ENGINEERING JUSTIFICATION PAPER (EJP)

OFFICIAL – FOR PUBLIC RELEASE

Rotating Machinery

Version: 1.0

Issue: Final

December 2024

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RIIO-GT3 NGT_EJP04

Contents

1 Summary Table

Table 1: Summary table for Rotating Machinery EJP

Name of Project	*Compressor Machinery Train Asset Health*		
Scheme Reference	*NGT_EJP04_Rotating Machinery_RIIO-GT3*		
Primary Investment Driver	*Asset Health*		
Project Initiation Year	*FY2027*		
Project Close Out Year	*FY2031*		
Total Installed Cost Estimate (£m, 2023/24)	109.86		
Cost Estimate Accuracy (%)	+/- 20%		
Project Spend to date (£m, 2023/24)	0		
Current Project Stage Gate	NDP Stage 4.0		
Reporting Table Ref	6.4, 11.6		
Outputs included in RIIO-T2 Business Plan	No		
Spend Apportionment (£m, 2023/24)	**RIIO-T2**	**RIIO-GT3**	**RIIO-GT4**
	1.44	107.31	1.11

2 Executive Summary

2.1.1 This paper requests £109.86m (2023/24) baseline funding in RIIO-GT3 for 262 interventions covering 60% of our operational compressor fleet excluding St Fergus, measured through an Asset Health – NARMS PCD. This programme delivers £84.26m of NARMS benefit.

2.1.2 The primary driver for this investment is Asset Health (Risk Management) to ensure safe, compliant, and reliable availability of compressor machinery train assets which are integral to meeting exit pressures and licence obligations.

2.1.3 Without suitable intervention in RIIO-GT3, failure of compression-related assets would directly impact NTS resilience through reduced availability and reliability whilst simultaneously increasing safety risk.

2.1.4 This EJP aims to deliver value to consumers by targeting interventions based on compression fleet strategy including forecasted running hours and expected out of service dates.

2.1.5 The assets in this investment are gas and electrically driven compressor units including gas turbines, power turbines and the associated vent systems. We have considered a mix of preventative and reactive interventions across the portfolio to address asset health risk. In summary we are proposing the intervention mix shown in Table 2.

Table 2: RIIO-GT3 volumes proposed in this EJP

	Replace	Overhaul/Refurbish	Decommission	Survey	Total
RIIO-GT3 volumes	[redacted]	[redacted]	[redacted]	[redacted]	**262**

2.1.6 Compared to RIIO-T2, our compressor rotating machinery train funding request represents an increase of £7m. This is driven by a variety of new investments related to specific issues arising from operating a complex asset base with condition challenges. Note that the 'decommission' volumes in Table 2 relate only to assets within compressor machinery trains not decommissioning compressor units which are detailed in the Compressor Fleet EJPs[1,2,3,4].

2.1.7 In RIIO-T2, we forecast to deliver 206 interventions, compared to our original allowance of 346. The delta is primarily driven by needing to prioritise costly complex interventions within business plan allowances. Intervention volumes differ in RIIO-GT3 aligned to when scheduled overhauls are due and inclusion of certain interventions to address specific problems across the fleet of compressors which has evolved during RIIO-T2.

Table 3: RIIO-T2 vs RIIO-GT3 (£m, 2023/24)

	RIIO-T2 Business Plan	RIIO-T2 Forecast Delivery	RIIO-GT3 Business Plan
Interventions	346	206	262
Investment	£103m	£89m	£110m

2.1.8 Papers closely related to this include Compressor Fleet[5,6,7,8], Control Systems[9], Network Decarbonisation[10] and Cab Infrastructure[11].

2.1.9 The deliverability of this work has been assessed and we have high confidence that this can be delivered during RIIO-GT3 aligned to compressor outages, demonstrable internal capability and effective engagement with proven delivery partners including specialist providers and OEMs. The profile of investment for RIIO-GT3 is shown in Table 4, aligned to the delivery programme.

Table 4: RIIO-GT3 funding request for Compressor Machinery Trains (£m, 2023/24)

	2026	2027	2028	2029	2030	2031	2032	Total	Funding Mechanism
Compressor Machinery Train	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	109.86	Baseline
Total	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	**109.86**	**Baseline**

1 NGT_EJP13_Compressor Fleet – Network Investments and Zone 1 (Scotland)_RIIO-GT3
2 NGT_EJP14_Compressor Fleet - Zones 2 and 3 (Central)_RIIO-GT3
3 NGT_EJP15_Compressor Fleet - Zones 4 and 5 (South Wales and South West)_RIIO-GT3
4 NGT_EJP16_Compressor Fleet - Zones 6 and 7 (East Midlands and South East)_RIIO-GT3
5 NGT_EJP13_Compressor Fleet – Network Investments and Zone 1 (Scotland)_RIIO-GT3
6 NGT_EJP14_Compressor Fleet - Zones 2 and 3 (Central)_RIIO-GT3
7 NGT_EJP15_Compressor Fleet - Zones 4 and 5 (South Wales and South West)_RIIO-GT3
8 NGT_EJP16_Compressor Fleet - Zones 6 and 7 (East Midlands and South East)_RIIO-GT3
9 NGT_EJP07_Control Systems_RIIO-GT3
10 NGT_EJP21_Network Decarbonisation_RIIO-GT3
11 NGT_EJP03_Cabs_RIIO-GT3

3 Introduction

3.1.1 This document sets out our asset health investment proposal for our rotating machinery assets which covers Compressor Machinery Trains (CMT) including ancillary equipment and systems. CMTs raise the pressure of the gas to drive its flow through the National Transmission System (NTS).

