are obtained from the REACH registration dossier: <https://echa.europa.eu/nl/registration-dossier/-/registered-dossier/26339>

Acute Toxicity

Based on an acute oral toxicity study in rats following OECD TG 401, the LD50 by oral route was 20,093 and 18,738 mg/kg for males and females respectively. LD50 by dermal route was > 10 ml/kg in rabbits.

Irritation

In an irritation study in rabbits according OECD Guideline 404 (Acute Dermal Irritation/ Corrosion), the substance was found not irritating to skin. In another study in rabbits the study was found corrosive to the eyes.

Sensitization

No data available

Genetic Toxicity

The substance was tested negative in the Ames test.

Repeated dose toxicity

Based on the results of a recent combined 28-day repeated dose toxicity study with the reproduction/ developmental toxicity screening test in rats, the Parental, Reproduction and Developmental No Observed Adverse Effect Levels (NOAEL) for the substance were established to be at least 1,000 mg/kg/day (Charles River (2019)).

Appendix 4 - EAL derivation Monoethanol Amine

https://assets.publishing.service.gov.uk/media/60951826d3bf7f6d661b6d6e/EAL_Consultation_document.pdf

7. Monoethanolamine (CAS Number 141-43-5)

Monoethanolamine (MEA), 2-aminoethanol, or ethanolamine is a colourless, viscous liquid with an ammoniacal odour (HSE 2016), whose vapour is denser than air. It is widely used in industry in the production of detergents and soaps, dyestuffs, rubber vulcanisation, and as a scrubber for acidic gases in enclosed atmospheres such as submarines. MEA is used in a range of consumer products including cosmetics and personal care products, washing and cleaning products, coating products, biocides, inks and toners, and adhesives and sealants.

Regulatory Guidelines

None	
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Recommended Environmental Assessment Level in Air

Long-term EAL	100 µg/m ³ as a 24-hour mean
Short-term EAL	400 µg/m ³ as a 1-hour mean

There are few authoritative reviews on the adverse effects from exposure to MEA (CNESST 2019, HSE 2016, SCOEL 1996). It is a strong respiratory, ocular and skin irritant. CNESST (2019) concluded that MEA is a skin and respiratory sensitiser, but this opinion has been disputed (HSE 2001 and 2016).

Supporting Information

Short-term inhalation exposure to MEA vapour results in localised respiratory irritation. The pivotal study for derivation of a short-term EAL is the sub-acute duration rodent study submitted as evidence in support of an application under REACH (HSE 2016) with a No Observed Adverse Effect Concentration (NOAEC) of 10 mg/m³. No correction for continuous exposure is applied because irritation is considered a concentration-dependent effect. The short-term EAL of 0.4 mg/m³ as a 1-hour mean is obtained by dividing the NOAEC by an uncertainty factor (UF) of 25.

The critical health effects from long-term inhalation exposure are considered to be respiratory irritation and neurobehavioral toxicity. The pivotal study for derivation of a long-term EAL is the same sub-acute rodent study used for the short-term EAL (HSE 2016). The long-term EAL of 0.1 mg/m³ as a 24-hour mean is obtained by dividing the NOAEC of 10 mg/m³ by a UF of 100. Although no UF for sub-acute to chronic duration is required because irritation is considered a concentration-based effect, an additional UF was included to take account of uncertainty over long-term effects.

References

[CNESST, 2019. Agents causing occupational asthma with key references. COMMISSION DES NORMES, DE L'ÉQUITÉ, DE LA SANTÉ ET DE LA SÉCURITÉ DU TRAVAIL, QUÉBEC, CANADA.](#)

[HSE, 2016. Substance Evaluation Report for 2-aminoethanol, Version 2. Health and Safety Executive.](#)

SCOEL, 1996. Recommendation from the Scientific Committee on Occupational Exposure Limits for Ethanolamine. SCOEL/SUM/24.

Appendix 5 - EAL derivation N-nitrosodimethylamine

9. N-nitrosodimethylamine (CAS Number 62-75-9)

N-nitrosamines are hydrocarbons with the generic chemical formula of (R₁R₂)-N-N=O, where R₁ and R₂ are alkyl groups, which are formed primarily by reaction of amines with oxidising agents including chlorine disinfectants, nitrites, and atmospheric nitrogen oxides. They have been detected in flue gases from carbon capture systems, which use amine-based solvents as reagents (SEPA 2014). N-nitrosodimethylamine (NDMA) is one of the most widely studied and has been detected in cosmetics, food, medicines, and drinking water (IPCS 2002).

N-nitrosamines are potent carcinogens (NIPH 2011, IPCS 2002) with epidemiological and animal studies reporting associations between exposure and cancers of the stomach, bowel, liver, kidneys, nasal cavity, and lungs. However, most available data for NDMA concerns its oral toxicity and evidence on other adverse effects is limited.

Regulatory Guidelines

None	
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Recommended Environmental Assessment Level in Air

Long-term EAL	0.0002 µg/m ³ as an annual mean
Short-term EAL	None (insufficient evidence)

Supporting Information

Carcinogenicity is the critical health effect from long-term chronic exposure to NDMA, although limited inhalation data is available. While other organisations have based their HBGVs on oral exposure, there is concern that NDMA is more potent via the inhalation route. The recommended long-term EAL of 0.2 ng/m³ as an annual mean is derived from a Benchmark Dose Level (BMDL₁₀) of 0.023 mg/m³ (a new analysis of data on the incidence of tumours in the nasal cavity in rodents from an inhalation study by Klein et al. 1991), adjusted for continuous exposure, divided by an appropriate margin of safety of 10,000.

