Kings Lynn SCR Technical Feasibility Study

PJ20602 – NG SCR Pre-FEED Study

[redacted]

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Overview

In this document, [redacted] will propose an SCR and CO catalyst solution that can be retrofitted to the Avon 1533 unit at unit B of the National Grid Kings Lynn site, unit A is to be decommissioned. The basis of the design has used exhaust data provided by National Grid and emissions limits stated in the IED legislation.

[redacted] have opted to proceed with a horizontal catalyst solution as well as a vertical arrangement as National grid have expressed a preference for a horizontal arrangement since there is sufficient space on each of the sites. Each unit will have a dedicated exhaust stack and catalyst unit. The exhaust gases must be cooled before entering the catalyst unit, this will be achieved with the entrainment of ambient air as this removes the need for cooling fans.

This document refers to the previous pre-FEED study carried out by [redacted] on the National Grid Kirriemuir site. Differences between the design and values used have been discussed.

Revision History

Revision	Date	Reason
Preliminary	20/7/22	Draft release for initial review
A	17/08/22	Initial submission
B	07/09/22	Revision B
C	20/09/22	Revised from comments

Contents

References

Reference Number	Reference
1	Pre-FEED Study of Selective Catalytic Reduction Innovation Project – Technical and Commercial Report, Document No: GB00358019, [redacted] Control No: MX16008, date 27/03/2017
2	TQ_20602_002 (ATEX Drawings)
3	TQ_20602_008_R (Process Duty Point Data)
4	TQ_20602_010 (Height restrictions enquiry)
5	TQ_20602_011 (Potential Storage Locations)
6	TQ_20602_016 (Electricity costs)
7	TQ_20602_020
8	SCR_review_scopev5(16.11.21)
9	Dwg. 72100803000004 (ATEX Drawing)

Abbreviations

FEED	Front End Engineering Design
[redacted]	[redacted]
SCR	Selective Catalyst Reduction
NOx	Nitrogen Oxides
CO	Carbon Monoxide
IED	Industrial Emissions Directive
MCPD	Medium Combustion Plant Directive
GT	Gas Turbine
MW	Mega Watt
ATEX	Explosive Atmospheres
TQ	Technical Query
CFD	Computational Fluid Dynamics
CEMS	Continuous Emissions Monitoring System
DAHS	Data Acquisition & Handling System

1. Introduction

The purpose of this pre-FEED study is to assess the feasibility of introducing Selective Catalyst Reduction (SCR) and a CO Catalyst to existing gas turbine exhaust at the National Grid Kings Lynn Compressor Station. The combined SCR and CO Catalyst will be known as the "Catalyst Unit" from this point on. [redacted] will also note differences between this Kings Lynn study and the [redacted] Kirriemuir report titled: *Pre-FEED Study of Selective Catalytic Reduction Innovation Project – Technical and Commercial Report, Document No: GB00358019,* [redacted] *Control No: MX16008, date 27/03/2017.*

From January 1st 2016, plants with a net thermal input exceeding 50MW need to comply with IED regulations. The duty points provided for the Kings Lynn site do not exceed the 50MW limit and hence the MCPD regulations could be applied. However, after enquiring with National grid it was decided that the IED emissions targets would be applied for this report similarly to the Wormington Pre-FEED study. This was done to ensure consistency across the sites under consideration as discussed in TQ_20602_025, additionally the IED is the same directive that was applied by [redacted] for the Pre-FEED study of the Kirriemuir Compressor Station and so the application of this directive allows for better comparison between the proposals for each of the sites.

In its current configuration, the gas turbine at National Grid Kings Lynn unit B exceeds the threshold for NOx emissions for both the IED and MCPD at all duty points provided and fails to meet the CO limits given by IED. The location of unit B is shown in Figure 1.

Figure 1- National Grid Kings Lynn - Unit B

[redacted]

2. Basis of Design

The following design parameters have been taken into consideration for the design of the combustion exhaust & catalyst unit. The catalyst unit inlet conditions differ from the values used in the [redacted] Kirriemuir report because [redacted] were provided different process duty points for the Kings Lynn site. [redacted] have been provided with a greater maximum exhaust gas temperature at 585.59°C (duty point 2), compared to the maximum temperature of 546°C seen at Kirriemuir.

As the 585.59°C maximum temperature at Kings Lynn is higher than Kirriemuir, the catalyst unit solution and specification of ancillary equipment may differ from the proposed design in the [redacted] report, and some aspects may not be directly comparable.

2.1. Gas Turbine Data

Gas Turbine:	Avon 1533, rated at 12.34MW
Unit Number:	Unit B
Location:	Kings Lynn, England

2.2. Catalyst Unit Inlet Conditions

Gas Flow:	51.87 – 70.23 kg/s
Temperature:	502.18 – 585.59 °C
NOx:	78.24 – 152.65 mg/m3
CO:	50.10 – 427.10 mg/m3

2.3. Catalyst Unit Emissions Limits

NOx Emissions:	35 mg/Nm3 (annual average)
CO Emissions:	100 mg/Nm3 (annual average)
NH3 Emissions:	3 mg/Nm3 (annual average)

2.4. Catalyst Unit Design Data

Cooling Air Flow (Entrainment):	22.00 kg/s (Max)
Catalyst Unit Total Gas Flow:	149998 – 266711 Nm3/hr
Catalyst Unit Air Temperature:	454.44°C
Reagent Selected:	Aqueous Ammonia
Reagent Concentration:	24.5% by weight
NOx Removal:	55.27 – 77.07 %
Catalyst Unit Voltage:	400V/3Ph/50Hz
Hours of Operation:	3000 hours per year (Base case)

2.5. Catalyst Unit System Performance

NOx Emissions:	35 mg/m^3 Annual average
CO Emissions:	100 mg/m^3 Annual average
NH3 Emissions:	3 mg/m^3 Annual average
Pressure Drop of Catalyst Unit:	<=6.9 mbar
Reagent Flowrate:	36 kg/hr
Compressed Air Consumption (Maximum Steady State):	1 SCFM
Compressed Air Consumption (Maximum Instantaneous):	5 SCFM

2.6. Environmental Design Data

Site Temperature Range:	-20 to +40 ^oC
Relative Humidity:	Up to 100%

2.7. Design Codes

Design Code:	In accordance with Eurocode EC0, BS EN 1990:2002
Fabrication & Execution Code:	In accordance with BS EN 1090-2:2009 & BS EN ISO 3834-2:2005.
NDE Requirements:	NDE requirements in line with Eurocode EC0, BS EN1990:2002 & [redacted] EI-096
Structural Code:	In accordance with Eurocode EC3, BS EN 1993:2007
Access Code:	In accordance with BS EN ISO 14122:2010
Load Combinations:	In accordance with Eurocode EC1, BS EN 1991-4:2006
Operating Effective Wind Speeds:	In accordance with Eurocode EC1, BS EN 1991-4:2006
Snow and Ice / Maintenance (access) Loads:	In accordance with Eurocode EC1, BS EN 1991-4:2006
Seismic g Loads:	In accordance with Eurocode EC8, BS EN 1998-1:2004
PED:	Equipment to be supplied in accordance with the Pressure Equipment Directive 97/23/EC. This product may be used within the European Economic Area and is subject to operating pressures above 0.5 barg, therefore the

	product and associated documentation must adhere to the full requirements of the PED.

2.8. Electrical

Equipment Zone Area:	Zone II
Electrical Code:	In accordance with BS EN 7671:2008
Earthing Code:	In accordance with BS EN 7430:2011
CE Marking:	Required
ATEX:	EU ATEX directives 94/9/EC and 1999/92/EC must be adhered to such that the equipment is suitable for the automatic operation and protections of rotating machinery in a Category 3 hazardous area.

2.9. Noise Design Data

[redacted] propose that the new exhaust system should have an 85dB(A) noise limit. This will be taken at an average at 1m from the new exhaust and 1.5m above grade.

Similarly, to [redacted] if this pre-FEED study progresses to a FEED study, [redacted] propose to carry out a noise assessment survey and reverse engineer the exhaust package to meet the noise level requirements. During FEED study stage, the acoustic attenuation of the catalyst unit should be determined, and National Grid will also have to confirm the required noise limit.

2.10. Load Conditions

For the basis of design, 8 process duty points have been considered. The values seen in Table 1, are the critical parameters needed to specify the catalyst unit. These values were provided by National Grid in response to TQ20602_008 and were used by the catalyst supplier to determine a suitable catalyst.