3.1.2 CMTs are either driven by a gas turbine or electrically. Gas driven CMTs comprise a gas generator, power turbine and a compressor. Electrically driven CMTs comprise a variable speed drive and compressor.

3.1.3 The associated auxiliary systems installed per CMT unit are also within the scope of this request as shown in Figure 1.

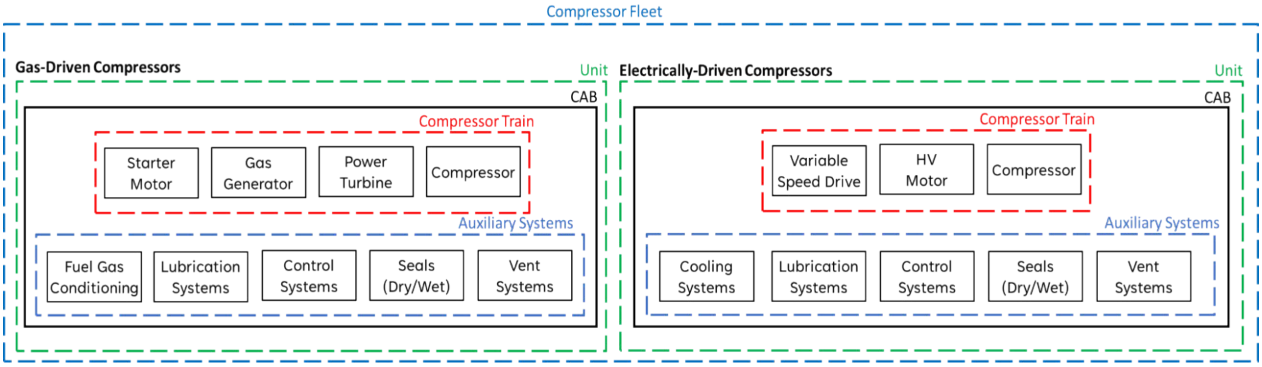

Figure 1: Compressor general overview

3.1.4 Asset health of the fleet is a primary investment driver. Ensuring the reliability and maintainability of compressor assets is fundamental to sustaining appropriate fleet availability.

3.1.5 This EJP has been structured as shown in the below figure to cover three sub-themes within the Rotating Machinery asset base.

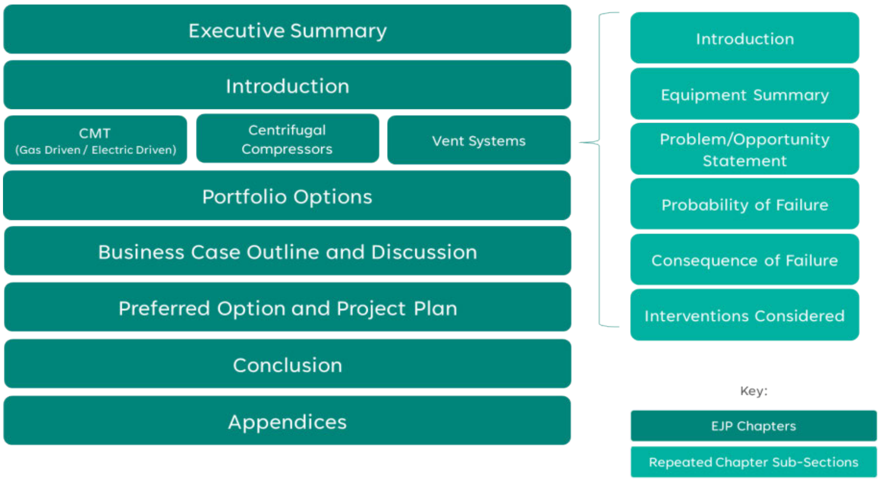

Figure 2: Rotating Machinery EJP document structure

3.1.6 The scope of this document is aligned with our Asset Management System (AMS) and relates to our Legislative Compliance, Asset Health and Stable Network Risk Business Plan Commitments (BPCs). More information on our AMS and a description of our commitments is provided in our Network Asset Management Strategy annex[12] and our BPCs are detailed within our main business plan document[13].

3.1.7 This EJP interacts with several others including, Compressor Acoustic Buildings (CABs) Infrastructure[14], Network Decarbonisation[15], Control Systems[16] and all Compressor Fleet EJPs[17,18,19,20].

[12] NGT_A08_Network Asset Management Strategy_RIIO_GT3
[13] NGT_Main_Business_Plan_RIIO_GT3
[14] NGT_EJP03_Cabs_RIIO-GT3
[15] NGT_EJP21_Network Decarbonisation_RIIO-GT3
[16] NGT_EJP07_Control Systems_RIIO-GT3
[17] NGT_EJP13_Compressor Fleet – Network Investments and Zone 1 (Scotland)_RIIO-GT3
[18] NGT_EJP14_Compressor Fleet - Zones 2 and 3 (Central)_RIIO-GT3
[19] NGT_EJP15_Compressor Fleet - Zones 4 and 5 (South Wales and South West)_RIIO-GT3
[20] NGT_EJP16_Compressor Fleet - Zones 6 and 7 (East Midlands and South East)_RIIO-GT3

4 Compressor Machinery Trains – £88m (2023/24)

4.1 Equipment Summary

4.1.1 The NTS compressor fleet comprises broadly two different types of Compressor Machinery Trains (CMTs), driven by gas turbines or electric motors. A summary of each type is presented below, with additional information such as health score at the beginning and end of the price control and monetised risk provided in the accompanying NGT_IDP14_Portfolio EJP Rotating Machinery_RIIO-GT3.