There was insufficient evidence on which to derive a short-term EAL.

References

[IPCS. 2002. N-Nitrosodimethylamine. Concise International Chemical Assessment Document 38. Geneva: International Programme on Chemical Safety, World Health Organization.](#)

[KLEIN R.G., JANOWSKY I., POOL-ZOBEL B.L., SCHEMZER P., HERMANN R., AMELUNG F., SPIEGELHALDER B., ZELLER W.J., 1991. Effects of long-term inhalation of N-nitrosodimethylamine in rats. IARC SCIENTIFIC PUBLICATIONS, 105, 322 – 328.](#)

[NIPH. 2011. Health Effects of Amines and Derivatives Associated with CO₂ Capture: Nitrosamines and Nitramines. Norwegian Institute of Public Health: Oslo.](#)

[SEPA. 2014. Review of amine emissions from carbon capture systems. Version 2.01. Scottish Environment Protection Agency: Stirling.](#)

References:

H.E Buist, *et al* (2013). Hazard assessment of nitrosamine and nitramine by-products of amine-based CCS: Alternative approaches. (Provided in Annex A folder).

Charles River (2019). Combined 28-Day Repeated Dose Toxicity Study with the Reproduction/ Developmental Toxicity Screening Test of DiHEP Aqueous Solution by Oral Gavage in Rats. FINAL REPORT Test Facility Study No. 20172120. (Provided in Annex A folder).

ECHA Registration dossier Mono Ethanol Amine, reviewed October 2023:
<https://echa.europa.eu/registration-dossier/-/registered-dossier/15808/7/5/1>

ECHA Registration dossier 2-piperazin-1-ylethanol, reviewed December 2023:
<https://echa.europa.eu/nl/registration-dossier/-/registered-dossier/19699/7/2/1>

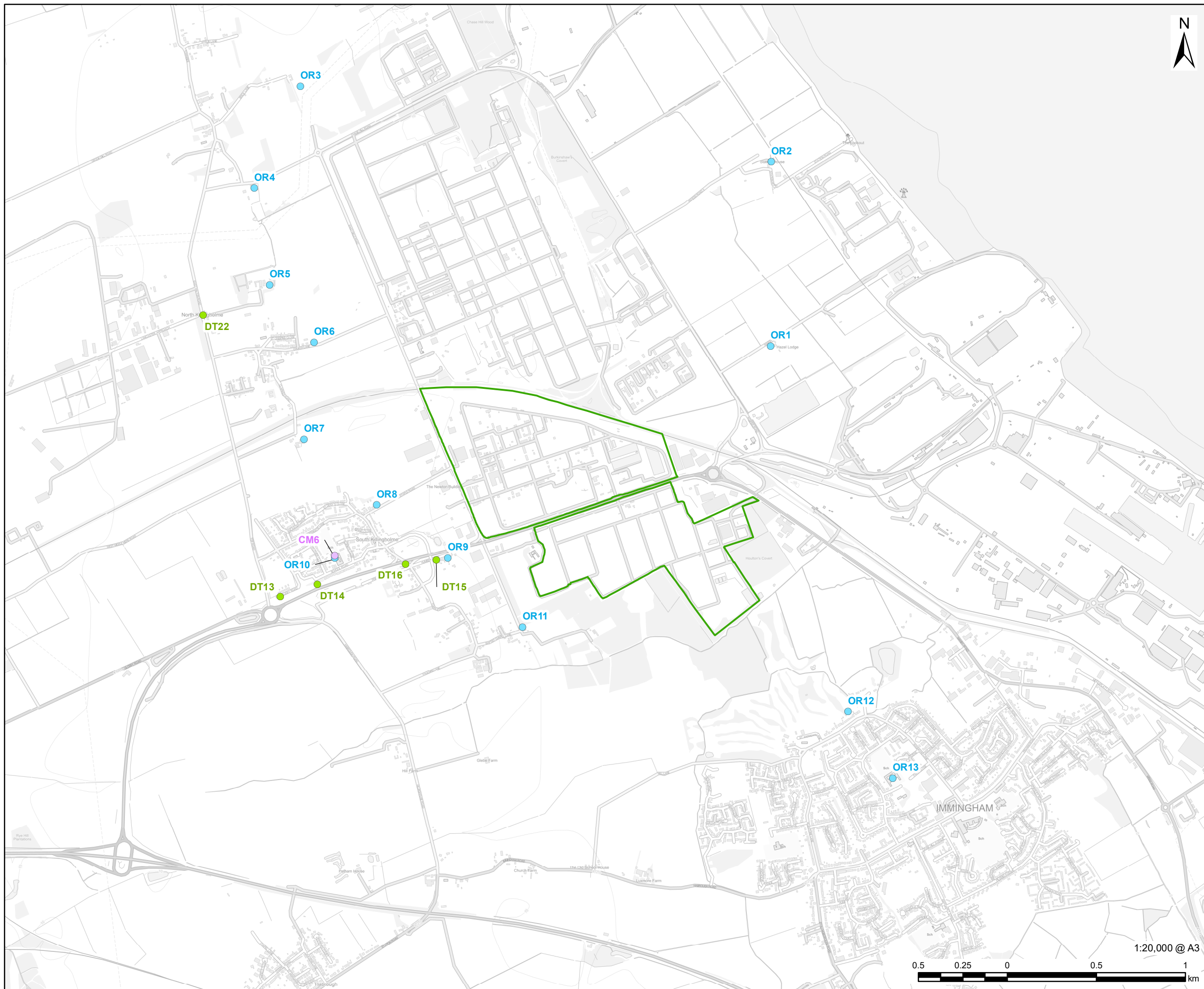
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<https://echa.europa.eu/mt/registration-dossier/-/registered-dossier/14941>

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Environment Agency (2020) Using our 2012 methodology to derive new Environmental Assessment Levels for emissions to air Revision of 10 existing EALs and derivation of two new EALs Date: October 2020

HSE (2016) Substance Evaluation Report for 2-aminoethanol, version 2. Health and Safety Executive
Plewa et al. University of Illinois. (2013). Technical Service Report on the Mutagenicity Analyses of Cansolv Nitrosamine Samples.