Table 1: Load Conditions of the 8 Process Duty Points

Inlet Exhaust Gas Conditions	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**	**Case 8**
Fuel Type:	Natural Gas							
Operating Hours / Year Base:	400	400	800	1000	200	100	50	50
Operating Hours / Year Mild Winter:	200	200	450	500	50	25	50	25
Operating Hours / Year Severe Winter:	450	400	200	150	50	25	200	25
Exhaust Mass Flow Rate (kg/s):	66.06	70.23	69.92	61.99	59.65	54.38	68.71	51.87
Gas Temp at Catalyst Face (C)	566.68	585.59	584.21	548.17	537.51	513.59	578.72	502.18
Inlet NOx, mg/m3	135.78	152.65	151.41	119.27	109.76	88.42	146.52	78.24
Inlet NOx, g/s	17.94	21.44	21.17	14.79	13.09	9.62	20.14	8.12
Inlet CO, mg/m3	135.60	50.10	56.36	219.22	267.40	375.55	81.14	427.10
Inlet CO, g/s	17.92	7.04	7.88	27.18	31.90	40.84	11.15	44.31
Outlet Emissions Requirements	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**	**Case 8**
Outlet NOx, mg/Nm3	35mg/Nm3 (annual average)	35mg/Nm3 (annual average)	35mg/Nm3 (annual average)	35mg/Nm3 (annual average)	35mg/Nm3 (annual average)	35mg/Nm3 (annual average)	35mg/Nm3 (annual average)	35mg/Nm3 (annual average)
Outlet CO, ppmvd @ 15 % O_2	100mg/Nm3 (annual average)	100mg/Nm3 (annual average)	100mg/Nm3 (annual average)	100mg/Nm3 (annual average)	100mg/Nm3 (annual average)	100mg/Nm3 (annual average)	100mg/Nm3 (annual average)	100mg/Nm3 (annual average)
Outlet NH_3 slip, mg/Nm3	3mg/Nm3 (daily & annual average)	3mg/Nm3 (daily & annual average)	3mg/Nm3 (daily & annual average)	3mg/Nm3 (daily & annual average)	3mg/Nm3 (daily & annual average)	3mg/Nm3 (daily & annual average)	3mg/Nm3 (daily & annual average)	3mg/Nm3 (daily & annual average)

3. Option 1 – Vertical Configuration - Equipment Description

[redacted] have chosen to cool the exhaust gases using air entrainment, this eliminates the need for a cooling fan and hence minimises the power requirements of the solution. The exhaust gases need to be cooled to 454^{o}C or below to prevent degradation of the catalyst bed as stated by the catalyst supplier.

A vertical exhaust system has been chosen as opposed to the horizontal exhaust system proposed by [redacted] have chosen a vertical exhaust system to reduce the required space and minimise the impacts on turbine removal or other site activities. This was also based on the response to TQ_20602_010 where it is stated that none of the sites under consideration are subject to specific height restrictions.

All sub-sections within Section 3, apart from Section 3.5, are [redacted] designs. Section 3.5 is derived from [redacted] catalyst supply partner.

3.1. Venturi Nozzle

The existing exhaust stack is to be removed and discarded in accordance with local disposal regulations.

The gas turbine outlet will interface with a new spool piece which guides the exhaust gases external to the enclosure and act as a venturi nozzle. The outer circumference of the venturi nozzle will act as the inner ring of the circular silencer that allows air to enter the plenum and be entrained into the exhaust gas flow. The ring will have perforate on the outer surface and filled with acoustic mineral wool behind a permeable glass cloth.

Fabricated from 10mm S355J2 carbon steel. Perforate to be 2mm carbon steel.

Surface treatment: Aluminium metal sprayed with high temperature sealer.

3.2. Plenum

The plenum will surround the venturi nozzle and annulus. The main purpose of the plenum is to provide environmental (wind and rain) protection to the venturi. The bottom section of the plenum will act as the outer ring of the circular silencer. The ring will have perforate on the inner surface and filled with acoustic mineral wool behind a permeable glass cloth.

Fabricated from 6mm S355J2 carbon steel. Perforate to be 2mm carbon steel.

Surface treatment: Aluminium metal sprayed with high temperature sealer.

3.3. Transition and Annulus

An annulus, part of the venturi section, will be situated at the bottom of the transition. The transition will be free floating at the bottom and interface with the 6.7 x 6.7m catalyst unit at the top. The annulus will be situated one times the diameter of the venturi nozzle above the venturi nozzle exit face. A circular hollow section band will be placed around the circumference of the annulus entry face to smooth entering air. Within the transitioning section, a pepper pot will be used to evenly mix and distribute the flow. Further CFD analysis of the pepper pot design is required to ensure an even and well distributed flow.

The transition will be internally lined with mineral wool insulation and stainless-steel cladding sheets.

Transition casing to be fabricated from 6mm S355J2 carbon steel. Stainless steel cladding sheets will be S/S 321, this has been chosen as it displays higher corrosion and work resistance between 400 - 800^{o}C.

Surface treatment: Carbon steel to be aluminium metal sprayed with high temperature sealer. Stainless steel to be left self-finish.

3.4. Support Steelwork

The steelwork will be used to support the entire exhaust stack and accompanying access platform. Support interfaces to be defined during detailed design.

Fabricated from S275J2 or S355J2 carbon steel dependant on section sizes. J2 required for the minimum ambient conditions experienced on site (-20^{o}C).

Surface finish: Hot dipped galvanised.

3.5. Catalyst Unit

3.5.1. Flow Distribution Grid

A further flow distribution grid may be placed in the catalyst unit if an even and distributed flow is not completely achieved by the pepper pot. The flow distribution grid is not included in the catalyst unit quote.

3.5.2. Vertical Catalyst Section

This section houses the multi-pollutant catalyst. It will have a cross section of 6.7m x 6.7m to minimise the back pressure on the gas turbine and will be 4m high.

Fabricated from stainless steel, grade and finish to be confirmed during detailed design.

3.5.3. Catalyst

The catalyst will be a multi-pollutant catalyst. This enables the reduction of NOx and CO emission using only one catalyst bed. Each catalyst module will be 3.25 x 1.65 x 0.89 m (W x L x D, Depth in flow direction) in size. There will be a total of 8 catalyst modules, arranged in a 2 x 4 grid, in the catalyst bed.

3.5.4. Catalyst Test Coupons

Test coupons, similarly, to the [redacted] report, are used to monitor and assess catalyst degradation. The test coupons can be removed and sent away for testing. Spare coupons are provided for this testing period.

3.5.5. Ammonia Vaporisation Skid

The ammonia vaporiser, injection fans and related ammonia injection equipment are mounted on the ammonia vaporisation skid.

Fabricated from S275J2 or S355J2 carbon steel dependant on section sizes and hot dipped galvanised.

3.5.6. Ammonia Vaporiser

The ammonia vaporiser turns the 24.5% aqueous ammonia into vapor. This is done using compressed air and turbine exhaust gases. There is only one ammonia vaporiser per catalyst unit. The temperature of the ammonia is initially raised by an immersion heater. The dilution chamber, where the air is mixed with the ammonia, will be made from SA-36.

3.5.7. Blowers

Two 100% duty blowers will be used to blow the vaporised ammonia into the ammonia injection manifold. Each blower will have filter silencers on their inlets to reduce aperture noise.

Equipment also includes:

- Manual butterfly valve (one per blower)
- Manual check valve (one per blower)

3.5.8. Ammonia Injection Grid and Manifold

The ammonia injection manifold distributes the vaporised ammonia to each section of the ammonia injection grid

The ammonia injection grid sits directly in the exhaust gas flow. It introduces the vaporised ammonia across the entire catalyst cross section via a series of spray bars. Each spray bar has a manual throttling valve so that the amount of ammonia introduced can be optimised.

Fabricated from stainless steel and will be self-finish.

Equipment also includes:

- Expansion joints in the main header
- Pressure gauge near manifold inlet
- Orifice plate at each spray bar branch
- Throttling valve at each branch
- Differential pressure gauge at each branch

3.6. Catalyst Unit Outlet Transition

The Catalyst Unit Outlet Transition will reduce the cross-sectional area from 6.7m x 6.7m to that of the Exhaust Silencer.

Transition casing to be fabricated from 6mm S355J2 carbon steel. Stainless steel cladding sheets will be S/S 321, this has been chosen as it displays higher corrosion and work resistance between 400 - 800^{o}C.

Surface treatment: Carbon steel to be aluminium metal sprayed with high temperature sealer. Stainless steel to be left self-finish.

3.7. Exhaust Silencer

A rectangular exhaust silencer will be located downstream of the outlet transition to provide acoustic attenuation to the exhaust gas flow before exiting the exhaust. The silencer will contain rectangular splitters which provide the acoustic attenuation.

Silencer casing to be fabricated from 6mm S355J2 carbon steel. Splitters to be made from stainless steel 321 with acoustic infill behind a permeable glass cloth.

Surface treatment: Carbon steel to be aluminium metal sprayed with high temperature sealer. Stainless steel to be left self-finish.