Gas Driven CMTs

4.1.2 Gas driven compressor trains comprise:

- Starter motors – used to start the gas generator and are either gas or electric depending on different situations and ages. There is one starter motor per CMT.
- Gas generator (also known as gas turbine) - produces high pressure (20 bar), high temperature exhaust gases to drive the power turbine.
- Power turbines – operate at atmospheric pressure to convert the energy in the high velocity exhaust gas from the gas generator into the mechanical energy required to drive the centrifugal compressor.

4.1.3 Gas driven CMTs require fuel gas from the NTS via associated assets to ensure correct pressure, temperature, and condition. Fuel gas conditioning involves pre-heating the gas to prevent the problems associated with overcooling including heavy hydrocarbon drop-out, reduced gas quality and the risk of damage to the turbines.

4.1.4 The installed fleet of gas CMTs is shown in Table 5. This excludes units installed at St Fergus which are covered in the St Fergus Rotating Machinery EJP[21]. Further information can be found in Appendix 6: Installed Compressor Units.

Table 5: Installed gas turbines

Gas Generator Type	Qty	Description
[redacted]	[redacted]	[redacted]
Total	**50**	

4.1.5 To manage availability during overhauls and unexpected failures, spare gas generators are held and maintained as follows: [redacted]. The Network Capability: Compressor Fleet – Zones and 3 EJP[22] details the spares investments proposed for RIIO-GT3.

Electrically Driven CMTs

4.1.6 Electric driven CMTs use a high voltage electrical supply to drive a compressor. Electrical variable speed drives are typically broken down into two sub assets: electric motor and variable speed drive (VSD).

4.1.7 Maintainable components include: HV reactor, converter transformer, inrush limiting resistor, variable frequency drive, harmonic filter, high voltage motor and exciter, magnetic bearing systems ([redacted]), converter and motor cooling systems, motor air purge systems, containers, cabling and containment.

4.1.8 VSDs allow compression of gas without direct emissions and environmental impacts associated w[redacted] gas driven CMTs and are essential to meet reduce emissions. VSD units are generally the lead unit at compressor stations as they use the best available techniques and, therefore, receive the most frequent usage.

4.1.9 This EJP covers investment on [redacted] included in the St Fergus Rotating Machinery EJP[23]. VSDs are generally rated with reference to their voltage and input power as shown in Table 6.

[21] NGT_EJP27_St Fergus: Rotating Machinery_RIIO-GT3
[22] NGT_EJP14_Compressor Fleet - Zones 2 and 3 (Central)_RIIO-GT3
[23] NGT_EJP27_St Fergus: Rotating Machinery_RIIO-GT3

Table 6: VSD fleet specifications

VSD Unit	Voltage (KV)	Power Rating (MW)	Manufacturer/Type
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]

4.1.10 There is one electric drive within each compressor unit. Therefore, overhaul or failure of the asset results in the unavailability of the unit. Redundancy is currently only provided through utilisation of gas turbine compressor units on site.

4.2 Problem/Opportunity Statement

Why are we doing this work and what happens if we do nothing?

4.2.1 Compressor machinery trains are an integral part of the NTS to meet exit pressures and licence obligations. Therefore, it is essential that we ensure the reliability and maintainability of these assets to achieve compressor availability.

4.2.2 Specifically, gas driven CMTs and ancillary systems are highly complex assets made up of multiple components. Operating at high pressures and temperatures, these critical assets require ongoing proactive management, without which they would become unusable.

4.2.3 If VSDs are unavailable, it requires gas driven CMTs to be run, resulting in higher emissions. Some gas driven CMTs are also subject to restricted running hours under the Industrial Emissions Directive, further highlighting the criticality of VSDs within the fleet.

4.2.4 Table 7 below presents the drivers for investment for our CMTs:

Table 7: Categories of driver for CMTs

Driver Category	Description
Legislation and standards	CMT equipment must comply with legislation and standards. For example, assets must be compliant and certified (i.e., ATEX certification) to relevant standards for equipment and protective systems intended for use in potentially explosive atmospheres – Directive 94/9/EC. Ongoing investment is required to maintain compliance and to prevent asset deterioration leading to non-compliance. Electricity at Work regulations (EAWR) are applicable to all electric assets, including VSDs. Meeting industry standard requirements such as BS EN 60079-14 and BS EN 60079-17 directly supports achieving the legislative requirements. Regulations regarding emissions associated with operating a fleet of gas driven CMTs have had significant ramifications requiring comprehensive changes which are detailed in the Compressor Fleet EJPs[24,25,26,27].
Asset Deterioration	CMTs are managed in accordance with Original Equipment Manufacturer (OEM) guidelines to account for them deteriorating with use. Degradation of gas driven CMTs is affected by the number of cycles and running hours alongside operating conditions including load changes, fuel, and combustion air. Degradation also occurs when machines are not running which must be managed. VSDs are also affected by operational conditions. CMTs are maintained and overhauled according to the duty they have undertaken in line with manufacturer recommendations and best practice across Europe. See Appendix 1: Gas Generator overhaul schedule (hours) and Appendix 2: Power Turbine overhaul schedule (hours) for how the overhaul guidance is applied to the asset base. Borescope inspections are routinely carried out to inform condition between overhauls.
Reliability and Availability	CMTs, including auxiliary systems, must be reliable to meet required availability levels. Performance issues and defects across the fleet have a direct impact on availability which require asset health intervention. The Reliability Availability Maintainability (RAM) model detailed in the Compressor Fleet EJPs[28,29,30,31] considers necessary Asset Health interventions aligned to network capability. Fuel gas conditioning is a necessary function for the safe operation of gas turbines and increases the lifespan and reliability of the engines, as well as safeguarding against catastrophic failure and therefore requires investment to prevent out of specification gas damaging CMTs.