Annex B- Figures



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LS11 9AR
www.aecom.com

- LEGEND**
- Installation Site Boundary
 - Human Health Receptor
 - North Lincolnshire Diffusion Tube
 - North Lincolnshire Continuous Monitor

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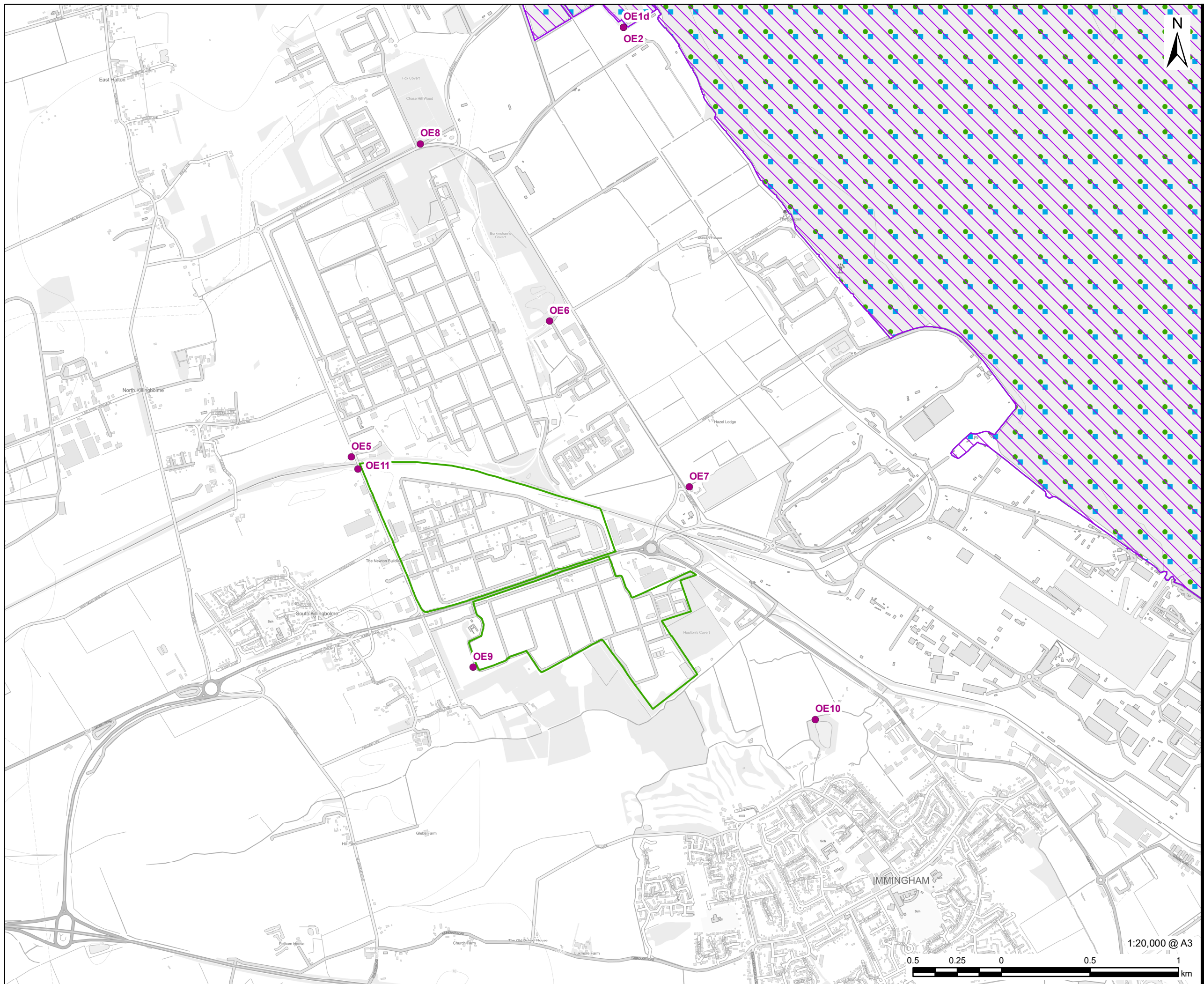
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FINAL
PROJECT NUMBER
60668866

FIGURE TITLE
Air Quality Study Area - Human Health
Receptors

FIGURE NUMBER
Figure 3.1



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LEGEND
Installation Site Boundary
Ecological Receptor
Ramsar
Special Protection Area (SPA)
Special Area of Conservation (SAC)

