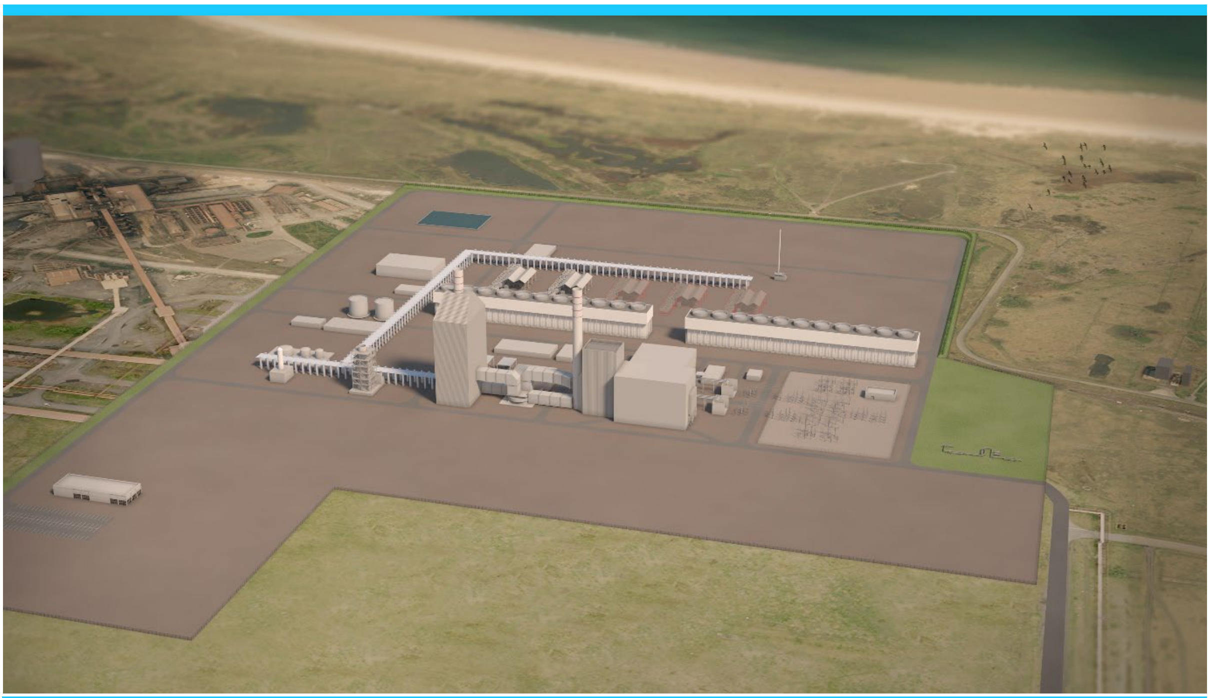
Net Zero Teesside Project

Environmental Permitting Reference: EPR/PP3501LR/A001

Technical Note to the Environment Agency and Natural England on Nitrogen Deposition

Environmental Permitting (England and Wales) Regulations 2016



Applicant: Net Zero Teesside Power Limited

Date: 22nd November 2023

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1. INTRODUCTION

1.1 Project Purpose

Net Zero Teesside Power Limited ('NZT') submitted an Environmental Permit application for a proposed Low Carbon Electricity Generating Station (the 'Proposed Installation') (Environment Agency Reference EPR/PP3501LR) in October 2021.

Urgent action is required to mitigate climate change from causing damage to the local and global environment. Phase 1 of the proposed development will contribute to a reduction in up to 4 million tonnes of carbon dioxide (CO_2) emissions per annum in the Teesside area, as well as potentially enabling further deployment of CCS technology around the world. Learnings from the early deployment of Carbon Capture and Storage (CCS) on such projects will be essential to ensure growth in the application of the technology more broadly to help mitigate climate change.

The Proposed Installation is part of the East Coast Cluster, selected as part of the Government's Track 1 CCUS in August 2022. It is envisaged that the deployment of CCS technologies have the potential to:

- Accelerate the Government's decarbonisation ambitions;
- Realise economic benefits across the East Coast of England; and
- Put the UK on a path to decarbonising the power system by 2035, whilst maintaining security of supply.

The Proposed Installation will lead the decarbonisation of industry within the Teesside area, and will facilitate the high-pressure compression facilities required to export captured CO_2 for off-shore storage. The Proposed Installation therefore underpins the decarbonisation of the Teesside area.

Specifically, the Proposed Installation will provide low carbon dispatchable power to help:

- Decarbonise the grid;
- Increase electricity security as the UK increase renewable power provision, which is reliant on climatic conditions for generation;
- Provide value for money through reduced system costs; and
- Refine Best Available Techniques (BAT) for emerging carbon capture techniques, leading the way for future projects.

1.2 Purpose of this Note

The Air Quality Impact Assessment provided with the Environmental Permit application assessed the impacts of nitrogen deposition (N-deposition) as a result of potential emissions of nitrogen dioxide (NO_2) and ammonia (NH_3). The impacts at Coatham Dunes, part of the Teesmouth and Cleveland Coast Site of Special Scientific Interest (SSSI), were predicted to be up to 3.9% of the Critical Load, at a location where the lowest value of the critical load range was already being exceeded by background concentrations.