[24] NGT_EJP13_Compressor Fleet – Network Investments and Zone 1 (Scotland)_RIIO-GT3
[25] NGT_EJP14_Compressor Fleet - Zones 2 and 3 (Central)_RIIO-GT3
[26] NGT_EJP15_Compressor Fleet - Zones 4 and 5 (South Wales and South West)_RIIO-GT3
[27] NGT_EJP16_Compressor Fleet - Zones 6 and 7 (East Midlands and South East)_RIIO-GT3
[28] NGT_EJP13_Compressor Fleet – Network Investments and Zone 1 (Scotland)_RIIO-GT3
[29] NGT_EJP14_Compressor Fleet - Zones 2 and 3 (Central)_RIIO-GT3
[30] NGT_EJP15_Compressor Fleet - Zones 4 and 5 (South Wales and South West)_RIIO-GT3
[31] NGT_EJP16_Compressor Fleet - Zones 6 and 7 (East Midlands and South East)_RIIO-GT3

Driver Category	Description
Age and Obsolescence	Most gas-powered CMTs utilise aero-derivative gas generators from the 1970s and 1980s. Components installed on these older units are becoming increasingly obsolete resulting in longer lead times for spares and repairs. Certain components on electrically driven CMTs are reaching end of life, resulting in increased asset health issues. OEMs have advised of obsolescence and technical support constraints across a range of CMT assets including fuel gas valves, harmonic filters etc.. The life expectancy of a VSD advised by Chartered Institute of Building Services Engineers (CIBSE) is 15 years. However, units on the NTS will be over 20 years by the end of RIIO-GT3. The HV motor life expectancy is 40 years if OEM maintenance and inspection requirements are followed.
Environment	Operating electric drives as primary units is essential to enable emissions reductions. At sites with both CMT types, gas turbine powered compressor running is often limited due to environmental impact, with some having running hour restrictions under Emissions legislative derogations – see the Compressor Fleet EJPs[32,33,34,35] for further information. Therefore, unavailability of electric driven units results in use of polluting gas driven units. It should be noted that although emission reductions are considered whenever practicable, only the Network Decarbonisation EJP[36] details specific interventions to reduce emissions.
Safety	HV Motor VSDs are designed and installed as compressor packages, supplied as fully certified and compliant units to meet with EC-Type examination ATEX certificates. Investment is required to perform tests to confirm safety compliance. These are mandated by standards such as BS EN60079-2 (Explosive Atmospheres-Equipment protection by pressurized enclosure "p").

What is the outcome we want to achieve?

4.2.5 The primary outcome sought to be achieved is enabling optimal availability of compression assets across the NTS to meet forecasted and actual demand including required resilience allowances.

How will we understand if the spend has been successful?

4.2.6 Success shall be measured by CMT availability within all constraints. Additionally, ALERT trip data, fleet issues and defects alongside completion of scheduled overhauls will be measurable metrics for this spend.

Narrative Real Life Example of Problem

4.2.7 [redacted] suffered a high-pressure turbine disc failure in March 2013 resulting in a loss of blade containment from the engine steel casing. During the incident, some of the rotor blades were ejected into the compressor enclosure, with other gas generator debris shown in Figure 3.

4.2.8 This resulted in extensive damage to the infrastructure in the immediate surroundings. The results of investigations showed that one of the contributing factors was poor fuel gas preheat and conditioning leading to poor combustion and high cycle fatigue.

Figure 3: [redacted]

4.2.9 The OEM recommends the temperature of gas delivered to the fuel gas governor is 20°C above the hydrocarbon dewpoint or 0°C, whichever is greater. [redacted] issued a service bulletin stating that liquid hydrocarbons in fuel gas, or glycol carryover etc. can cause 'spluttering' combustion which results in carbon deposition on burner heads causing in high temperature spreads. A high Exhaust Cone Temperature (ECT) spread can lead to high cycle fatigue on the blades due to cycling them through a large temperature differential.

4.2.10 This event demonstrated the need to invest in fuel gas conditioning which began in RIIO-T2. Continuation of this is required to ensure all gas driven CMTs are equipped with suitable gas conditioning systems.

[32] NGT_EJP13_Compressor Fleet – Network Investments and Zone 1 (Scotland)_RIIO-GT3
[33] NGT_EJP14_Compressor Fleet - Zones 2 and 3 (Central)_RIIO-GT3
[34] NGT_EJP15_Compressor Fleet - Zones 4 and 5 (South Wales and South West)_RIIO-GT3
[35] NGT_EJP16_Compressor Fleet - Zones 6 and 7 (East Midlands and South East)_RIIO-GT3
[36] NGT_EJP21_Network Decarbonisation_RIIO-GT3

Project Boundaries

4.2.11 The boundaries of spend proposed by this paper are limited to the CMTs installed across the NTS, outside of St Fergus. This scope covers all the components downstream of the VSD HV power cables.