3.8. Weather Cowl

A weather cowl has been positioned at the top of the exhaust stack. It prevents water from entering further down the stack while the unit is not in operation.

As the weather cowl will be subjected to hot exhaust gases and moisture from rain, it will be fabricated from S/S 321 as it provides a high level of corrosion protection at elevated temperatures.

Surface treatment: Weather cowl is to be left self-finish.

3.9. Stair Access

Stair access will be provided to allow operators to reach the access platform. The stairs will comply with BS EN ISO 14122.

Fabricated from S275J2 or S355J2 carbon steel dependant on section sizes and hot dipped galvanised.

3.10. Access Platform

The access platform will be used by the operators during the changing of catalyst unit cassettes, maintenance activities and to access the CEMS.

Fabricated from S275J2 or S355J2 carbon steel dependant on section sizes and hot dipped galvanised.

3.11. Lifting Equipment

Details of lifting equipment to be determined during FEED study as layout details of the catalyst unit are not determined at pre-FEED stage

3.12. Control Panel

The control panel will be in the main onsite control room.

3.13. Ancillary Equipment

3.13.1. Ammonia Storage Tank

One ammonia storage tank is to be provided for the turbine unit at Kings Lynn. The tank is to be located between Cab B and the redundant plant area; this area was recommended as a potential storage area by national grid in TQ_20602_011. Placing the storage tank here would prevent the tank interfering with any other site activities such as turbine removal from Cab B. Furthermore, Ammonia tankers are only able to offload to the left, this makes the identified location ideal as it allows for ammonia tankers approaching from the access road to offload the ammonia to left without the need for turning on site as they can simply follow the road round.

This location should also be outside of the UKEX zones provided in TQ_20602_002 as shown in Figure 2. The advantage of using non-UKEX zones for storage is that atmospheric tanks can be used, these tanks are less expensive and simpler in design than pressurised tanks and additionally will require less frequent inspection. The tanks may be constructed from using carbon steel to further reduce costs; however, the outer surface will have to be painted to provide corrosion protection.

If it is found upon further investigation that under the new configuration the tank would be in any UKEX zones, nitrogen blanketing may be suitable for reducing the explosion risk, though this would require further inspection and confirmation during detailed design.

A horizontal tank was considered to reduce the foundation loads and improve access to it, however due to the length of the tank it would hinder access to the catalyst unit and hence a vertical tank has been selected.

Figure 2 - Ammonia Storage Tank Location

[redacted]

Ammonia will have to be piped from storage tank to the catalyst unit and hence a further site survey would be required to determine the exact path of the ammonia pipes and any pipe bridges required, however due to the proximity to the unit, the pipework required should be minimal.

The storage tank has a specified capacity of 38m3. This value is derived from advice from [redacted]: A nominal delivery of 28 tonnes, plus three times daily use (to allow for a 48-hour lead time), plus the minimum amount of ammonia to maintain the integrity of the equipment. A maximum design flow rate of 60kg/hr was given by the catalyst supplier, taking a worst-case scenario of running 24 hours per day, three times daily use is 4.32 tonnes. This along with a heel of 1.44 tonnes and the nominal delivery of 28 tonnes gives a storage capacity of 38m3.

Using the average top up frequency of 2.6 years, the tank will contain enough ammonia for approximately 949 days of operation.

The storage tank is to be situated in a concrete bunded area that will act as containment in the case of tank leakage/failure. The volume of the bunded area is to be the tank capacity plus 10% giving a value of 42m3. The concrete bund will also be fitted with a pump to remove any water that may collect inside it.

3.13.2. Packing

Packing is to be in accordance with [redacted] Standard Spec 22.

4. Process Flow Diagram

Table 2 shows the expected values at each of the locations represented in the process flow diagram. See Dwg. 600-010342 in the appendix.

Table 2: Process Flow Values

Location	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Description	Inlet	Waste Heat	Ammonia Injection Air	Catalyst Inlet	Stack Outlet	Ammonia	Compressed Air
Temperature (^{o}C)	502.18– 585.59	502.18 – 585.59	-	454.44	TBC	Ambient	Ambient
Flow (Nm3/hr)	149998 – 266711	768 (Average)	993 (Average)	149998 – 266711	149998 – 266711	-	225
NOx (mg/m3) *@ 15%O2*	78.24 – 152.65	-	-	78.24 – 152.65	35.0	-	-
NH3 (mg/m3) *@ 15%O2*	-	-	-	-	3.0	-	-
NH3 (kg/hr)	-	-	-	-	-	36	-

5. SCR Outline Mass and Energy Balance

Table 3: Mass and Energy Balance for the 8 Process Duty Points

Case		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Average**
Cooling Air	Kg/s	17.7	22	21.7	13.8	11.8	7.6	20.4	5.8	15.1
Exh. Temp ***(After adding cooling air)***	^oC	454.44	454.44	454.44	454.44	454.44	454.44	454.44	454.44	454.44
Exh. Mass Flow	kg/s	66.06	70.23	69.92	61.99	59.65	54.38	68.71	51.87	62.85
Exh. Vol. Flow	Nm3/hr	191032	203091	202195	179263	172496	157256	198695	149998	181753
NOx at GT	mg/m3 **@ 15%O2**	135.78	152.65	151.41	119.27	109.76	88.42	146.52	78.24	122.76
SCR Cooling Temp	^oC	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4
SCR Cooling Air	Nm3/hr	51185	63620	62752	39907	34123	21978	58993	16772	43666
Exh. Stack Total Flow	Nm3/hr	242217	266711	264947	219169	206619	157256	198695	149998	213201
Exh. Stack Temp	^oC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC
NOx at Stack (design)	mg/m3 **@ 15%O2**	35	35	35	35	35	35	35	35	35
NOx Removal	%	74.22	77.07	76.88	70.65	68.11	60.42	76.11	55.27	69.84
NH3 Concentration	%	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5
NH3 Flow	kg/h	36	36	36	36	36	36	36	36	36
Inlet CO	mg/m3	135.6	50.1	56.36	219.22	267.4	375.55	81.14	427.1	201.56
CO at Stack (design)	mg/m3 ***@ 15%O2***	100	100	100	100	100	100	100	100	100
CO Removal	%	26.25	0.00	0.00	54.38	62.60	73.37	0.00	76.59	36.65

6. Equipment General Arrangement, Plan & Process Drawings

General Arrangement: 600-010259

Process Drawing: 600-010342

7. Outline Process Description

The exhaust gases exit a venturi nozzle which entrains ambient air from the plenum. The air enters the plenum via an aperture at the bottom, this inlet has two rings of silencing elements to reduce the aperture noise. The ambient air is required to cool the exhaust temperature down from a maximum of 585.59^{o}C to 454^{o}C.

The exhaust gases and ambient air mix then enters an annulus. A pepper pot mixes and conditions the exhaust gas mixture, but further CFD will be required to optimise the pepper pot design.

The duct then transitions to a 6.7 x 6.7m square, this is the cross-sectional area of the catalyst unit.

If the flow is not suitably conditioned, a further conditioning grid can be installed at the inlet face of the catalyst. The vaporised ammonia is injected into the flow via an ammonia injection grid which comprises of multiple spray bars, the amount of ammonia injected by each bar can be adjusted to optimise efficiency.

The mixture is then passed through a multipollutant catalyst bed, this reduces the amount of NOx and CO in the exhaust mixture.

The ducting then transitions down to a silencer that reduces aperture noise emitted from the top of the stack.

Another transition is required to connect the silencer to the weather cowl. This transition will contain the probes required for the Continuous Emissions Monitoring System (CEMS). The CEMS samples are taken back to the operations room via heated and ATEX zone II rated lines. The samples are then analysed, and results provided by the Data Acquisition and Handling System (DAHS).

The exhaust gases then leave the stack via the weather cowl, the cowl prevents water entering the stack.

8. Justification for Selection of Catalyst

The catalyst is to be a multi-pollutant catalyst. This means only one catalyst section is needed to both reduce NOx and CO emission, allowing the catalyst unit to be shorter in height and require less material for construction.

Below show the compounds before and after the multi-pollutant catalyst:

$$4NO + 4NH_3 + 0_2 \rightarrow 4N_2 + 6H_2O$$

$$2NO + 2NO_2 + 4NH_3 \rightarrow 4N_2 + 6H_2O$$

$$6NO_2 + 8NH_3 \rightarrow 7N_2 + 12H_2O$$

CO oxidation to CO_2

VOC oxidation to CO_2 and H_20

9. Justification for Selection of Reducing Agent

Several reductants are currently used in SCR applications including anhydrous ammonia, aqueous ammonia, or urea.