During determination of the Environmental Permit, the Environment Agency have identified the requirement to include within the assessment additional potential nitrogen deposition from amines, which can also be present in the emissions from the carbon capture plant. As such, the Environment Agency and Natural England have expressed concern that actual N-deposition could be up to double that was predicted in the original assessment, and therefore have asked for additional information to be provided.

The Air Quality Impact Assessment provided with the Environmental Permit application was based on a number of worst-case assumptions, as the project was in a very early stage of development. Since the original assessment was carried out in 2021, additional information is now available which has been used in this reassessment.

This note presents additional information on the future operation of the Proposed Installation and the associated N-depositional impacts, including emissions of NO_2, NH_3 and amines.

This modelling demonstrates to the Environment Agency and Natural England that impacts will be less than those presented in the original impact assessment and that a deposition rate below 1% of the critical load is achievable.

2. CHANGES FROM ORIGINAL ASSESSMENT AND ADDITIONAL INFO

2.1 Background Nitrogen Deposition

Since the original assessment was undertaken in 2021, several updates to the Air Pollution Information System (APIS website[1]) have been carried out. The background pollution maps have been updated from the years 2017 – 2019 to 2018 – 2020. Also, a mapping error in APIS NH_3 data had occurred, which translated to an error in the total N-deposition backgrounds. This has resulted in the NH_3 mapping grid being "shifted a few kilometres north". As a result, the background N-deposition for the grid square where the maximum N-deposition impacts occur from the Proposed Installation has increased from the 10.5Kg N/ha/yr used in the original assessment to 12.5Kg N/ha/yr.

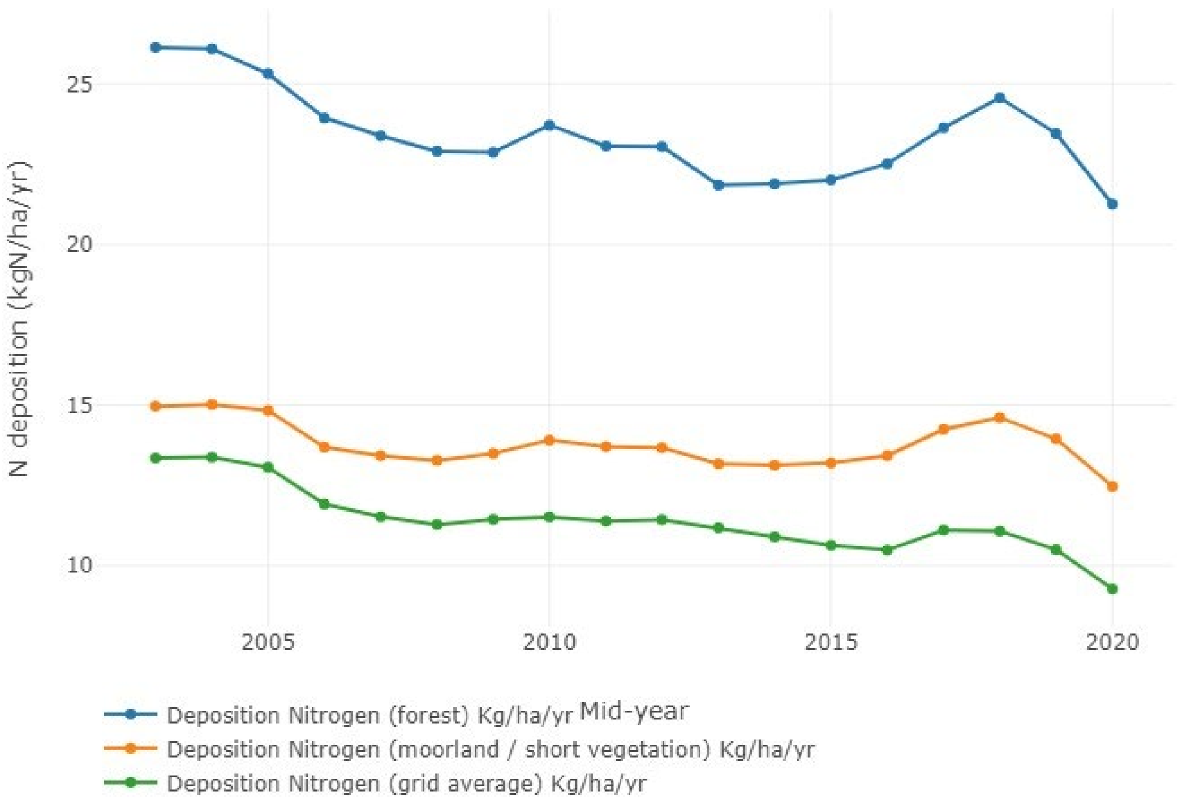
The background N-deposition for the locality of the Proposed Installation is shown in Figure 1, as reproduced from the APIS website. The grid square used for the derivation of the appropriate background concentration has been circled in red.