4.2.12 Out of scope for this investment are:

- Investments on the units at St Fergus are covered in the St Fergus: Rotating Machinery EJP[37].
- Changing the capability of the compressor fleet (e.g., new units, decommissioning, site reconfigurations and re-wheels to adjust envelopes) as well as emissions compliance and spares are covered in our Compressor Fleet EJPs[38,39,40,41].
- Compressor Acoustic Buildings (Cabs) which house compressor trains, including their air intake and exhaust are covered in the Cabs EJP[42]. Investment in cabs is required to ensure compressor machinery trains are contained within optimal operational environments. Without suitable intervention, there is a risk that increased spend will be incurred to rectify compressor machinery train assets as a result. Cabs also enable works detailed in this EJP to be conducted (e.g., cranes to lift PT/GG for overhauls).
- Interventions involving compressor trains which are driven by emissions reduction and contributing to our Net Zero target are addressed in the Network Decarbonisation EJP[43].
- Control systems for our compressor units are covered in the Control Systems EJP[44].
- Assets upstream of VSD power cables such as HV switchgear are covered in the Electrical EJPs[45].

4.2.13 Assessment of the investment programme across the entire capital investment plan has been conducted to ensure alignment of all interdependencies and links.

4.3 Probability of Failure

Failure Modes

4.3.1 Probability of failure (PoF) has been assessed utilising historical defects and our Network Asset Risk Metric (NARMs) model. This model is built within our Copperleaf asset management decision support tool to assess the forward-looking probability of failure.

4.3.2 Not all modelled failures will result in real-world asset failure and this forecast is not a prediction of how many defects will be identified.

4.3.3 Likely failure modes for CMTs with an average proportion of failures of 0.5 or above are provided in Table 8, the full list of failure modes is available in the NARMS methodology.

Table 8: CMT failure modes

Failure Mode	Average Proportion of Failures
Loss of unit - trip	0.91
Loss of gas quality information	0.80
Failure of compressor gas seal	0.59
Corrosion no oil leak	0.59
Oil spill from wet seal	0.56
Loss of stream regulator slam shut - trip	0.53
Unable to wash engine	0.53

4.3.4 The highest average proportion of failure modes is loss of unit - trip. Table 8 also shows other failures which result in unit trips e.g., failure of lube oil system.

4.3.5 When applied to the asset count with an assumption that no investment is made, a forecast of failures across the RIIO-GT3 period is produced, shown in Table 9. The average failure rate represents the proportion of that asset type with an unresolved failure. The forecast failures per year shows the quantity of new failures modelled to occur each year.

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[37] NGT_EJP27_St Fergus: Rotating Machinery_RIIO-GT3
[38] NGT_EJP13_Compressor Fleet – Network Investments and Zone 1 (Scotland)_RIIO-GT3
[39] NGT_EJP14_Compressor Fleet - Zones 2 and 3 (Central)_RIIO-GT3
[40] NGT_EJP15_Compressor Fleet - Zones 4 and 5 (South Wales and South West)_RIIO-GT3
[41] NGT_EJP16_Compressor Fleet - Zones 6 and 7 (East Midlands and South East)_RIIO-GT3
[42] NGT_EJP03_Cabs_RIIO-GT3
[43] NGT_EJP21_Network Decarbonisation_RIIO-GT3
[44] NGT_EJP07_Control Systems_RIIO-GT3
[45] NGT_EJP10_Electrical Infrastructure: Switchgear and Transformers_RIIO-GT3

Table 9: Forecast CMT failures

Asset Type	No. of Assets	Cumulative Average Failure Rates					Forecast Failures per Year				
		2027	2028	2029	2030	2031	2027	2028	2029	2030	2031
Electrical (A.2.4)-Frequency Converters-High Voltage	[redacted]	0.58	0.61	0.65	0.68	0.68	0.28	0.32	0.37	0.26	0.01
Electrical (A.2.4)-Harmonic Filters-High Voltage	[redacted]	0.86	0.88	0.88	0.88	0.88	0.23	0.13	0.00	0.00	0.00
Rotating (A.2.2)-Electric Motors-Asynchronous	[redacted]	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Rotating (A.2.2)-Electric Motors-Asynchronous-Control and Monitoring	[redacted]	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Rotating (A.2.2)-Electric Motors-Asynchronous-Fuel System	[redacted]	0.53	0.59	0.65	0.71	0.78	0.10	0.11	0.12	0.13	0.14
Rotating (A.2.2)-Electric Motors-Synchronous	[redacted]	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Rotating (A.2.2)-Electric Motors-Synchronous-Control and Monitoring	[redacted]	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Rotating (A.2.2)-Electric Motors-Synchronous-Lubrication System	[redacted]	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Rotating (A.2.2)-Electric Motors-Synchronous-Miscellaneous	[redacted]	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Rotating (A.2.2)-Gas Turbines	[redacted]	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Rotating (A.2.2)-Gas Turbines-Aero Derivative	[redacted]	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Rotating (A.2.2)-Gas Turbines-Aero Derivative-Control and Monitoring	[redacted]	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Rotating (A.2.2)-Gas Turbines-Aero Derivative-Fuel System	[redacted]	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Rotating (A.2.2)-Gas Turbines-Aero Derivative-Lubrication System	[redacted]	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Rotating (A.2.2)-Gas Turbines-Aero Derivative-Starting System	[redacted]	0.93	0.95	0.96	0.97	0.98	1.56	0.92	0.43	0.31	0.33
Rotating (A.2.2)-Gas Turbines-Control and Monitoring	[redacted]	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Rotating (A.2.2)-Gas Turbines-Fuel System	[redacted]	0.63	0.64	0.67	0.69	0.71	0.09	0.11	0.12	0.14	0.16
Rotating (A.2.2)-Gas Turbines-Industrial	[redacted]	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Rotating (A.2.2)-Gas Turbines-Industrial-Control and Monitoring	[redacted]	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Rotating (A.2.2)-Gas Turbines-Industrial-Fuel System	[redacted]	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Rotating (A.2.2)-Gas Turbines-Industrial-Lubrication System	[redacted]	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Rotating (A.2.2)-Gas Turbines-Industrial-Miscellaneous	[redacted]	0.87	0.90	0.92	0.95	0.98	0.31	0.26	0.29	0.33	0.24
Rotating (A.2.2)-Gas Turbines-Industrial-Starting System	[redacted]	0.91	0.93	0.93	0.94	0.94	0.25	0.18	0.04	0.05	0.05
Rotating (A.2.2)-Gas Turbines-Lubrication System	[redacted]	0.65	0.66	0.66	0.66	0.66	0.00	0.01	0.01	0.01	0.01
Rotating (A.2.2)-Gas Turbines-Miscellaneous	[redacted]	0.55	0.59	0.63	0.68	0.73	0.10	0.11	0.13	0.15	0.14
Rotating (A.2.2)-Gas Turbines-Starting System	[redacted]	0.60	0.67	0.75	0.84	0.95	0.17	0.20	0.24	0.28	0.32
Rotating (A.2.2)-Power Turbines-Aero Derivative	[redacted]	0.15	0.15	0.16	0.17	0.17	0.33	0.37	0.41	0.44	0.48
Rotating (A.2.2)-Pumps-Centrifugal	[redacted]	0.56	0.59	0.64	0.68	0.74	0.21	0.25	0.29	0.34	0.39