24.5% aqueous ammonia was chosen as its concentration is below the 25% threshold which requires more stringent storage regulations. Aqueous ammonia is safer to store and transport than anhydrous ammonia but must be vaporised to be used with an SCR system. Aqueous ammonia is available in two variants, normal water based, or distilled water based. It is essential for the longevity of the SCR system that distilled water is always used.

Pure anhydrous ammonia is extremely toxic and difficult to safely store under pressure but does not need further conversion to work with an SCR system. Specialist input would be required for the storage tank and transfer/control the product. It would also fall under more stringent site regulations, and hence storage and monitoring would be greater burden for the site operations team.

Urea is the safest reductants to store. However, it requires thermal decomposition to be converted to an effective reductant. Therefore, it requires a higher volume and increased power to create the ammonia level required. It is also more expensive than the alternatives.

10. Projected Electrical Loads

Table 4: Projected Electrical Loads per Unit

Device	Voltage	kW Consumption
Immersion Heater	400V	180kW
Injection Fan (x2)	400V	15kW
NH3 Pump (x2)	400V	<10kW (rated)
Total		230kW

11. Projected Service Requirements

[redacted] cannot provide a recommended parts list as the Catalyst Design is not in detailed design phase. Therefore, components are not defined.

12. Outline Civil & Structural Design or Requirements

As this is a pre-FEED study, [redacted] will not produce a foundation load drawing, as per TQ20602_020, because loads are likely to change during detailed design. [redacted] have indicated position where the steelwork columns could land and still provide access to the enclosures.

13. Outline Interface/Tie-in Requirements

Table 5: Interface and Tie-In Requirements

Item	Service Required	Service Conditions	Location
Ammonia Supply	24.50% Aqueous Ammonia	60 kg/hr Max.	Skid Battery Limit
Compressed Air Supply	Instrument Air	80 – 125 PSIG	Skid Battery Limit
Electrical Power	400V, 50 Hz, 3 Phase	205kW	Skid Battery Limit

14. Major Maintenance Requirements

Maintenance is required to ensure optimal efficiency of the catalyst unit and to achieve the emissions targets. [redacted] agree with the recommendation in the [redacted] Report.

14.1. Daily Maintenance

- Visually inspect overall system. Look at exterior surfaces, noting any colour changes, leaks, etc. which might require attention.
- Inspect fans. Listen for excessive noise, vibration, or other symptoms of developing problems.
- Review controls. Note any changes in operating temperatures or pressure drops which might provide an indication of developing problems. Log pressure and temperature readings.

14.2. Monthly Maintenance

- Visually inspect fan belts for signs of wear, looseness, fraying, etc.
- Check fan bearings by feeling for excessive heat and/or vibration.
- Inspect all electrical switches and contacts; clean if necessary.
- Inspect all piping, valves, and ductwork for leaks, deterioration, or damage.

14.3. Quarterly Maintenance

- Grease fan bearings. Use grease recommended in fan manual.
- Open fan access door(s) and inspect fan wheel for signs of build-up and wear.

14.4. Semi-Annual Maintenance

- Inspect atomising nozzle orifice for plugging.
- Inspect catalyst for signs of plugging or damage.
- Inspect static mixer and silencer (if required) for signs of plugging or damage.

14.5. Annual Maintenance

- Inspect lining. Pack small pieces of blanket material into cracks or gaps which may have opened in linings.

14.6. Refractory Maintenance

The use of refractory is yet to be determined as part of the design; therefore no guidance can be provided.

15. How Weather and Environmental Conditions May Impact the Catalyst Unit Performance

Weather and environmental conditions are not expected to have any impact on the performance of the catalyst unit. The suggested design uses the plenum as entrainment protection while still allowing for airflow with air intake on its bottom face. In wet conditions, this will minimise the amount of water being drawn into the exhaust system whilst also providing wind protection to the venture nozzle. AT 24.5%, Aqueous Ammonia doesn't freeze above -56^{o}C and hence there should be no issues with the suggested reagent.

The maintenance instructions above should be carried out to monitor and mitigate any weathering of the exhaust and catalyst unit, this was recommended by [redacted] also.

16. How the Performance of the Catalyst will be Monitored to Determine the Rate of Degradation

When first commissioned, the catalyst unit will function at its highest capacity with efficiency dropping over time and use. This degradation may be accelerated if the exhaust gases passing through the catalyst bed are not cooled sufficiently and exceed 454^{o}C.

To monitor the efficiency of the catalyst over its design life, removable test modules will be periodically tested. These can then be tested by the original equipment manufacturer or a testing laboratory. Replacement modules can be provided to fill in the missing test modules.

17. Emissions Monitoring Provisions, Including Outline Scope of Continuous Emissions Monitoring and Data Acquisition & Handling System

17.1. CEMS

A Continuous Emission Monitoring System (CEMS) will be implemented for data acquisition and monitoring. The samples will be collected using a sample probe made from stainless steel 316 and will be mounted to the exhaust system using a DN65 PN6 flange.

Heated sample lines are used to transfer the sample between the probe and analyser. The heated sample lines are maintained at 180^{o}C to prevent condensation forming, condensations could have an impact on the results. An ATEX Zone II rated heater line controller unit is required to regulate and limit the temperature of the sampling lines.

An analyser panel is required to compute the sample results. The panel is IP54 rated and air-conditioned. The air-conditioning is required so that the sampling analysers work at ambient temperature, so there is no influence due to a change in the sample pressure. The analyser can measure CO, NOx, H_2O and NH_3 levels. The analyser panel may be placed in the field to minimise the extent of heated sample lines required, interface signals would then require cabling back to the SCR control panel with the CEMS workstation being located in the main control room, as stated in the [redacted] SCR Innovation FEED Study.

17.2. Integrated PLC Control

Similarly, with the [redacted] report, the CEMS controls are integrated with the catalyst unit controls for seamless operation.

17.3. DAHS

A Data Handling and Acquisition System can be provided by the CEMS supplier. The DAHS continually acquire data from the CEM panel and generates the necessary reports. A PC can be provided with the complete data acquisition and reporting software. This can be located anywhere on site, but it is advised to be located within the control room.

18. CFD Modelling of Exhaust Gas Flow Through SCR

Not required as per *"SCR_review_scopev5(16.11.21)"*

19. Air Dispersion Emissions Modelling Inputs

Not required as per *"SCR_review_scopev5(16.11.21)"*

20. Actual and Typical Guaranteed Levels for Pollutant Abatement

The maximum guaranteed level for NOx abatement for this application is 77.07%. The actual NOx reduction efficiency is 55.27 – 77.07 %. The [redacted] report states a NOx reduction range of 84.09 – 90.73%. Though the abatement specified in this report is lower, it is worth noting that the catalyst specified by [redacted] unnecessarily reduces the NOx emissions beyond the allowable 35mg/m3 stated in the IED.

The maximum guaranteed level for CO abatement for this application is 76.59%. The actual CO reduction efficiency is 0.00 – 76.59%. The reason in some cases the CO reduction is 0, is because the CO emissions at these duty points is already below the required 100mg/m3 and hence requires no further reduction. No CO reduction was given in the [redacted] report.

The catalyst specified satisfies both NOx and CO emissions as per the IED regulations.

21. Ammonia Slip Typical Levels Over Operating Life and Management Controls

Ammonia slip levels will remain consistent over the life of the catalyst, the catalyst is designed to ensure that the ammonia slip levels do not exceed 3 mg/m^3 (Annual average). The catalyst has an operating life of 26280 hours. If the turbines at Kings Lynn run at the base hours of 3000 hours per year, the ammonia slip levels will stay consistent for 8.76 years.

The ammonia slip levels can be monitored by the CEMS.

22. Safety and Environmental Hazards Identification Summary

22.1. Electrical

The electrical components will be specified to meet the ATEX area classification.

22.2. Ammonia

All equipment will be suitable selected for use with ammonia in it aqueous or vaporised forms. Similarly, to the [redacted] report, exposure to ammonia in either liquid form or vapours will be limited and controlled.

22.3. Rotating Machinery

All rotating machinery will provide adequate personnel protection to rotating parts. This will be mainly concerning the ammonia pumps and injection blowers.

22.4. Pressure

The only high-pressure parts of the system are the compressed air and ammonia piping. The pipe will be sized for the pressure experienced in these systems.

The catalyst unit operates under a low positive pressure.

22.5. High Temperature

Any hot surface of the catalyst system that could be touched by site operators will be thermally insulated so that the maximum surface of 60^{o}C. Any surface unable to be thermally insulated will be cordoned off so that operators cannot touch it and have suitable warning signs attached.

22.6. EMF

All panels to be tested for compliance with adequate shielding to comply with standards for radiation.

22.7. Confined Space

The catalyst unit and the ammonia storage tanks are the only confined spaces of this system. The doors will carry signs indication that they are confined spaces and National Grid personnel must have adequate training to access these confined spaces.