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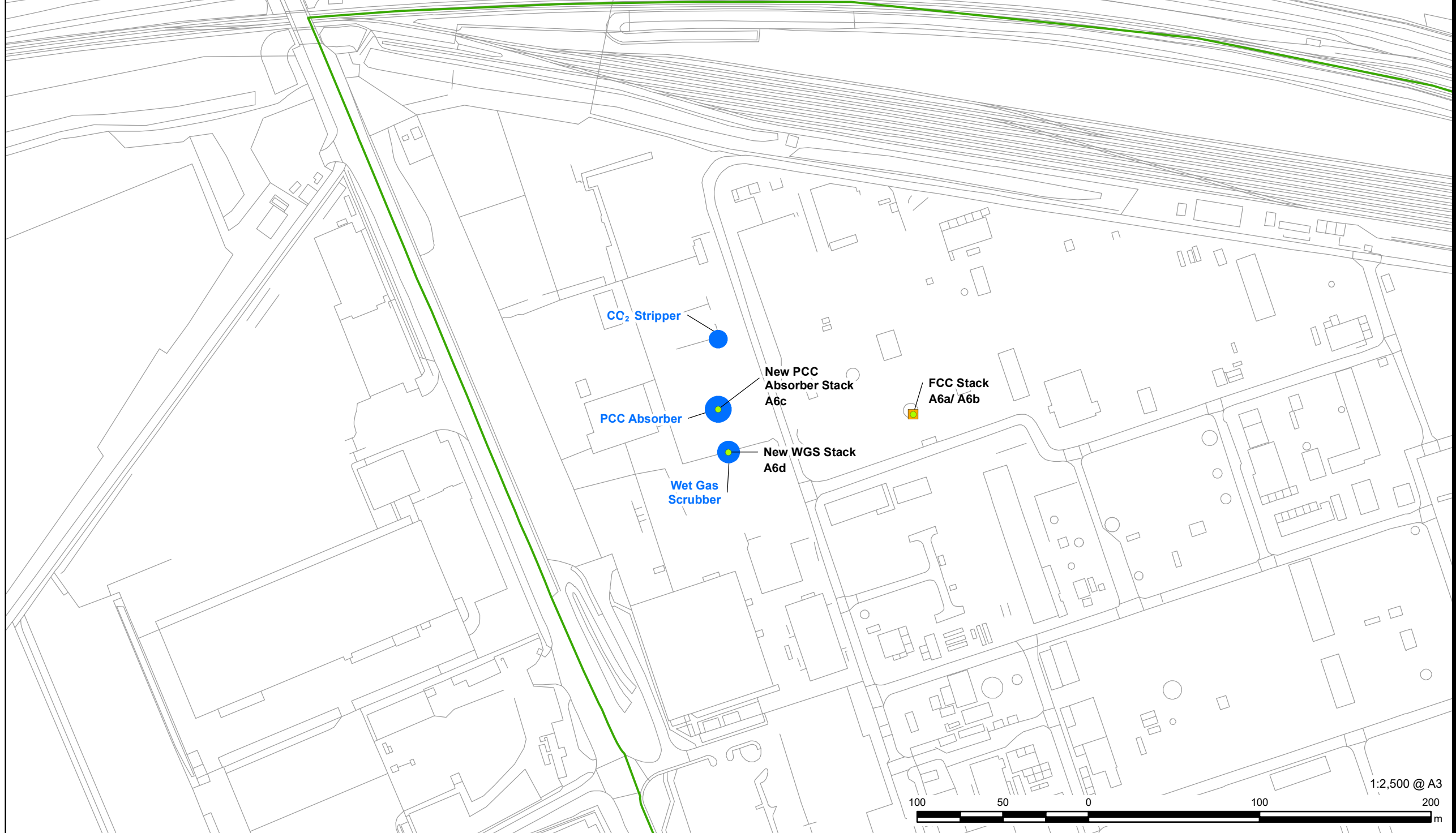
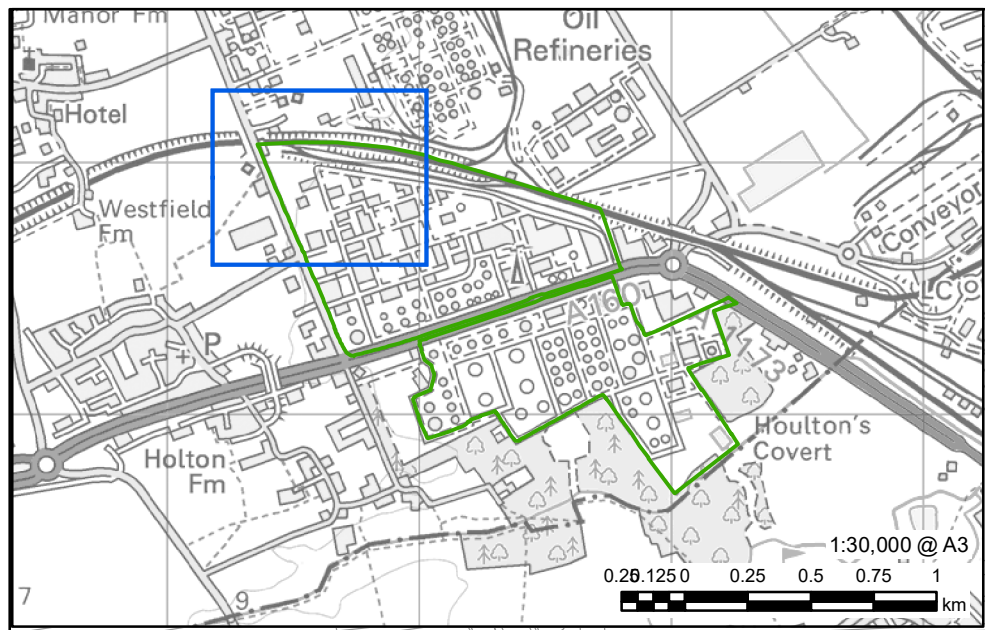
PROJECT NUMBER
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FIGURE TITLE
Air Quality Study Area - Ecological Receptors