Trips

4.3.6 Given the potentially significant impact combined with the high probability of trips, the Reliability Availability Maintainability (RAM) model evaluated unit availability across the entire fleet. Developed in collaboration with [redacted], the study used ALERT trip data from 2016-2020 to assess compressor fleet capability to meet flows based on expected unit type availability.

4.3.7 Further information on the RAM study is contained within the Compressor Fleet EJPs[46,47,48,49] and only certain CMT asset health interventions recommended by the output of the RAM model are included in this paper.

4.3.8 Alongside running trips, the alert system collates starting trip data to calculate start probability statistics. A monthly rolling view for the last two years is shown in Figure 4.

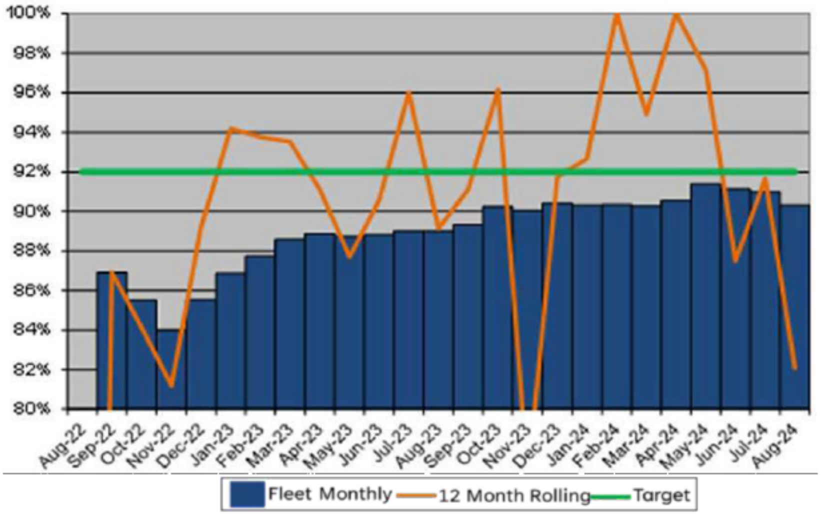


Figure 4: Compressor start probability

4.3.9 Figure 4 shows the average compressor starting probability is [redacted]% which is below the target of [redacted]%. The start probability fluctuates significantly in line with the number of attempted starts which is primarily attributed to compression generally being required more in the colder months. Overall, the chart shows that the probability of compressors starting declines at the times when higher levels of reliability are needed, therefore indicating a need to intervene. Faults on compressor machinery may be undetectable in the summer due to them not running during planned outages aligned to seasonality of demand. Therefore, breakdowns which occur when run will need addressing, often within a limited timeframe. Interventions considered to address this include starter gas generator starter motor swaps and fuel gas conditioning.

4.3.10 In addition to forecasted failures, running and starting trip data, known defects are present across the fleet. In these instances, interventions are required to remediate defects and issues. For example, Table 10 includes some defects extracted from the Computerised Maintenance Management System (CMMS) which show recurrent defects on cooling systems installed within the VSD units at [redacted] which cause frequent tripping, signalling the need for a holistic solution to the problem. Trips require manual intervention which involves maintenance personnel diagnosing the problem and arranging rectification action. This has a direct impact on compressor availability and a secondary impact to routine maintenance if personnel are called to fix issues.

Table 10: [redacted] VSD cooling system defects

Unit	Fault/Problem Description
[redacted]	Short circuit on one of the windings at the terminal box of the liquid cooling system fan.
	Liquid cooling system control panel is now obsolete and requires replacing. System is no longer supported by OEM.
	HMI unit for Glycol water cooling nearing end-of-life and discontinued
	Glycol cooling system, pump changeover fault found to have intermittent fault, changeover not performing correctly
	Unit E Water cooling temperature currently exceeds ATEX rating of the motor, this is a safety concern due to internal protection systems breaking down due to temperatures.