[1] Air Pollution Information System | Air Pollution Information System (apis.ac.uk)

Figure 1: Background N-deposition (moorland (short vegetation)) - KgN/ha/yr

The APIS website provides detail on the N-deposition trends since 2003. These are shown for the location of Coatham Sands in Figure 2.

Figure 2: Background N-Deposition Trends for Coatham Sands 2003 - 2020



It can be seen that the background N-deposition for moorland/ short vegetation has ranged by 2.5kg N/ha/yr from 15 kg N/ha/yr in 2003 to the 12.5 kg N/ha/yr provided for 2020.

A reduction between 2003 to 2015 can be seen from 15.0 to 13.1 kg N/ha/yr, however an increase then occurred between 2015 to 2018 back up to 14.6 kg N/ha/yr before a sharp decline 2018 – 2020, down to 12.5 kg N/ha/yr. This potentially could be associated with reduced traffic and industry as a result of the Covid-19 lockdowns during this time.

2.2 Critical Loads

The Critical Load class used for the original assessment was that of a Critical Load range of 10 – 15 kg N/ha/yr selected to apply to the type of dunes present at Coatham Dunes. Figure 1 shows that the background N-deposition is exceeding the lower end of the critical load range across the Coatham Dunes area of the Teesmouth and Cleveland Coast SSSI, however it remains below the upper end of the critical load range.

Additional information provided by Natural England[2] on the species classification for the area of Coatham Dunes has been reviewed, and Figure 3 shows the distribution of the contributing dunes types according to their National Vegetation Classification (NVC). The Proposed Installation boundary (indicative only) is shown in green and the boundary of the SSSI is shown in red.

[2] Stuart Hedley (2015). NVC Survey to Inform Review of Protected Sites around Teesside, Report to Natural England and Stuart Hedley (2017). NVC Survey of the Cleveland Golf Course, Report to Natural England