23. General Hazardous Areas Compliance Statement

Equipment shall comply with the UKEX Zone they are situated within. The UKEX Zones used for this report were from National Grid drawing 72100803000004.dg, provided in TQ_20602_024

24. CE Marking Compliance Statement

[redacted] can provide a Declaration of Incorporation and UKCA and UKEX certificates where possible.

25. Ex-works Cost Estimates

Equipment prices delivered ex-works [redacted] domestic packed to [redacted] standards are detailed below. Prices are prudent budgetary costs and do not constitute a formal proposal or quotation.

Table 6: Ex-works Cost Estimates

Item	Description	Price (£)
1	Catalyst Unit	[redacted]
2	Exhaust Stack	
3	Ammonia Tank	
4	Steelwork and Access Platform	
5	Bund Pump	
6	CEMS	
7	DAHS	
	Total	

26. Delivery Cost Estimate

As some of the new exhaust equipment exceeds standard load sizes. During the future FEED study stage, splitting equipment should be explored so that the sizes conform to standard UK lorry load dimensions, therefore [redacted] cannot provide all delivery costs at time of writing.

The delivery cost of the catalyst unit is not available as the location of manufacture has not been determined.

27. Installation & Training Cost Estimate

Installations and training prices based upon current day labour rates are detailed below. Prices are prudent budgetary costs and do not constitute a formal proposal or quotation.

Table 7: Installation and Training Costs

Item	Description	Price (£)
1	Installation Supervision	[redacted]
2	Installation Labour	
3	Craneage	
4	Access Equipment	
5	Site Establishment	
6	Lifting Equipment	
7	Power & Welding	
8	General Tools	
9	Plant Hire & Equipment	
10	Misc Materials	
	Total	

28. Operating Cost Estimate

Operating costs are based upon the 8 duty points provided. Only reagent, energy and catalyst replacement costs will be provided.

28.1. Reagent Usage Cost

The reagent costs are based on the average top up frequency.

Table 8: Reagent Usage

Case		1	2	3	4	5	6	7	8	Average
Aq. Ammonia Concentration	%	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5
Aq. Ammonia Flow	kg/hr	36	36	36	36	36	36	36	36	36
Operating Hours per Year (Base)	hr/yr	400	400	800	1000	200	100	50	50	375
Aq. Ammonia Consumption	kg/yr	14400	14400	28800	36000	7200	3600	1800	1800	13500
Ammonia Tank Storage Volume	m^3	38	38	38	38	38	38	38	38	38
Ammonia Tank Storage Capacity	kg	34656	34656	34656	34656	34656	34656	34656	34656	34656
Top Up Frequency	yrs	2.4	2.4	1.2	1.0	4.8	9.6	19.3	19.3	2.6

Over a 5-year period, the tank will have to be filled up 1.92 times. This works out to be approximately 73m3 of ammonia over 5 years (1.92 x storage capacity of 38m3). 24.5% Aqueous Ammonia costs [redacted] per tonne, this equates to a cost of [redacted] over a year period. This can be averaged to a cost of [redacted] per year.

28.2. Yearly Energy Costs

To determine the yearly energy costs, the price of electricity (p/kWh) is multiplied by the equipment power rating (kW) and total operating hours per year (3000 hours).

Price of electricity has been provided by National Grid via TQ20602_016.

Table 9: Energy Costs for 5 Year Period

Year	2022	2023	2024	2025	2026
kWh	690000	690000	690000	690000	690000
Projected cost per kWh (p/kWh)	5.846983	5.636029	5.777145	5.715619	5.605205
Cost per Year (£)	[redacted]				

28.3. Catalyst Replacement Costs

1m^3 of catalyst bed costs [redacted]. There is approximately 15 m^3 of catalyst bed, meaning the total replacement cost will be [redacted]. Replacement period should be based on 26280 operational hours.

28.4. 5 Year Total Projected Operating Costs

Table 10: Yearly costs

Year	2022	2023	2024	2025	2026	Total
Reagent (£)	[redacted]					
Energy (£)						
Total (£)						

29. Typical Delivery Lead-Time from Placement of Order

At time of writing, [redacted] believe the lead time will be driven by the catalyst unit. We have been advised that the lead time will be 1 year. The delivery of the other exhaust equipment and steelwork will depend on [redacted] engineering and production capacity at time of contract agreement. Time estimates have been provided in Section 30.

30. Outline Programme from Placement of Order to Turnover the Client

The following timescales have been based on the time taken to design, progress through the G35, procure and manufacture sections of the exhausts for the National Grid Aylesbury site. Though Peterborough includes only one unit as opposed to the two at Aylesbury, some of the timeframes are very similar due to the time taken to design and progress through the G35.

Table 11: Exhaust Section Timescales

Section	Days
Exhaust	112
Vent Pipework and Sample Points	114
Steelwork	116
Civils	68
Stairs and Platform	60
Lighting	55
Lightning Protection	56
CEMS	185

The following table details timescales for other activities.

Table 12: Activity Timescales

Activity	Days
Hazard Studies	35
Site Setup and Decommissioning	30
Installation (per Unit)	106
Commissioning (per Unit)	11

All timings are subject to change.

31. Detail Typical Equipment Guarantees

31.1. Catalyst Unit Performance

Performance of the catalyst unit is based on the 8 process duty points. If the conditions vary significantly from the points provided, the catalyst unit performance will be different and thus this guarantee is null and void.

[redacted] guarantees that the catalyst unit provided will provide the required NOx and CO abatement required to satisfy IED regulations, providing that the system is installed and operated under the guidelines of the Installation and Operating Manuals, which includes but is not limited to:

- Operation under specified temperature ranges and maintaining high temperature excursions und the time periods specified.
- Use of reagent grade aqueous ammonia as per the specifications
- [redacted] will not be responsible for operating non-conformance resulting from the introduction of materials not identified by the purchaser into the equipment covered by this warranty.

31.2. Differential Pressure

[redacted] are not able to provide the pressure drops for the stack silencer and weather cowl at this stage as the designs are likely to changes during FEED study stage once an acoustic survey has been performed and a final acoustic limit provided.

The change in pressure across the catalyst was provided by the catalyst supplier. The other changes in pressure were calculated at the 'worst case scenario', this was defined as the duty point with the highest flow rate (case 2). As stated above, pressure drops for the vertical silencer and weather cowl were not calculated at this stage and hence the figures below don't represent to the total system pressure loss.

Table 13: Differential Pressure of Equipment

Description	ΔP Calculated (Pa)
Transition (Pre- Catalyst unit)	564.41
Catalyst	690
Transition (Post Catalyst to Silencer)	1.88
Transition (Silencer to Weather Cowl)	8.38

32. Option 2 – Horizontal Solution - Equipment Description

[redacted] have chosen to cool the exhaust gases using air entrainment, this eliminates the need for a cooling fan and hence minimises the power requirements of the solution. The exhaust gases need to be cooled to 454^{o}C or below to prevent degradation of the catalyst bed as stated by the catalyst supplier.

A horizontal exhaust system has now been proposed to reduce the stack height. The horizontal system will make use of the redundant area available for redevelopment identified by national grid in TQ_011 and hence will not have any impact on turbine removal.

All sub-sections within Section 32, apart from Section 32.7, are [redacted] designs. Section 32.7 is derived from [redacted] catalyst supply partner.

32.1. Venturi Nozzle

The existing exhaust stack is to be removed and discarded in accordance with local disposal regulations.

The gas turbine outlet will interface with a new spool piece which guides the exhaust gases external to the enclosure and act as a venturi nozzle. The outer circumference of the venturi nozzle will act as the inner ring of the circular silencer that allows air to enter the plenum and be entrained into the exhaust gas flow. The ring will have perforate on the outer surface and filled with acoustic mineral wool behind a permeable glass cloth.

Fabricated from 10mm S355J2 carbon steel. Perforate to be 2mm carbon steel.

Surface treatment: Aluminium metal sprayed with high temperature sealer.

32.2. Plenum

The plenum will surround the venturi nozzle and annulus. The main purpose of the plenum is to provide environmental (wind and rain) protection to the venturi. The bottom section of the plenum will act as the outer ring of the circular silencer. The ring will have perforate on the inner surface and filled with acoustic mineral wool behind a permeable glass cloth.

Fabricated from 6mm S355J2 carbon steel. Perforate to be 2mm carbon steel.

Surface treatment: Aluminium metal sprayed with high temperature sealer.

32.3. Ducting and Lobster Back Bends

The ducting and bends will have an internal diameter of 1980mm and a thickness of 10mm. The ducting will be cladded with 200mm basalt lining to act as thermal insulation.