Probability of failure data assurance

4.3.11 Both NARMs and RAM models used historical defect and trip data collated from the defect system and ALERT.

[46] NGT_EJP13_Compressor Fleet – Network Investments and Zone 1 (Scotland)_RIIO-GT3
[47] NGT_EJP14_Compressor Fleet - Zones 2 and 3 (Central)_RIIO-GT3
[48] NGT_EJP15_Compressor Fleet - Zones 4 and 5 (South Wales and South West)_RIIO-GT3
[49] NGT_EJP16_Compressor Fleet - Zones 6 and 7 (East Midlands and South East)_RIIO-GT3

Further engineering judgement, operational experience and support from specialists including OEMs have validated the modelled assumptions.

4.4 Consequence of Failure

4.4.1 The consequences of not investing in the asset health of CMTs could lead to an inability to manage pressures across the NTS. This would lead to loss of supply to customers with far reaching economic and political implications. The consequence of failure associated with CMTs aligned to NARMS service risk measures are described in Table 11.

Table 11: Consequence of failure summary

Impact / Consequence			
Environment	**Financial**	**Availability**	**Safety**
Failure of any component part of the gas driven CMT may result in venting of gas. This may be deliberate to avert catastrophic damage to plant and people or accidental following gas leaking from failed components or systems. Not complying with emissions legislation affecting gas driven CMTs for any reason would be a breach and would incur financial and reputational penalties. VSD asset failure may lead to loss of gas through trips and vents of the unit. Potential noise excursions would result in non-compliance with environmental permits. Failure of VSDs would require increased usage of gas driven CMTs units, increasing emissions across the network.	Costs of operating and maintaining the assets would increase without suitable investment to address asset health failures. Financial penalties can also be incurred for non-compliance with safety and environmental legislation. Potential financial penalties for being unable to supply gas as and when it is needed and associated entry constraints.	CMTs provide compression to the NTS, without which gas would not achieve the required pressure on the network. Although redundancy is built into the NTS, the consequence of losing compression during trip events or unplanned outages could result in loss of supply to customers. The mix of CMTs is critical to achieving overall network capability and resilience as demonstrated in the Compressor Fleet EJPs[50,51,52,53].	People, plant and equipment must always be kept safe. Due to the intrinsic risks associated with gas powered CMTs, operating in suboptimal condition is avoided on process safety grounds. If isolated due to safety and integrity concerns, CMTs cannot provide compression to the NTS. VSDs operate at High Voltage. Any failure could result in dangerous conditions without suitable mitigation.

[50] NGT_EJP13_Compressor Fleet – Network Investments and Zone 1 (Scotland)_RIIO-GT3
[51] NGT_EJP14_Compressor Fleet - Zones 2 and 3 (Central)_RIIO-GT3
[52] NGT_EJP15_Compressor Fleet - Zones 4 and 5 (South Wales and South West)_RIIO-GT3
[53] NGT_EJP16_Compressor Fleet - Zones 6 and 7 (East Midlands and South East)_RIIO-GT3

4.5 Interventions Considered

4.5.1 A mix of preventative and reactive interventions have been considered to address the problems as categorised below:

Overhauls

4.5.2 Overhaul interventions are primarily driven by consumed hours. Forecast running hours for each unit are compared against overhaul schedules set by OEMs and in line with other operators as shown in Appendix 1: Gas Generator overhaul schedule (hours) and Appendix 2: Power Turbine overhaul schedule (hours). Overhaul frequency also takes into consideration number of cycles (start/stops) and time elapsed for components which degrade with time rather than use.

Known Issues and Defects

4.5.3 For issues and defects which are known, specific interventions have been developed. For example, continuing with the programme which commenced in RIIO-T2 to install fuel gas conditioning skids on all [redacted] units expected to stay past 2030 shall address problems associated with improper fuel gas temperature. Certain interventions have been developed in collaboration with industry partners, including OEMs, such as the implementation of recommendations and crucial service bulletins. Other interventions are based on experience across the fleet, e.g., power cable integrity testing has been considered following lessons learnt from cable failures experienced at the St Fergus gas terminal.

Forecasted Issues

4.5.4 It is inevitable for issues to arise across the fleet of complex, ageing CMT assets during RIIO-GT3. Therefore, provision for breakdowns is essential to ensure ongoing compressor availability. Aligned to the approach taken throughout RIIO-T2, the compressor breakdown budget intervention will enable swift rectification of major breakdowns to restore critical capability. Specifically, this will be used where inspection/monitoring of the asset indicates that the condition has deteriorated to a point where it can no longer be used without repair or refurbishment.