Figure 3: South Gare and Coatham Sands NVC

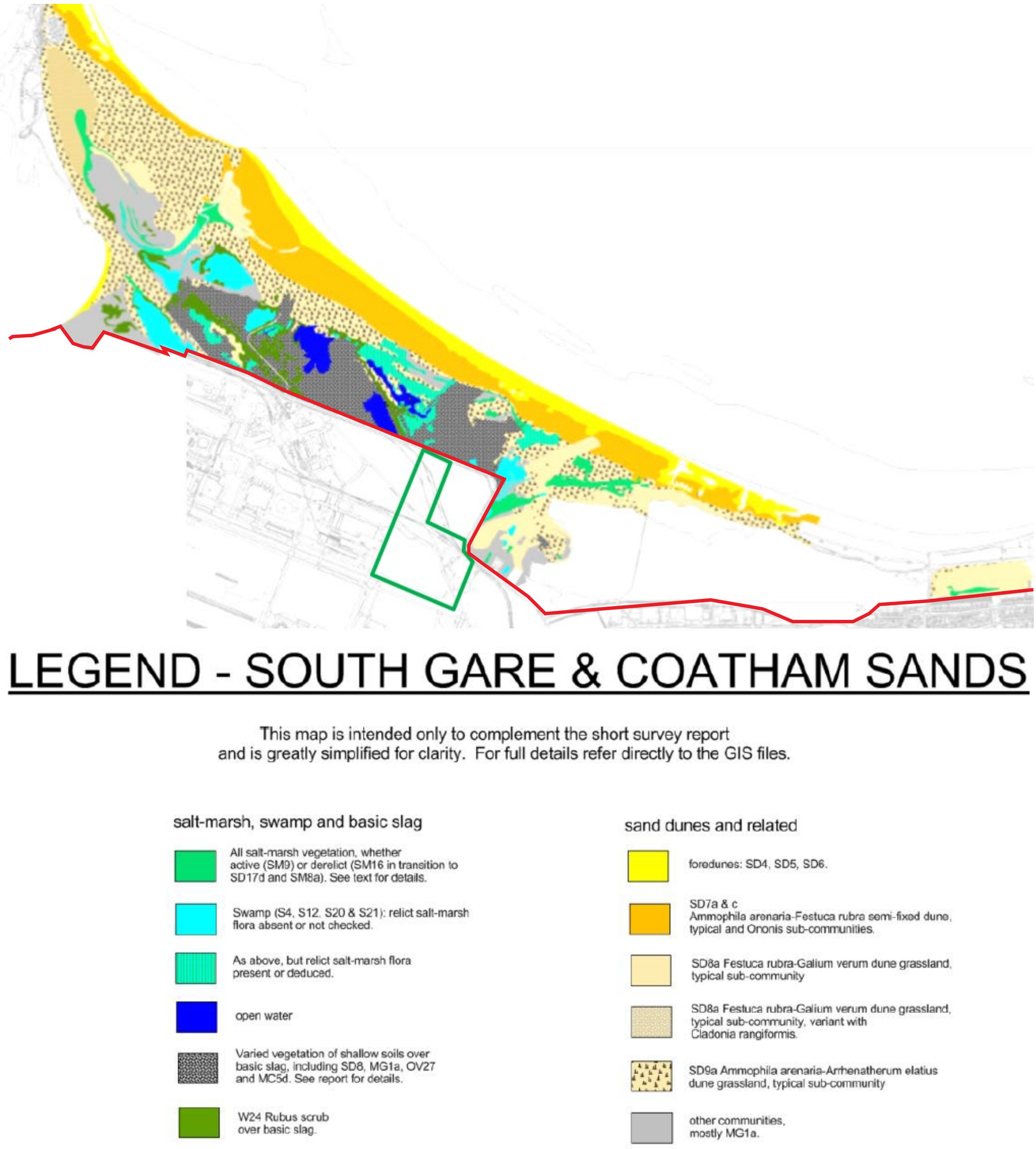


Table 1 shows the relevant NVCs for South Gare and Coatham Dunes, as seen in Figure 3, and provides the relevant Critical Loads for assessment.

Table 1: National Vegetation Classification (NVC) Present at South Gare and Coatham

NVC	Nitrogen Critical Load Class	Critical Load Range (kg N/ha/yr)	Total Hectarage in South Gare and Coatham SSSI
SD4	Shifting coastal dunes	10 - 20	6.09
SD5	Shifting coastal dunes	10 - 20	1.85
SD6	Shifting coastal dunes	10 - 20	13.00
SD7	Coastal dune grasslands (grey dunes)	For calcareous dunes use the 10 - 15	28.90
SD8	Coastal dune grasslands (grey dunes)	For calcareous dunes use the 10 - 15	16.38
SD9	Coastal dune grasslands (grey dunes)	For calcareous dunes use the 10 - 15	44.65

The revised N-deposition impacts presented in this note, have therefore been compared to the lower value in this Critical Load range (i.e. 10 kg N/ha/yr).

2.3 Additional Receptor Information

The Magic.gov.website shows that the South Gare and Coatham Dunes comprise SSSI interest Units 28 and 29 ("South Gare and Coatham Dunes" and "Coatham Quarries and Lagoons") of the Teesmouth and Cleveland Coast SSSI, with the main habitat type stated to be supralittoral sediment. The units cover a total area of 143.5ha and 65.8ha respectively.

In 2018 both Units 28 and 29 were assessed as being in an "unfavourable condition – recovering". There are no Integrated Site Assessments (ISA) surveys provided for either unit on the magic website.

The 2015 NVC Survey provided by Natural England confirms that the dune systems are calcicolous in nature. The report also states that despite the Teesmouth Dunes being one of the most influenced by human activity in Britian (both recreation and industrial) they support very large populations of introduced species and that the resilience of the dune processes in the face of this might very well be said to form a substantial part of the interest of this feature.

2.4 Operating Profile

The original assessment assumed that the Proposed Installation would be operational for 8,760 hours per year (i.e. 100% of the time), as a worst case. The actual purpose of the Proposed Installation will be to provide dispatchable power, and therefore it is not intended that it would ever operate at this load.

For the first two years of operation however, it is anticipated the Proposed Installation will operate for, on average, 64% of the time to ensure stabilisation of the CO_2 pipeline and underground storage until other industrial users come online. After this time, operation of the Proposed Installation will reduce.

In order to provide a more realistic assessment of the potential impact from the operation of the Proposed Installation, these reduced operating hours have been taken into account in this reassessment. For the purpose of this reassessment as a worst-case it has been assumed that the operational profile will be maintained at 64% for 12 years from 2028 to 2040 and then from 2040 to 2053 it is assumed that operation will drop to an average of 35% of the year. These numbers are operational averages for these periods based on a number of commercial operating scenario projections. A more rapid rollout of wind, solar and batteries could quickly push the Proposed Installation in to playing a more marginal role.

As depositional impacts on habitats occur over several years, rather than over a short one year period, it is considered appropriate to use the average model output for the 5 years of meteorological data used, rather than only the worst case year. This also aligns with the approach of looking at the operational profile over several years, rather than assuming the worst-case operational profile for one year for the assessment.

3. IMPACT ASSESSMENT

3.1 Assessed Emissions

The Environmental Permit application submitted for the Proposed Installation is for a "technology neutral" Monoethanolamine based Carbon Capture plant. This is because the application was made prior to detailed design being carried out, and therefore the purpose of the assessment was to ensure that a worst-case assessment was reported to create an envelope that the actual impacts would fit within, following detailed design.

The project has now undertaken a competitive Front-End Engineering Design (FEED) and post-FEED optimisation phase, which was carried out by two separate consortia. As such, there is more detailed design information now available, which is more representative of the Proposed Installation.

For the purpose of this revised impact assessment, the Proposed Installation has been assessed (as in the original Permit Application) with exhaust gas reheat applied. As both consortia have confirmed that reheat will be applied to their design it has not been necessary to rerun the original model without reheat as was done in the original impact assessment.