32.4. Flexible Joints

Four flexible joints will be used along the length of the exhaust: one between venturi nozzle and plenum and the first lobster back bend, the next between the horizontal silencer and the second lobster back bend, the third between bend three and the expansion/round to square transition and the final one being between square to round transition and the fourth lobster back bend. These joints are intended to reduce the stresses caused by thermal expansion during operation.

32.5. Expansion Transition

An expansion transition will be situated between the ducting from the enclosure and the catalyst unit in order to increase the cross-sectional area from that of the ducting and lobster back bends to the 6.7m x 6.7m required for the catalyst unit. This transition also works to convert the round ducting to square to match that of the catalyst unit.

Within the transitioning section, a pepper pot will be used to evenly mix and distribute the flow. Further CFD analysis of the pepper pot design is required to ensure an even and well distributed flow.

The transition will be internally lined with mineral wool insulation and stainless-steel cladding sheets.

Transition casing to be fabricated from 6mm S355J2 carbon steel. Stainless steel cladding sheets will be S/S 321, this has been chosen as it displays higher corrosion and work resistance between 400 - 800^{o}C.

Surface treatment: Carbon steel to be aluminium metal sprayed with high temperature sealer. Stainless steel to be left self-finish.

32.6. Support Steelwork

The steelwork will be used to support the entire exhaust stack. This includes the vertical part of the stack and access platform, as well as supporting steel work on the horizontal ducting and silencer. Support interfaces to be defined during detailed design.

Fabricated from S275J2 or S355J2 carbon steel dependant on section sizes. J2 required for the minimum ambient conditions experienced on site (-20^{o}C).

Surface finish: Hot dipped galvanised.

32.7. Catalyst Unit

32.7.1. Flow Distribution Grid

A further flow distribution grid may be placed in the catalyst unit if an even and distributed flow is not completely achieved by the pepper pot. The flow distribution grid is not included in the catalyst unit quote.

32.7.2. Vertical Catalyst Section

This section houses the multi-pollutant catalyst. It will have a cross section of 6.7m x 6.7m to minimise the back pressure on the gas turbine and will be 4m in length.

Fabricated from stainless steel, grade and finish to be confirmed during detailed design.

32.7.3. Catalyst

The catalyst will be a multi-pollutant catalyst. This enables the reduction of NOx and CO emission using only one catalyst bed. Each catalyst module will be 3.25 x 1.65 x 0.89 m (W x L x D, Depth in flow direction) in size. There will be a total of 8 catalyst modules, arranged in a 2 x 4 grid, in the catalyst bed.

32.7.4. Catalyst Test Coupons

Test coupons, similarly, to the [redacted] report, are used to monitor and assess catalyst degradation. The test coupons can be removed and sent away for testing. Spare coupons are provided for this testing period.

32.7.5. Ammonia Vaporisation Skid

The ammonia vaporiser, injection fans and related ammonia injection equipment are mounted on the ammonia vaporisation skid.

Fabricated from S275J2 or S355J2 carbon steel dependant on section sizes and hot dipped galvanised.

32.7.6. Ammonia Vaporiser

The ammonia vaporiser turns the 24.5% aqueous ammonia into vapor. This is done using compressed air and turbine exhaust gases. There is only one ammonia vaporiser per catalyst unit. The temperature of the ammonia is initially raised by an immersion heater. The dilution chamber, where the air is mixed with the ammonia, will be made from SA-36.

32.7.7. Blowers

Two 100% duty blowers will be used to blow the vaporised ammonia into the ammonia injection manifold. Each blower will have filter silencers on their inlets to reduce aperture noise.

Equipment also includes:

- Manual butterfly valve (one per blower)
- Manual check valve (one per blower)

32.7.8. Ammonia Injection Grid and Manifold

The ammonia injection manifold distributes the vaporised ammonia to each section of the ammonia injection grid

The ammonia injection grid sits directly in the exhaust gas flow. It introduces the vaporised ammonia across the entire catalyst cross section via a series of spray bars. Each spray bar has a manual throttling valve so that the amount of ammonia introduced can be optimised.

Fabricated from stainless steel and will be self-finish.

Equipment also includes:

- Expansion joints in the main header
- Pressure gauge near manifold inlet
- Orifice plate at each spray bar branch
- Throttling valve at each branch
- Differential pressure gauge at each branch

32.8. Catalyst Unit Outlet Contraction Transition

The Catalyst Unit Outlet Transition will reduce the cross-sectional area from 6.7m x 6.7m to that of the square to round transition.

Transition casing to be fabricated from 6mm S355J2 carbon steel. Stainless steel cladding sheets will be S/S 321, this has been chosen as it displays higher corrosion and work resistance between 400 - 800^{o}C.

Surface treatment: Carbon steel to be aluminium metal sprayed with high temperature sealer. Stainless steel to be left self-finish.

32.9. Square to Round Transition

The square to round transition will convert the square section of the contraction transition to a round cross section to match that of the lobster back bends and ducting of the stack.

Transition casing to be fabricated from 6mm S355J2 carbon steel. Stainless steel cladding sheets will be S/S 321, this has been chosen as it displays higher corrosion and work resistance between 400 - 800^{o}C.

Surface treatment: Carbon steel to be aluminium metal sprayed with high temperature sealer. Stainless steel to be left self-finish.

32.10. Exhaust Silencers

Two silencers will be located along the exhaust; one as the flow leaves the first bend downstream from the venturi nozzle and plenum and one in the vertical section of the exhaust stack downstream of the catalyst unit outlet transition. These will provide acoustic attenuation to the exhaust gas flow before exiting the exhaust. The silencer will contain splitters which provide the acoustic attenuation.

Silencer casing to be fabricated from 6mm S355J2 carbon steel. Splitters to be made from stainless steel 321 with acoustic infill behind a permeable glass cloth.

Surface treatment: Carbon steel to be aluminium metal sprayed with high temperature sealer. Stainless steel to be left self-finish.

32.11. Weather Cowl

A weather cowl has been positioned at the top of the exhaust stack. It prevents water from entering further down the stack while the unit is not in operation.

As the weather cowl will be subjected to hot exhaust gases and moisture from rain, it will be fabricated from S/S 321 as it provides a high level of corrosion protection at elevated temperatures.

Surface treatment: Weather cowl is to be left self-finish.

32.12. Stair Access

Stair access will be provided to allow operators to reach the access platform. The stairs will comply with BS EN ISO 14122.

Fabricated from S275J2 or S355J2 carbon steel dependant on section sizes and hot dipped galvanised.

32.13. Access Platform

The access platform will be used by the operators during the changing of catalyst unit cassettes, maintenance activities and to access the CEMS.

Fabricated from S275J2 or S355J2 carbon steel dependant on section sizes and hot dipped galvanised.

32.14. Lifting Equipment

Details of lifting equipment to be determined during FEED study as layout details of the catalyst unit are not determined at pre-FEED stage

32.15. Control Panel

The control panel will be in the main onsite control room.

32.16. Ancillary Equipment

32.16.1. Ammonia Storage Tank

One ammonia storage tank is to be provided for the turbine unit at Kings Lynn. The tank is to be located between Cab B and the redundant plant area; this area was recommended as a potential storage area by national grid in TQ_20602_011. Placing the storage tank here would prevent the tank interfering with any other site activities such as turbine removal from Cab B. Furthermore, Ammonia tankers are only able to offload to the left, this makes the identified location ideal as it allows for ammonia tankers approaching from the access road to offload the ammonia to left without the need for turning on site as they can simply follow the road round.

This location should also be outside of the UKEX zones provided in TQ_20602_002 as shown in Figure 2. The advantage of using non-UKEX zones for storage is that atmospheric tanks can be used, these tanks are less expensive and simpler in design than pressurised tanks and additionally will require less frequent inspection. The tanks may be constructed from using carbon steel to further reduce costs; however the outer surface will have to be painted to provide corrosion protection.

If it is found upon further investigation that under the new configuration the tank would be in any UKEX zones, nitrogen blanketing may be suitable for reducing the explosion risk by reducing the amount of air present, though this would require further inspection and confirmation.

A horizontal tank was considered to reduce the foundation loads and improve access to it, however due to the length of the tank it would hinder access to the catalyst unit and hence a vertical tank has been selected.

Figure 3 - Ammonia Storage Tank Location

[redacted]

Ammonia will have to be piped from storage tank to the catalyst unit and hence a further site survey would be required to determine the exact path of the ammonia pipes and any pipe bridges required, however due to the proximity to the unit, the pipework required should be minimal.

The storage tank has a specified capacity of 38m3. This value is derived from advice from [redacted]: A nominal delivery of 28 tonnes, plus three times daily use (to allow for a 48-hour lead time), plus the minimum amount of ammonia to maintain the integrity of the equipment. A maximum design flow rate of 60kg/hr was given by the catalyst supplier, taking a worst-case scenario of running 24 hours per day, three times daily use is 4.32 tonnes. This along with a heel of 1.44 tonnes and the nominal delivery of 28 tonnes gives a storage capacity of 38m3.