FIGURE NUMBER
Figure 3.2

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Revision: 1 Drawn: ER Checked: LC Approved: HW Date: 2023-01-09
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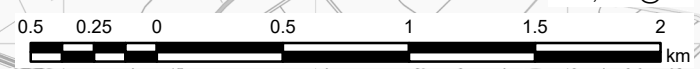
- LEGEND**
- Installation Site Boundary
 - Baseline Emission Source
 - Future Emission Source
 - Building Location

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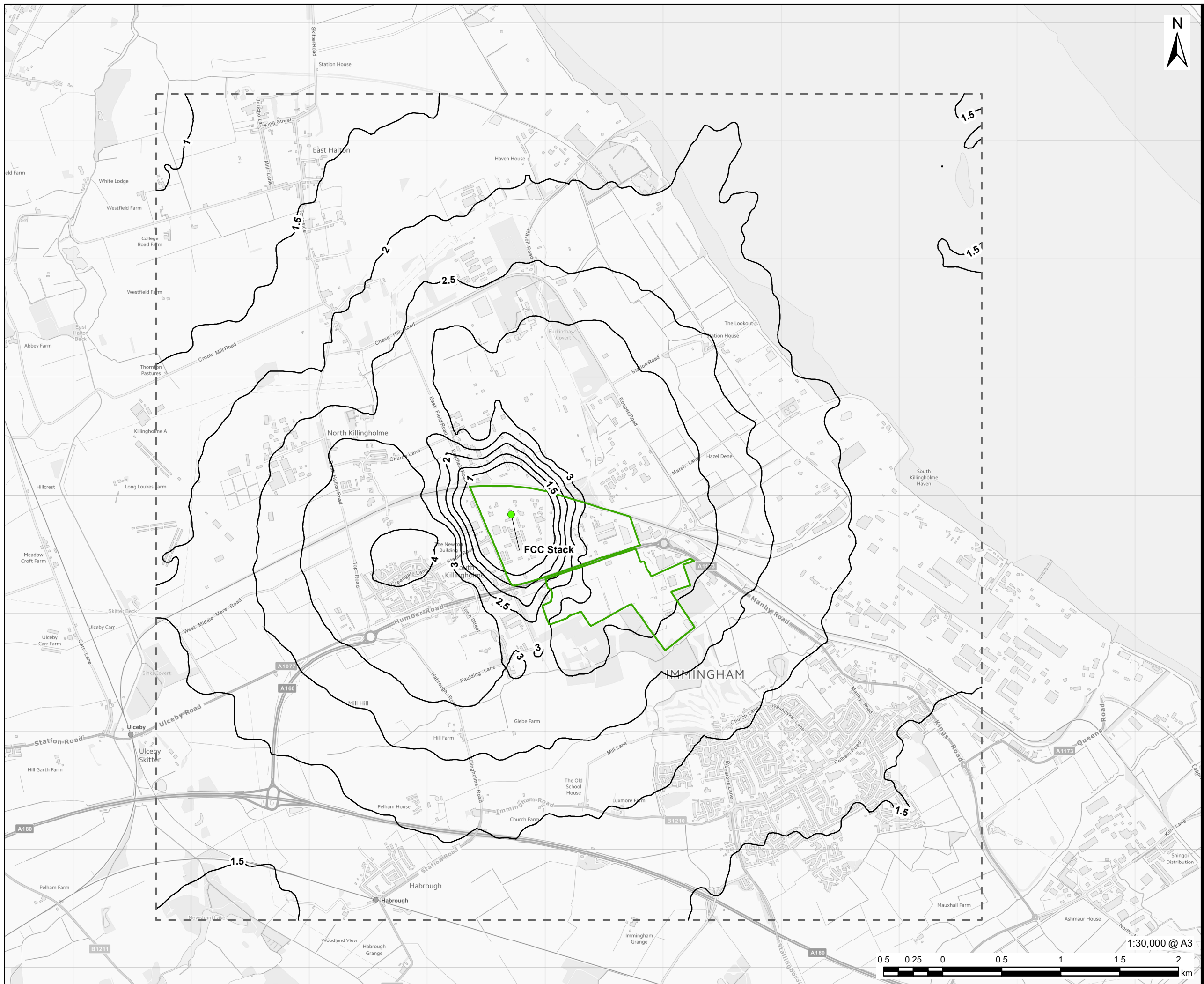
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PROJECT NUMBER
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FIGURE TITLE
Stack and Building Visualisation

FIGURE NUMBER
Figure 4.2

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LEGEND

- Installation Site Boundary
- Modelled Domain
- 99.79th%ile 1 Hour Mean NO₂ PC (µg/m³)
- Modelled Emission Sources – Phillips 66

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FIGURE TITLE
 Baseline Assessment - 99.79th Percentile of 1 Hour Mean NO₂ Process Contribution – 2021 Meteorological

FIGURE NUMBER
 Figure 6.2

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- LEGEND**
- Modelled Domain
 - Installation Site Boundary
 - Annual Mean NO₂ PC (µg/m³)
 - Modelled Emission Sources – Phillips 66

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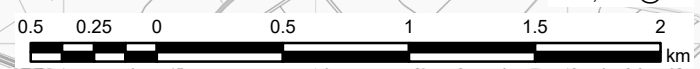
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FIGURE TITLE