In addition, both consortia have confirmed that annual average emission concentrations for both ammonia and amine below 1mg/m^3 are achievable, considering the effectiveness of acid wash, and therefore these emission values are used in the reassessment. The location of the stack has been assessed in the southwest corner location of the four originally modelled stacks, as this resulted in the worst-case impacts at the Coatham Dunes receptor.

The modelled emissions are shown in Table 2.

Table 2: Remodelled Emissions for N-Deposition

Ref.	OS Grid Coordinates	Stack Height (m)	Stack Diameter (m)	Temp °C	Flow Rate Am^3/s	Flow Rate Nm^3/s	Efflux Velocity Am/s	Substance	Conc	Emission Rate
									mg/Nm^3	g/s
A1	456758, 525359	115	6.6	60	917.0	1,084	26.8	NOx	34.0	36.8
								NH3	1.0	1.08

Ref.	OS Grid Coordinates	Stack Height (m)	Stack Diameter (m)	Temp °C	Flow Rate Am^3/s	Flow Rate Nm^3/s	Efflux Velocity Am/s	Substance	Conc	Emission Rate
									mg/Nm^3	g/s
								Amines	1.0	1.08

[1] Flows normalised to dry, 0°C, 15% O_2, based on O_2 (dry) 11.9% H_2O 5.5%

3.2 Deposition Calculations

The deposition of nutrient nitrogen at the Teesmouth and Cleveland Coast SSSI has been calculated using the modelled PCs predicted at the relevant receptor points located along the area of dunes that are adjacent to the Proposed Installation. The deposition rates are determined using conversion rates and factors contained within published guidance [3], which takes into account variations in the deposition mechanisms for different types of habitat.

AQMAU recently issued draft guidance on the assessment of amine species deposition (Appendix 1). The guidance recommended a two-step process, including an initial screening step, using conversion factors to determine the deposition from amine species. A further, more detailed, dispersion modelling step could then be applied, if necessary, to provide further detailed assessment, using the ADMS amines module and taking into account atmospheric processes which can affect deposition of amines. For the purpose of this assessment, it is considered that the effects of these processes on emissions from the Proposed Installation would be minimal, given that there would be limited time for these atmospheric process to occur before any deposition occurred. As such, the conversion factor for the deposition of MEA, as detailed in the AQMAU guidance for the first screening step, has been applied.

The conversion rates and factors used in the assessment are shown in Table 3.

Table 3: Deposition Conversion Rates Ecological Receptors

Pollutant	Deposition Velocity Grasslands (m/s)	Nutrient Nitrogen ($\mu g/m^3/s$ to kg/ha/yr)
NOx as NO_2	0.0015	95.9
NH_3	0.02	259.7
Amines (MEA)	0.02	72

3.3 Results

As stated previously, the Proposed Installation has been re-modelled at the release conditions used for the Environmental Permit application, but taking into account:

- Reheat will be applied to the CO_2 absorber stack;
- Emissions of amines will be $1mg/Nm^3$, as an annual average;

[3] 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

- Emissions of ammonia will be 1mg/Nm^3, as an annual average; and
- The operational profile conservatively assumed to be 64% of the year for the first 12 years of operation, reducing to 35% of the year after this time.

The modelled results are shown in Table 4, and isopleth figures of the N-deposition are shown in Figure 4 and Figure 5.

Table 4: Predicted N-Deposition at the Teesmouth and Cleveland Coast SSSI

Operation Profile	Critical Load Range	Background Nitrogen Deposition kg N/ha/yr	BC/ CL	Modelled Process Contributions µg/m³			Process Contribution to N-Deposition kg N ha/yr			Total PC Kg N ha/yr	Total PC % of lower CL	PEC kg N ha/yr	PEC/ CL
				NO_2	NH_3	Amine	NO_2	NH_3	Amine				
64%	10 - 15	12.50	125%	0.22	0.009	0.009	0.032	0.049	0.013	0.09	0.9%	12.59	126%
35%				0.12	0.005	0.005	0.018	0.027	0.007	0.05	0.5%	12.55	126%

BC = Background concentration, CL = Critical Load, PC = Process Contribution, PEC = Predicted Environmental Concentration

The modelled process contribution is below 1% confirming that, even with contribution of amines, the proposed Installation will have a lower predicted N-deposition than presented in the original assessment.

Figure 4: 64% Operation N-Deposition Isopleths kg N/ha/yr

It can be seen for the 64% operational profile model, that the location of maximum N-Deposition occurs over the beach rather than the dune areas. The N-deposition over the dunes is typically 0.09 kg N/ha/yr (or 0.9% of the lower end of the critical load range) at the worst case location. The predicted environmental concentration including the background is 12.59kg N/ha/yr.

When compared to the trend in background concentrations for the Coatham Dunes site (Figure 2), which have varied by 2.5kg N/ha/yr over the last 17 years, this 0.09 kg N/ha/yr addition represents less than 4% of this variance, and predicted concentrations remain well within the background N-deposition concentrations that have been experienced at the site since 2003. As such, it is considered that the small increase as a result of the Proposed Installation would not impact the Coatham Dunes site, which has experienced levels of N-deposition up to 15kg N/ha/yr over the last 17 years.