Using the average top up frequency of 2.6 years, the tank will contain enough ammonia for approximately 949 days of operation.

The storage tank is to be situated in a concrete bunded area that will act as containment in the case of tank leakage/failure. The volume of the bunded area is to be the tank capacity plus 10% giving a value of 42m3. The concrete bund will also be fitted with a pump to remove any water that may collect inside it.

32.16.2. Packing

Packing is to be in accordance with [redacted] Standard Spec 22.

33. SCR Outline Mass and Energy Balance

See option 1.

34. Equipment General Arrangement, Plan & Process Drawings

General Arrangement: 600-010637

35. Outline Process Description

The exhaust gases exit a venturi nozzle which entrains ambient air from the plenum. The air enters the plenum via an aperture at the bottom, this inlet has two rings of silencing elements to reduce the aperture noise. The ambient air is required to cool the exhaust temperature down from a maximum of 585.59ºC to 454ºC.

The exhaust gases and ambient air mix then enters the ducting of bend 1 that turns 90 degrees. The exhaust flow then passes through a silencer, followed by bends 2 and 3 that take the air to a round to square expansion transition. A pepper pot mixes and conditions the exhaust gas mixture, but further CFD will be required to optimise the pepper pot design.

The duct then transitions to a 6.7 x 6.7m square, this is the cross-sectional area of the catalyst unit.

If the flow is not suitably conditioned, a further conditioning grid can be installed at the inlet face of the catalyst. The vaporised ammonia is injected into the flow via an ammonia injection grid which comprises of multiple spray bars, the amount of ammonia injected by each bar can be adjusted to optimise efficiency.

The mixture is then passed through a multipollutant catalyst bed, this reduces the amount of NOx and CO in the exhaust mixture.

The air then passes through a contraction transition and square to round transition before the ducting turns 90 degrees to take the exhaust air to the stack. The air then passes through a bullet silencer and final ducting that connects the silencer to the weather cowl.

This ducting will contain the probes required for the Continuous Emissions Monitoring System (CEMS). The CEMS samples are taken back to the operations room via heated and ATEX zone II rated lines. The samples are then analysed, and results provided by the Data Acquisition and Handling System (DAHS).

The exhaust gases then leave the stack via the weather cowl, the cowl prevents water entering the stack which the turbine is not in operation.

36. Justification for Selection of Catalyst

See option 1.

37. Justification for Selection of Reducing Agent

See option 1.

38. Projected Electrical Loads

See option 1.

39. Projected Service Requirements

See option 1.

40. Outline Civil & Structural Design or Requirements

See option 1.

41. Outline Interface/Tie-in Requirements

See option 1.

42. Major Maintenance Requirements

See option 1.

43. How Weather and Environmental Conditions May Impact the Catalyst Unit Performance

See option 1.

44. How the Performance of the Catalyst will be Monitored to Determine the Rate of Degradation

See option 1.

45. Emissions Monitoring Provisions, Including Outline Scope of Continuous Emissions Monitoring and Data Acquisition & Handling System

See option 1.

46. CFD Modelling of Exhaust Gas Flow Through SCR

Not required as per *"SCR_review_scopev5(16.11.21)"*

47. Air Dispersion Emissions Modelling Inputs

Not required as per *"SCR_review_scopev5(16.11.21)"*

48. Actual and Typical Guaranteed Levels for Pollutant Abatement

See option 1.

49. Ammonia Slip Typical Levels Over Operating Life and Management Controls

See option 1.

50. Safety and Environmental Hazards Identification Summary

See option 1.

51. General Hazardous Areas Compliance Statement

Equipment shall comply with the UKEX Zone they are situated within. The UKEX Zones used for this report were from National Grid drawing 72100803000004.dg, provided in TQ_20602_024

52. CE Marking Compliance Statement

[redacted] can provide a Declaration of Incorporation and UKCA and UKEX certificates where possible.

53. Ex-works Cost Estimates

Equipment prices delivered ex-works [redacted] domestic packed to [redacted] standards, based upon current material and labour rates. Prices do not constitute a formal proposal or quotation.

Table 14: Ex-works Cost Estimates

Item(s)	Description	Price (£)
1	Catalyst Unit	[redacted]
2	Venturi Section, Expansion Transition, Contraction Transition, Rectangular to Round Transition, Circular Silencer Outer Ring and Plenum, Weather Cowl, and Pepper Pot – Total Cost	
3	Cladded Bends	
4	Cladded Spool Duct	
5	Lined Bullet Silencer	
6	Support Steelwork	
7	Access Stairs and Platform	
8	Ammonia Tank	
9	Bund Pump	
10	CEMS	
11	DAHS	
	Total	

54. Delivery Cost Estimate

As some of the new exhaust equipment exceeds standard load sizes. During the future FEED study stage, splitting equipment should be explored so that the sizes conform to standard UK lorry load dimensions, therefore [redacted] cannot provide all delivery costs at time of writing.

The delivery cost of the catalyst unit is not available as the location of manufacture has not been determined.

55. Installation & Training Cost Estimate

Installations and training prices based upon current day labour rates are detailed below. Prices are prudent budgetary costs and do not constitute a formal proposal or quotation.

Table 15: Installation and Training Costs

Item	Description	Price (£)
1	Installation Supervision	[redacted]
2	Installation Labour	
3	Craneage	
4	Access Equipment	
5	Site Establishment	
6	Lifting Equipment	
7	Power & Welding	
8	General Tools	
9	Plant Hire & Equipment	
10	Misc Materials	
	Total	

56. Operating Cost Estimate

See option 1.

57. Typical Delivery Lead-Time from Placement of Order

At time of writing, [redacted] believe the lead time will be driven by the catalyst unit. We have been advised that the lead time will be 1 year. The delivery of the other exhaust equipment and steelwork will depend on [redacted] engineering and production capacity at time of contract agreement. Time estimates have been provided in Section 58.

58. Outline Programme from Placement of Order to Turnover the Client

The following timescales have been based on the time taken to design, progress through the G35, procure and manufacture sections of the exhausts for the National Grid Aylesbury site and a similar [redacted] horizontal SCR exhaust for [redacted]. Though Peterborough includes only one unit as opposed to the two at Aylesbury, some of the timeframes are very similar due to the time taken to design and progress through the G35. These estimates are currently estimated based on previous works and a strict programme would be created upon moving to a formal quotation.

Section	Days
Exhaust	100
Vent Pipework and Sample Points	114
Steelwork	95
Civils	68
Stairs and Platform	40
Lighting	55
Lightning Protection	40
CEMS	130

Activity	Days
Hazard Studies	35
Site Setup and Decommissioning	30
Installation	106
Commissioning	11

59. Detail Typical Equipment Guarantees

59.1. Catalyst Unit Performance

Performance of the catalyst unit is based on the 8 process duty points. If the conditions vary significantly from the points provided, the catalyst unit performance will be different and thus this guarantee is null and void.

[redacted] guarantees that the catalyst unit provided will provide the required NOx and CO abatement required to satisfy IED regulations, providing that the system is installed and operated under the guidelines of the Installation and Operating Manuals, which includes but is not limited to:

- Operation under specified temperature ranges and maintaining high temperature excursions und the time periods specified.
- Use of reagent grade aqueous ammonia as per the specifications

59.2. Differential Pressure

[redacted] are not able to provide the pressure drops for the stack silencers and weather cowl at this stage as the designs are likely to changes during FEED study stage once an acoustic survey has been performed and a final acoustic limit provided.

The change in pressure across the catalyst was provided by the catalyst supplier. The other changes in pressure were calculated at the 'worst case scenario', this was defined as the duty point with the highest flow rate (case 2). As stated above, pressure drops for the vertical silencer, horizontal silencer and weather cowl were not calculated at this stage and hence the figures below don't represent to the total system pressure loss.

Table 16: Differential Pressure of Equipment

Description	ΔP Calculated (Pa)
Bend 1 – Enclosure to Silencer	192.8
Bend 2 and 3 – Silencer to Transition	385.7
Expansion Transition to Catalyst	535.7
Contraction Transition from Catalyst	1.5
Catalyst	690
Square to Round Transition	10.7
Bend 4 - Transition to Stack	192.8

60. Summary of Major Project and Technical Risks

The risks [redacted] can foresee at time of writing are:

- The steelwork design will be complex due to high dead and wind loads with the addition of careful foot placement to maintain access to the enclosures, particularly for turbine removal.
- There is a risk that the existing instrument air package does not have adequate capacity to support the new SCR plant. This may result in further cost escalation if new instrument air is required.