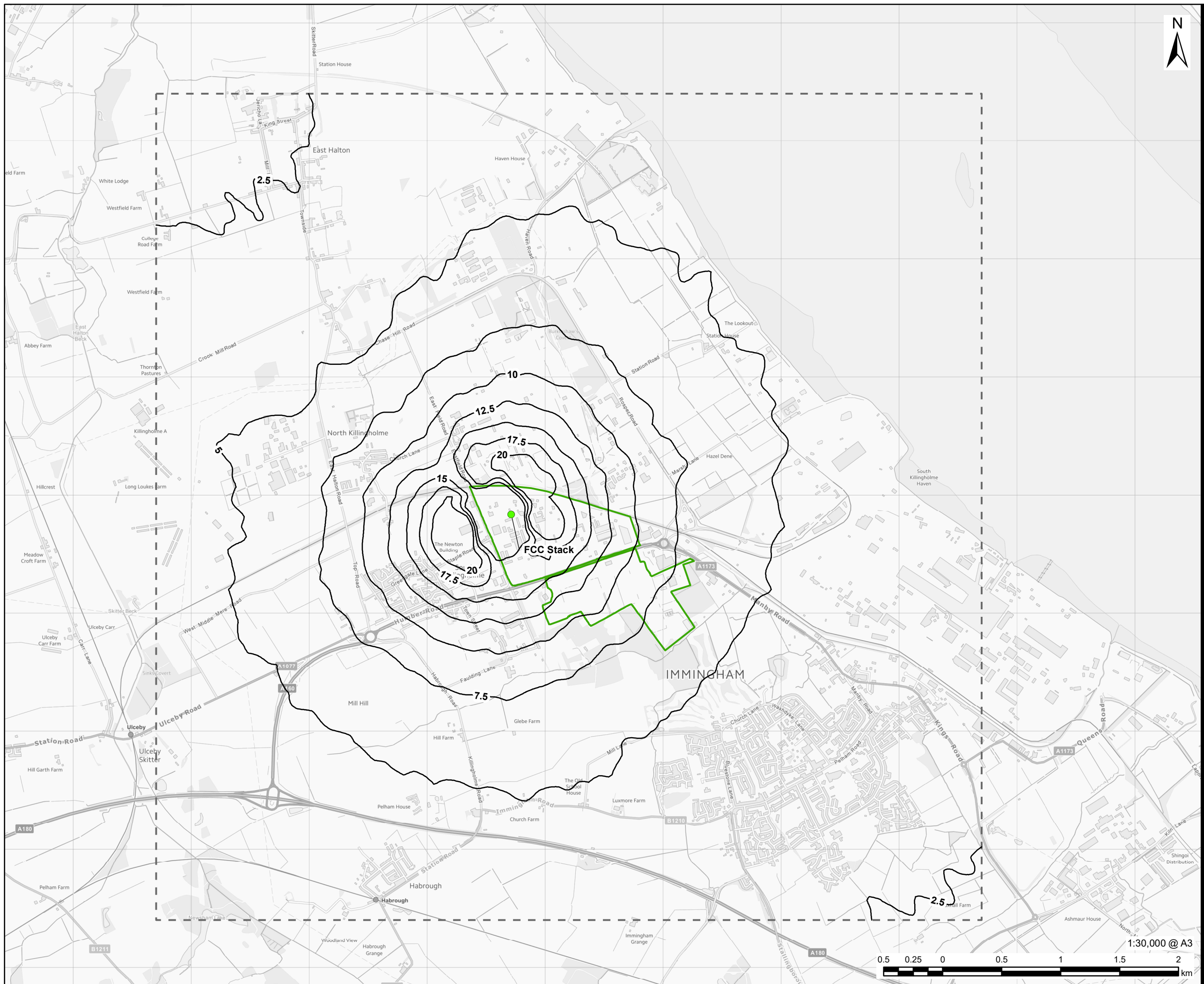
Future Assessment - Annual Mean NO₂
 Process Contribution – 2021
 Meteorological Year

FIGURE NUMBER

Figure 6.3



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LEGEND

- Installation Site Boundary
- 99.79th%ile 1 Hour Mean NO₂ PC (µg/m³)
- Modelled Domain
- Modelled Emission Sources – Phillips 66

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PROJECT NUMBER
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FIGURE TITLE
 Future Assessment 99.79th percentile of
 Hourly Mean NO₂ Process Contributions –
 2021 Meteorological year

FIGURE NUMBER
 Figure 6.4

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Annex C – Model Sensitivity

Main Assessment

The maximum predicted concentrations of NO₂ at the worst-affected human health receptor and NO_x at the worst-affected statutory designated ecological receptors (E11 for short term impacts and E6 for long term impacts) associated with the variable input parameters, are presented in Table C1 as the percentage of maximum reported values in the main assessment for the Future Assessment.

Table C1: Dispersion Model Sensitivity Analysis –Future Assessment

Model Input Variable	Human Health Receptor		Ecological Receptor	
	Short-term	Long-term	Short-term	Long-term
Result Presented in Main Assessment (µg/m³)	2.6	0.12	4.6	0.3
Meteorological data (5-year min-max)	62%	37%	18%	84%
Surface roughness representation (1.0m)	100%	123%	100%	106%
Surface roughness representation (0.3m)	99%	87%	99%	97%

The main uncertainty associated with the model is considered to be the meteorological data, with a NO₂ process contribution variation of 62% in the hourly mean NO₂ results for the Phillips 66 site; this is equivalent to an overall uncertainty at the worst-affected receptor of -1 µg/m³ (or -0.5% of the relevant AQAL).