Figure 5: 35% Operation N-Deposition Isopleths kg N/ha/yr

It can be seen in Figure 5 for the 35% operational profile model, that the location of maximum N-Deposition again occurs over the sands rather than the dune areas. The dunes experience N-Deposition of 0.05 kg N/ha/yr (or 0.5% of the lower end of the critical load range) at the worst-case location. The predicted environmental concentration including the background is 12.55kg N/ha/yr, which is within the concentrations that have been experienced at the site since at least 2003, and remains below the upper end of the critical load range.

4. CONCLUSIONS

The Air Quality Impact Assessment provided with the Environmental Permit application assessed the impacts of N-deposition as a result of emissions of NO_2 and NH_3. The impacts at Coatham Dunes, part of the Teesmouth and Cleveland Coast Site of Special Scientific Interest (SSSI), were predicted to be up to 3.9% of the lower Critical Load, at a location where the lowest value of the critical load range was already being exceeded by background concentrations.

The Environment Agency have identified the requirement to include additional nitrogen deposition from amines, which can also be present in the emissions from the carbon capture plant. As such, the Environment Agency and Natural England have expressed concern that actual N-deposition could be double those predicted in the original assessment, and therefore have asked for additional information to be provided. A subsequent communication from Natural England indicated that a deposition exceeding 1% of the critical load had the potential to damage the specified features of the SSSI.

Additional information on the proposed future operation of the Proposed Installation has now been provided and the associated N-depositional impacts have been reassessed, including emissions of NO_2, NH_3 and amines, in order to provide assurance to the Environment Agency and Natural England that a process contribution of 1% or lower of the lower critical load is achievable.

This re-modelling carried out considering detailed design information now available results in a predicted N-deposition of 0.05 - 0.09 kg N/ha/yr (or 0.5 – 0.9% of the lower end of the critical load range) at the worst-case location over the lifespan of the Proposed Installation. This is lower than the 3.9% of the critical load presented in the original impact assessment and below the 1% significance threshold indicated in the Natural England communication.

The maximum predicted environmental concentration including the background is 12.59kg N/ha/yr, which remains below the maximum value of 15 kg N/ha/yr that has been experienced at the Coatham Dunes site over the last 17 years, as reported on the APIS website. In addition, the condition of the SSSI interest units are stated as being in a recovering condition, despite the fact that the lower end of the critical load range has been exceeded during this time.

Once the final consortia has been selected for the Proposed Installation, an Environmental Permit variation application will be submitted to align the Environmental Permit with the final plant design. Therefore, at this time a further impact assessment will be carried out to support this Environmental Permit variation.

Appendix 1: Proposed assessment method to include amines and degradation products in nutrient nitrogen deposition estimations at ecological sites

Proposed assessment method to include amines and degradation products in nutrient nitrogen deposition estimations at ecological sites

AQMAU reference: AQMAU-C2600-RP01

AQMAU report date: October 2023

Summary

Amines used in amine-based solvent scrubber techniques in carbon capture can be a large group of chemical substances. When these substances are released to ambient air, they may react with atmospheric radicals to form nitrosamines and nitramines. Amines, nitrosamines, and nitramines contain nitrogen in their chemical structure, thus have the potential to contribute to nutrification of habitats.

The Air Quality Modelling and Assessment Unit (AQMAU) proposes an interim framework to include amines and amine degradation products in nutrient nitrogen deposition estimations from air dispersion modelling. Our recommended methodology is based on the available evidence found by us and provided to us at the time of writing this document.

At the time of writing this document, the only commercially available modelling software to evaluate the potential impacts from amines atmospheric reaction products is the ‘amines chemistry module’ within ADMS. The module is based on established science considering published research on amines reaction mechanisms. Although the validation of the module is not possible at the moment, the ADMS air dispersion modelling algorithms are continually validated against real world situations, field campaigns and wind tunnel experiments. We do not endorse a specific modelling software and we acknowledge the level of uncertainty.

The purpose of this document is to set guidelines for applicants to make judgements on the assessment of nutrient nitrogen deposition impacts at ecological sites from these substances. The document includes a practical example of the framework, which consists of:

1. Identification of pollutants with nutrifying effect
2. Approaching potential screening (‘business as usual’ assessment)
3. Detailed assessment (use of available transformation and deposition models)

1 Introduction

1.1 Amines used in amine-based solvent scrubber techniques in carbon capture can be a large group of chemical substances. When these substances are released to ambient air, they may react with atmospheric radicals to form nitrosamines and nitramines.

1.2 In addition, amine degradation products such as nitrosamines can be directly released from the stack (i.e., directly released nitrosamines). Nitrosamines (either directly released or formed in ambient air) may or may not be stable in the atmosphere. There can be two potential sources of nitrosamines, such as N-nitrosodimethylamine (NDMA), oftentimes referred as 'direct' and 'indirect':

- 'indirect': NDMA formed in ambient air through chemical reaction of dimethylamine (DMA) with hydroxyl radical (OH).
- 'direct': NDMA directly emitted from the stack.