61. Areas of Potential Project Opportunity or Improvement

The following are areas of potential opportunities/improvements

- Explore direct injection ammonia, will removed the need of the vaporiser.
- Acoustic survey and design of silencer.
- Determine acoustic attenuation of catalyst unit.
- Acoustic noise limit provided by National Grid.
- Further design of steelwork.
- Refinement of exhaust equipment based on the actions above.

62. List of Exclusions or Areas Which Would be Expected to be Provided by National Grid

The following items and/or services are not included under the scope of this proposal and shall be included in future studies/RFQs or be furnished by the purchaser or others of their choice:

- Vent pipework.
- Project management or electrical design costs (report account for mechanical design, production, and installations hours only).
- All transport costs for [redacted] build equipment.
- Foundations and concrete work.
- Grounding, electrical hook-up or power regulation. Motor starters and motors with space heaters.
- Lightning protection.
- Control room and other enclosures.
- Performance and/or compliance testing.
- Demolition and/or removal of any existing concrete.
- Cross-site ammonia line and equipment.
- All other items not specifically listed as included herein

Appendices

This section includes:

- Drawing 600-010342
- Drawing 600-010259
- Drawing 600-010637

[redacted]

References

None

Discussion

Can National Grid provide the latest ATEX area drawings for the following sites:

- **Wormington**
- **Kings Lynn**
- **St Fergus**
- **Peterborough**

Actions & Date

National Grid to advise on the above. Response to be by the 13/1/22 via formal TQ document (supplied below).

Attachments

TQXXXXX_001.docx

Client Response (13/01/2022):

The following hazardous area drawings are provided for use:

Wormington:
72600803000004 - Wormington Hazardous Area Drawing rev S

King's Lynn:
7210/08/03/00/0004 – Hazardous areas drawing

Peterborough:
Operational Drawings
7220/08/03/00/0004/001 - Hazardous areas drawing
7220/08/03/00/0004/002 - Hazardous areas drawing

Construction drawings / future operation
7054-0180-038-03-1027-001 – Hazardous area drawing

***Note**: Hazardous areas are shown on the above combination of operational drawings and construction drawings to show the current status of the site and the status after the completion of the ongoing emissions reduction projects which includes installation of 2 new gas turbine driven compressors which will be fully commissioned prior to and potential installation of SCR on the Avon driven units.*

St Fergus:
St Fergus Hazardous Area Drawings Sheet 1 to 31:

60110803000004x01
60110803000004x02
60110803000004x03
60110803000004x04
60110803000004x05
60110803000004x06
60110803000004x07
60110803000004x08
60110803000004x09
60110803000004x10
60110803000004x11
60110803000004x12
60110803000004x13
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60110803000004x20
60110803000004x21
60110803000004x22
60110803000004x23
60110803000004x24
60110803000004x25
60110803000004x26
60110803000004x27
60110803000004x28

[redacted]

References

None

Discussion

As per the SCR Technical Feasibility Study - 2021 Review and Update: Outline Scope document. For [redacted] to be able to form the Basis of Design, can National Grid provide the process duty points with the same information fields as figure 2, section 2.10 (see picture below) in the [redacted] report for the following sites:

- **Wormington**
- **Kings Lynn**
- **St Fergus**
- **Peterborough**

2.10. LOAD CONDITIONS

For the basis of design, 10 process duty points for Kirriemuir unit C201-A have been considered, as per [redacted] document ref: 7063-0200-01-0001-001-Rev P3, as shown below in figure 2:

Required information fields

Case		1	2	3	4	5	6	7	8	9	10
Gas Molar Flow	MSCMD	28.33	32.47	33.20	32.77	34.98	35.43	37.03	43.34	42.63	55.19
Gas Volumetric Flow	m^3/h	16024	18696	19556	20900	21617	23209	24142	26738	29142	34518
Compressor Head	kJ/kg	7.05	12.93	18.01	22.61	30.49	21.00	28.58	25.23	20.95	17.18
Compression Power	MW	2.39	4.52	6.27	7.67	11.62	7.55	11.03	10.72	8.81	9.90
Compressor Suction Pressure	bara	62.63	61.32	60.05	55.65	57.83	54.65	53.11	56.72	53.37	55.37
Compressor Suction Temp.	°C	12.1	11.9	11.4	9.4	12.0	10.3	4.5	7.9	13.5	5.1
Compressor Disch. Pressure	bara	66.68	68.74	70.29	67.68	74.86	65.50	68.25	70.73	63.75	64.57
Gas Specific Gravity		0.622	0.629	0.638	0.628	0.644	0.645	0.639	0.624	0.639	0.621
Ambient Temperature	°C										
Running hours (average)	h/year	46	52	99	44	33	79	78	106	119	218
Running hours (cold winter)	h/year	5	4	27	3	18	59	180	248	63	32
Running hours (mild winter)	h/year	21	47	108	1	0	65	0	66	141	31
Running hours (extended)	h/year	42	142	233	48	166	205	165	222	403	1309
Compressor Speed	RPM	3100	4005	4503	5124	5730	4800	5726	5488	5247	5282
Gas Generator Speed	RPM	3695	5284	5586	5818	6098	5716	6096	5990	5875	5892
	%	49.3%	70.5%	74.5%	77.6%	81.3%	76.2%	81.3%	79.9%	78.3%	78.6%
Gas Turbine Efficiency	%	11.4%	18.3%	21.3%	23.1%	26.7%	23.2%	25.9%	25.9%	24.2%	24.7%
Net Thermal Input	MW	20.86	24.67	29.40	33.16	43.53	32.51	42.66	41.45	36.34	40.03
Fuel Flow	kg/s	0.45	0.54	0.64	0.72	0.95	0.71	0.93	0.90	0.79	0.87
Exhaust Gas Temperature	°C	412.7	433.2	456.1	480.1	560.3	475.5	554.7	546.3	505.1	535.5
Exhaust Mass Flow	kg/s	38.93	55.66	58.84	61.28	64.23	60.21	64.22	63.09	61.89	62.06
CO_2 Mass Flow	kg/s	1.20	1.42	1.70	1.92	2.51	1.88	2.46	2.39	2.10	2.31
NOx Mass Flow	g/s	2.33	3.59	4.13	4.69	6.60	4.53	6.47	6.16	5.20	5.83
CO Mass Flow	g/s	21.62	25.73	22.37	19.17	11.18	19.55	11.61	12.09	15.96	12.82
UHC Mass Flow	g/s	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NOx Concentration	mg/Nm^3	73.3	79.0	85.9	93.8	125.9	92.2	123.3	119.6	102.8	115.0
CO Concentration	mg/Nm^3	680.5	566.3	465.6	383.3	213.2	397.6	221.5	234.7	316.0	253.1
UHC Concentration	mg/Nm^3										

Figure 2 – Basis of design 10 process duty points for Kirriemuir unit A ([redacted] document ref: 7063-0200-01-0001-001-Rev P3).

Actions & Date

National Grid to advise on the above. Response to be by the 13/1/22 via formal TQ document (supplied below).

Attachments Response 25-01-22

Data for Wormington and Peterborough is provided in the attached:

TQ008_NG%20Response.xlsx

[redacted]

References

Discussion

Can National Grid indicate which areas [redacted] could use to locate the SCR system, any areas that are to be kept clear for site activities (not restricted to turbine removal) and any units that are to be demolished for the following sites:

- **Wormington**
- **Kings Lynn**
- **St Fergus**
- **Peterborough**

Actions & Date

National Grid to advise on the above. Response to be by the 25/1/22 via formal TQ document (supplied below).

Attachments

TQXXXXX_001.docx

Response – 25/01/22

Preliminary ammonia storage locations are indicated on the attached layout drawings. Final equipment location and layout will be subject to formal layout review including review workshop in accordance with National Grid procedures.

For Wormington and St Fergus it has been assumed that single storage tank will be provided for all SCR systems. Consideration should be given to availability and single points of failure on the ammonia storage and loading system should be avoided. For all sites a suitable sparing philosophy which provides high availability is required.

For Wormington three potential options have been indicated. Of these locations option 2 is preferred at this stage. It is anticipated that utilising option 1 may require relocation of HV cables. Option 3 is located where the aftercoolers, which are no longer in use are currently located.

[redacted]

References

Discussion

As discussed in the meeting at 3pm on 20/1/22, [redacted] have been informed that there was a previous vertical catalyst system study.

Can National Grid provide the vertical catalyst report and any vertical height limits for the following sites:

- **Wormington**
- **Kings Lynn**
- **St Fergus**
- **Peterborough**

Actions & Date

National Grid to advise on the above. Response to be by the 25/1/22 via formal TQ document (supplied below).

Attachments

TQXXXXX_001.docx