The annual average NO₂ process contribution varies by 37%, equivalent to an overall uncertainty at the worst-affected receptor of -0.1 µg/m³ (or -0.3% of the relevant AQAL).

The surface roughness has been varied and it was found that a higher surface roughness (1.0 m), on the whole resulted in either equivalent or higher impacts at the worst-case receptor for the Installation, however for receptors further away from the source, the impacts would be reduced over those reported in the main assessment.

The lower surface roughness of 0.1m resulted in lower impacts.

N-Amine Assessment

The sensitivity of the N-amines model to various input parameters has been tested and is reported in this annex. The parameters that have been varied in the model input include:

- sensitivity to the meteorological data and background data used in the model, comparing the maximum results presented to the results for the meteorological year returning the lowest results;
- the main model assumed a percentage of NO₂ within the NO_x emission of 5%. Sensitivity of the model has been tested at 10%;
- the main model was run with dilution and entrainment turned on. Sensitivity of the model has been tested with no dilution and entrainment; and
- Some of the k values in the literature reviewed provided a +/- sensitivity value, and therefore these have been applied to the values used in the main model to provide sensitivity for the higher values and the lower values.

The results of the sensitivity testing are shown in Table C2 and represent the PCs of nitrosamine and nitramine combined as a percentage against the AQAL.

Table C2: Sensitivity of PC/ AQAL Results at the Worst-case Receptor R8

Model Input Varied	AQAL (ng/m ³)	Nitrosamine PC (ng/m ³)	Nitramine PC (ng/m ³)	Combined PC (ng/m ³)	Combined PC/AQAL %
Results presented in main assessment (Table 6.15)		0.027	0.033	0.060	30%
Meteorological data (lowest year)		0.009	0.008	0.017	8%
NOx to NO ₂ Ratio 10%	0.2	0.026	0.034	0.061	30%
No dilution and entrainment		0.015	0.032	0.048	24%
High sensitivity		0.057	0.108	0.165	82%
Low sensitivity		0.021	0.022	0.044	22%

Annex D - Stack Height Assessment

The selection of an appropriate stack release height requires a number of factors to be taken into account, the most important of which is the need to balance a release height sufficient to achieve adequate dispersion of pollutants against other constraints such as the visual impact of tall stacks.

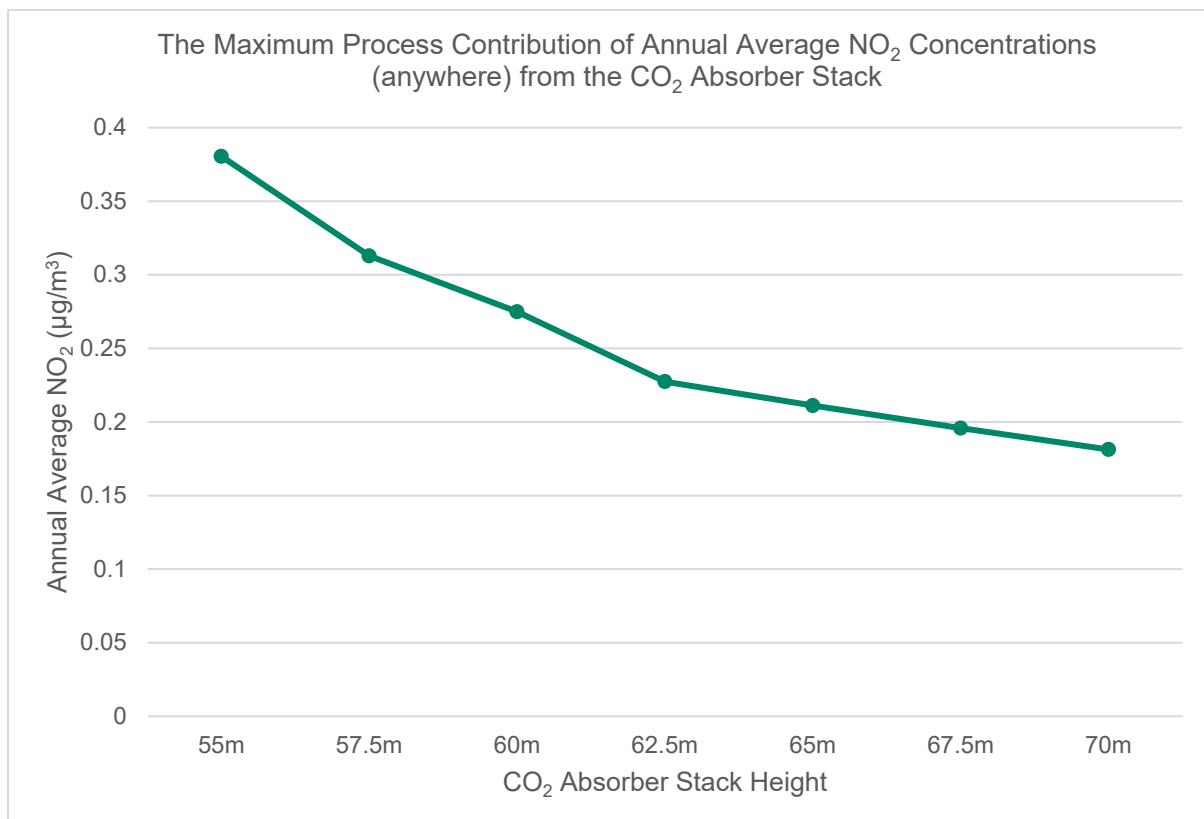
The emissions from the PCC Plant occur from a stack on top of the CO₂ Absorber Column. The CO₂ Absorber column itself has been included in the model as a building at a height of 51m AGL.