1.3 Amines, nitrosamines, and nitramines contain nitrogen in their chemical structure, thus have the potential to contribute to nutrification of habitats in addition to nitrogen dioxide (NO_2) and ammonia (NH_3).

1.4 The amines chemistry module incorporated in the Cambridge Environmental Research Consultants (CERC) Air Dispersion Modelling Software (ADMS) estimates the unreacted amines and transformed products concentrations at downwind locations of emitting sources, although validation is not possible at the moment.

- When the ADMS amines chemistry option is not used, concentrations are estimated using common transport and dispersion algorithms (i.e., 'business as usual' air dispersion modelling).
- When the ADMS amines chemistry option is used, concentrations are estimated incorporating atmospheric reaction mechanisms into the common dispersion and transport algorithms (i.e., 'amines modelling'). In ADMS, deposition cannot be modelled when the amines chemistry option is selected.

1.5 The order of magnitude of concentrations at ecological sites is case specific, mainly dependent on:

- The amine emission levels.
- The substance specific atmospheric transformation reactions (inputs to the ADMS amines chemistry module).
- The overall site-specific dispersion and transport case and location of receptors.

1.6 ADMS is the only commercially available modelling software to evaluate the potential impacts from amines atmospheric reaction products. The module is based on established science considering published research on amines reaction mechanisms. Although the validation of the module is not possible at the moment, the ADMS air dispersion modelling algorithms are continually validated against real world situations, field campaigns and wind tunnel experiments. We do not endorse a specific modelling software and we acknowledge the level of uncertainty.

1.7 The purpose of this document is to propose a method and set guidelines for applicants to make judgements to include amines and amine degradation products in nutrient nitrogen deposition estimations at ecological sites. This document includes an example of the framework. For context, it is recommended that this document is read alongside our Environment Agency modelling guidance[1] and the AQMAU recommendations document[2].

[1] Guidance: Environmental permitting: Air dispersion modelling reports. Available at https://www.gov.uk/guidance/environmental-permitting-air-dispersion-modelling-reports [Accessed in October 2023]
[2] AQMAU recommendations for the assessment and regulation of impacts to air quality from amine-based post-combustion carbon capture plants. AQMAU-C2025-RP01. November 2021. Available at AQMAU-C2025-RP01.pdf (ukccsrc.ac.uk).

2 AQMAU recommended process to estimate nutrient nitrogen deposition

A summary of the framework recommended by AQMAU is:

- Step 1: Identification of pollutants with nutrifying effect
- Step 2: Approaching potential screening
- Step 3: Detailed assessment

Step 1: Identification of pollutants with nutrifying effect

2.1 Identify the pollutants with nitrogen in their chemical structure, the amine(s') chemical reaction(s) and their molecular weight(s). In this case, the substances are:

- Directly emitted pollutants (direct) with nitrogen in their chemical structure: amines, nitrosamines, in addition to NO_2 and NH_3.
- Pollutants formed through atmospheric reactions (indirect) with nitrogen in their chemical structure: nitrosamines, nitramines.

2.2 Estimate the factors to convert dry deposition flux (µg/m^2/s) to nutrient nitrogen deposition (kg N/ha-y) using the nitrogen (N) available for deposition within the pollutant molecule (i.e., nitrogen atomic weight, 14, divided by the species molecular weight).

2.3 Assign a deposition velocity to each substance based on similarities in physicochemical behaviour to substances with known deposition velocities[3]. These judgements should be made per substance(s), also considering those formed through atmospheric chemical reaction(s). You may need to consult published research and chemical databases to justify your decision. If in doubt, use a conservative deposition velocity as a precautionary approach. If an alternative to a known/published deposition velocity is proposed, you will need to justify your choice.

Step 2: Approaching potential screening

2.4 Calculate the nutrient nitrogen Process Contributions (PCs) per pollutant with the assumption that emitted amines do not react and the directly emitted nitrosamines are stable (i.e., pollutants only transport and disperse 'business as usual' air dispersion modelling).

2.5 Evaluate how much each pollutant contributes to the total nutrient nitrogen deposition at the ecological receptor. Use these results, contour plots and air dispersion modelling knowledge to estimate the level of uncertainty in the total nutrient nitrogen PCs and judge whether you may need to carry out a detailed assessment using the available transformation and deposition models (i.e., Step 3).

Step 3: Detailed assessment

2.6 As deposition cannot be modelled in conjunction with amine chemistry in ADMS, the CERC ADMS 6 amines chemistry supplement[4] proposes the following method to estimate the deposition fluxes (µg/m^2/s), D:

$$D = C1 \cdot \left(\frac{D2}{C3}\right)$$

[3] AQTAG06 Technical guidance on detailed modelling approach for an appropriate assessment for emissions to air, March 2014 (Habitats Directive)

[4] ADMS 6 Amine chemistry. User Guide Supplement. Version 6.0. Cambridge Environmental Research Consultants Ltd. (CERC). March 2023

Where:

- C1 is the output concentration from run with the amines chemistry ON (Run 1)
- D2 is the output deposition flux from run with amines chemistry OFF and deposition ON (Run 2)
- C3 is the output concentration from run with amines chemistry OFF and deposition OFF (Run 3)

2.7 Following the AMDS amines chemistry supplement, add the deposition velocity in the pollutants palette (refer to point 2.3).

2.8 Carry out the suggested model runs and calculations to judge the significance of your results:

- Estimate the deposition fluxes, D, according to the equation presented above (refer to point 2.6). Then convert to kg N/ha-y to calculate the nutrient nitrogen deposition PCs.
- Evaluate the significance of your nutrient nitrogen deposition PCs against the critical loads at the ecological site (refer to point 2.5).

We note that there is also an aqueous amine scheme within ADMS 6 which includes an option to incorporate the absorption of amines (and their products) into any liquid water in the plume. Further information can be found in the CERC ADMS 6 Amine chemistry supplement.

3 Example of nutrient nitrogen calculations

3.1 An example of the recommended framework and calculation steps is presented in Table 2.

3.2 The emitted and formed substances to consider in the model and nutrient nitrogen deposition calculations are presented in Table 1. The emissions are amines MEA and DMA and nitrosamine NDMA, in addition to NO_X and NH_3. NDMA is directly emitted, and it is also formed from the reaction of DMA in ambient air.

3.3 In Step 3 of this example, the deposition flux (D) has been estimated for DMA and MEA only. Noting the comparatively small contribution of nitrosamines and nitramines in this example (in the order of ng/m^3), a conservative screening approach for calculating the nutrient nitrogen deposition has been used for these substances.

Table 1 – Emitted and formed substances in the example

Directly emitted ('direct')	Formed ('indirect')	Conceptual reaction
MEA	MEA-NO_2	MEA → MEA-NO_2
DMA	NDMA DMA-NO_2	DMA → NDMA DMA → DMA-NO_2
NDMA NO_X NH_3	- - -	- - -

Table 2 – Example of the calculation steps and recommended framework to include amines and degradation products in nutrient nitrogen deposition estimations at ecological sites

STEPS	PARAMETERS	UNITS	NO_2	NH_3	NDMA (emitted)	MEA	DMA	NDMA (formed)	$MEA\text{-}NO_2$ (formed)	$DMA\text{-}NO_2$ (formed)	
					nitrosamine	amine	amine	nitrosamine	nitramine	nitramine	
Identification	Molecular weight	g/mol	46	17	74	61	45	74	106	90	
	N in the molecule which is available for deposition	-	0.30	0.82	0.19	0.23	0.31	0.19	0.13	0.16	
	Conversion factor $\mu g/m^2/s$ to kg N/ha-y	-	96	260	60	72	98	60	42	49	
	Deposition velocity species approximation	-	NO_2	NH_3	Precautionary NH_3 deposition velocity assumed						
	Deposition velocity	m/s	0.003	0.03	0.03	0.03	0.03	0.03	0.03	0.03	[AQTAG06]

PARAMETERS	UNITS	Value	
Critical Load value (Clo)	**kg N/ha-y**	**10**	[APIS]

STEPS	PARAMETERS	UNITS	NO_2	NH_3	NDMA (emitted)	MEA	DMA	NDMA (formed)	$MEA\text{-}NO_2$ (formed)	$DMA\text{-}NO_2$ (formed)	
Screening No amines model	PC (C3) - chemistry OFF, deposition OFF	$\mu g/m^3$	0.12	0.08	4.16E-05	0.208	0.104	-	-	-	['business as usual' modelling]
	Nutrient Nitrogen deposition	kg N/ha-y	0.04	0.65	7.44E-06	0.45	0.31	-	-	-	
	PC % of critical load	%	**0.36%**	**6.48%**	**<0.001%**	**4.52%**	**3.06%**	-	-	-	
	Total Nutrient Nitrogen deposition PC/Clo (Screening)	**%**	**14.4%**								
Detailed Amines and deposition model	PC (C1) - chemistry ON, deposition OFF	$\mu g/m^3$	-	-	-	0.195	0.099	1.06E-04	1.66E-04	4.50E-04	[amines modelling]
	Deposition flux (D2) - chemistry OFF, deposition ON	$\mu g/m^2/s$	-	-	-	3.88E-03	1.94E-03	-	-	-	[deposition modelling]
	Calculated deposition flux (D) = C1*(D2/C3)	$\mu g/m^2/s$	-	-	-	3.65E-03	1.84E-03	-	-	-	
	Nutrient Nitrogen deposition	kg N/ha-y	-	-	-	0.26	0.18	1.9E-04	2.07E-04	6.63E-04	
	PC % of critical load	%	-	-	-	**2.64%**	**1.80%**	**<0.002%**	**<0.002%**	**0.01%**	

PARAMETERS	UNITS	Value
Nutrient Nitrogen deposition PC/Clo (Amines and degradation products)	**%**	**4.4%**
Total Nutrient Nitrogen deposition PC/Clo (Detailed)	**%**	**11.3%**