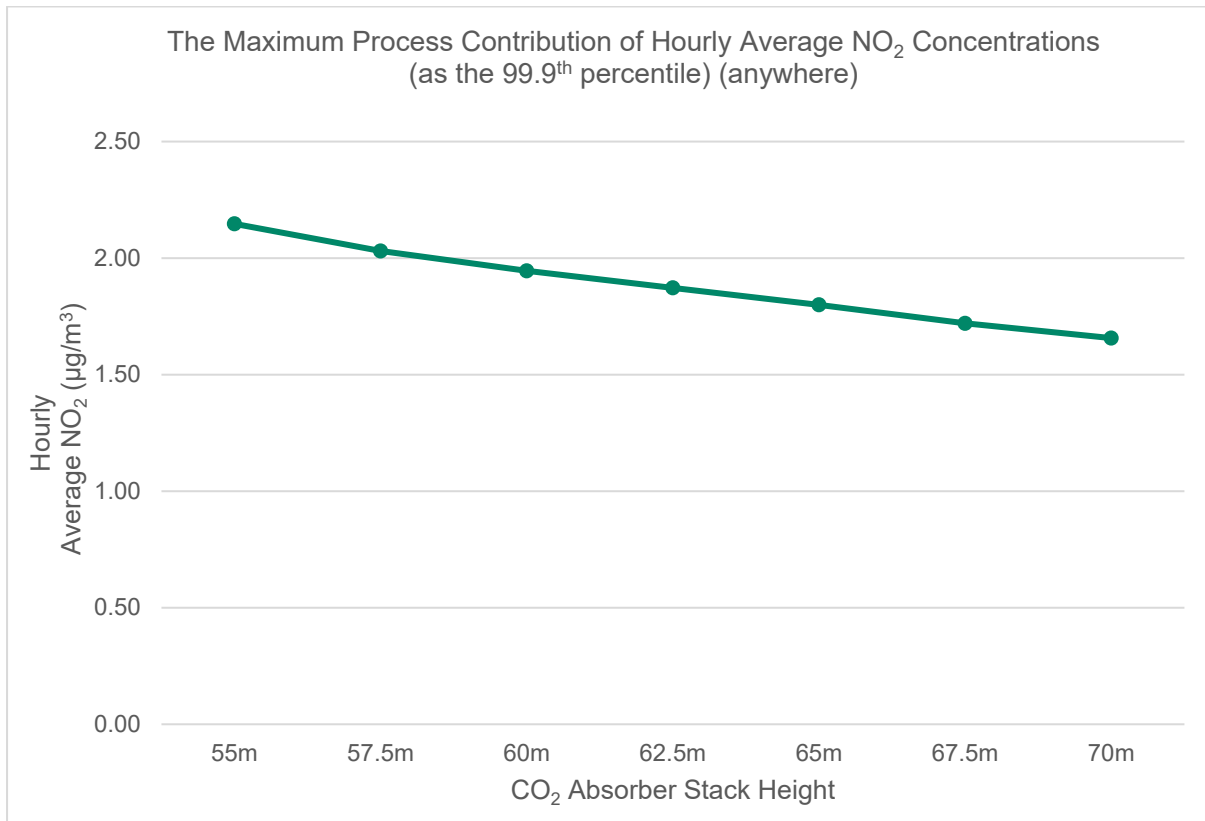
Given the already tall height of the CO₂ Absorber Column, the stack has been modelled at heights between 55m and 70m, at 2.5m increments. Graph showing the percentage PC against the relevant AQAL for the annual mean and maximum 1-hour NO₂ concentrations are presented in Figure D1. The purpose of the graph is to evaluate the optimum release height in terms of the dispersion of pollutants which would occur, against the visual constraints of further increases in release height, with the 'elbow' of the resulting curve showing where the reductions in ground level concentrations become disproportionate to the increasing height, regarded as the stack height that represents BAT for the emission source.

Analysis of the annual average NO₂ PC curve shows that the benefit of the incremental increase in release heights between 55m and 62.5m are relatively pronounced. At heights above 65m, the air quality benefit of increasing release height further is reduced. The hourly average NO₂ PC curve however shows a relatively straight line.

In order to ensure that the CO₂ Absorber stack has adequate length to install the required CEMS monitoring equipment, the minimum final stack height would be 65m.

Figure D1: Stack Height Determination





Annex E – Visible Plumes

The ADMS model set up is identical to that used for the main assessment of pollutant emission from the Future Assessment, except for the selection of plume visibility in the model set-up and the input of initial water content in the plume.

The initial water vapour mixing ratio of the plume is 0.031 kg/kg for the WGS release point and 0.052 kg/kg for the PCC Plant Absorber stack. As the PCC Plant stack has the higher water content, this results in the worst-case visible plumes from the two sources, and it should be noted that emissions will only occur from one of these stacks and any one time. As such, only the PCC Plant Absorber stack results are presented in Table E1.

The results show that the plumes are predicted to be visible for up to 22% of the time, with average plumes being up to 12 m. Occasional longer plumes are predicted (up to 241 m), however these are predicted to occur for less than 1% of the time.

Table E1: Visible Plumes from the PCC Plant Stack

Met Year	Percentage of Time Plume is Visible	Longest Visible Plume Length	Average Visible Plume Length (m)	Percentage of Year Visible Plume is Over 65 m
2017	18%	194m	12m	1%
2018	22%	241m	12m	1%
2019	19%	174m	8m	<1%
2020	16%	147m	7m	<1%
2021	20%	174m	11m	1%