4.5.5 The full list of interventions considered against the above categories are included in Table 12.

Intervention Summary

Table 12: Gas Driven CMT interventions technical summary

Category	Intervention	Benefit (years)	Scope	Positives	Negatives	Taken Forward
N/A	Counterfactual (Do Nothing)	N/A	Continuing with routine maintenance activities to meet statutory obligations and enhanced maintenance.	Least cost option.	Adversely impacts availability. Not in line with OEM guidance. Does not address issues.	No
	Rotation Programme		Swapping assets between compatible compressor trains to balance run hours and prolong intervals between overhauls.	Phased approach to overhauls. Proactive fleet management	More outages potentially. Benefit not as great as overhaul. Only possible for compatible CMTs. Requires suitable spares. Potential to backload all overhaul costs.	No
Overhaul	Compressor Overhauls [redacted]	25	Overhaul [redacted] generator based on manufacturer recommendations and consistent with programmes applied by other European gas transmission operators.	Can be aligned to unit outage plan. Provides age and reliability benefit. Meets OEM guidance and in line with other European gas transmission operators. Maintains operational capability by complying with policy, without which units may not be allowed to run as part of wider process safety obligations.	Cost. Outage required. Significant works to remove GG from service, transport and recommission.	Yes
	Compressor Overhauls [redacted]	25	Overhaul [redacted] generator based on manufacturer recommendations and consistent with programmes applied by other European gas transmission operators.		Cost. Outage required. Significant works to remove GG from service, transport and recommission.	Yes
	Compressor Overhauls [redacted]	25	Overhaul [redacted] turbine based on manufacturer recommendations and consistent with programmes applied by other European gas transmission operators.		Capex required. Outage required.	Yes

Category	Intervention	Benefit (years)	Scope	Positives	Negatives	Taken Forward
	Compressor Overhauls [redacted]	25	Overhaul power turbine based on manufacturer recommendations and consistent with programmes applied by other European gas transmission operators.	As above	Capex required. Outage required.	Yes
	Compressor Overhauls [redacted]	25	Overhaul [redacted] generator based on manufacturer recommendations and consistent with programmes applied by other European gas transmission operators.		Capex required. Outage required. Significant works to remove GG from service, transport and recommission.	Yes
	Compressor Overhauls [redacted]	25	Overhaul power turbine based on manufacturer recommendations and consistent with programmes applied by other European gas transmission operators		Capex required. Outage required.	Yes
	GG/PT/Compressor Oil System Major Refurb	10	Refurbish oil system installed on Gas Generators and Power Turbines in line with RAM model. Includes replacing smaller components, flushing, and overhauling pumps.	Meets RAM model outputs to ensure unit is sufficiently reliable, available, and maintainable in line with fleet requirements.	Capex required. Outage required.	Yes
	[redacted] Compressor Overhaul Including New Stator	0	Overhaul motor including replacement stator.	Proactive and cost-effective approach in line with OEM guidance. Maintains operational capability by complying with policy, without which units may not be allowed to run as part of wider process safety obligations.	Capex required, requires unit outage.	Yes
	Electric Drives - HV Stator Motor Rewind	20	Overhaul motor reusing existing stators.		Capex required, requires unit outage.	Yes
	Electric Drives - Frequency Converter - Major Refurb	40	Refurbish frequency converter to restore asset life.		Capex investment required.	Yes
	Electric Drives - HV Motor Overhaul	10	Overhaul motor in accordance with OEM guidance.		Capex required, requires unit outage.	Yes
	Compressor Breakdown Budget	N/A	Breakdown Budget for rectifying arising issues on highly complex, aging assets. Used for repairs in cases where minor issues arise, but a full overhaul would be excessive.	Enables swift rectification of issues to restore availability and mitigate against network constraints.	Capex required.	Yes
Forecasted Issue	Upgrade gas powered starter motors to electric	25	Replacing gas-powered starters with electric starters to address starting trips at [redacted]	Improves starting reliability to increase availability as detailed in Figure 4 enabling a suitably capable, agile, and resilient NTS by removing constraints. Electric starters reduce emissions compared to gas.	Capex required. Outage required.	Yes
Known Issue/Defect Resolution	Upgrade Fuel Metering Valves (FMVs) to [redacted]	N/A	Replacing FMVs to address issues with current outdated FMVs which have limited torque and are proven to be vulnerable to the gas fuel supply, resulting in unexpected shutdowns.	Addresses known issue to restore full capability, improve functionality, maintainability, and reliability whilst meeting the required Safety Integrity Level.	Capex required. Outage required.	Yes
	Inlet strainers removal	N/A	Strainers require removal once the CMT has been commissioned and been operational in line with policy. In some cases, strainers are still installed on the suction streams which pose an asset health risk.	In line with policy and risk reduction.	Capex required. Outage required.	Yes

Category	Intervention	Benefit (years)	Scope	Positives	Negatives	Taken Forward
	Install fuel gas conditioning skids	40	Continue programme to install fuel gas conditioning skids on all [redacted] units expected to stay past 2030. All the installed low emission gas generators already have enhanced fuel gas conditioning skids installed.	Performance and safety benefit. Continuation of RIIO-T2 strategy. Reduces trips aligned to Figure 4.	Capex required. Outage required.	Yes
	Replace Inconel Bolts for Exhaust to transition piece	15	Proactively replacing bolts with an improved type to prevent repeated failure experienced across fleet. If not replaced, they will likely fail unexpectedly with potential for exhaust gas to leak into enclosure.	Based on lessons learnt from previous failures. In accordance with OEM recommendations.	Capex required. Outage required.	Yes
	Implement Slow Roll System and install staging valve monitoring	N/A	Implementing 'slow roll' solution involving updating the legacy software installed during the original delivery in 1998 and installing alternative starter motors will mitigate known issue on [redacted] assets which causes CMT to lockout following a hot trip. The lockout lasts 4 hours, during which time the CMT cannot provide compression to the NTS. Further monitoring of [redacted] staging valves will predict failures so they can be planned for.	Solution to a known issue which affects asset availability and operational constraints, compounded by the trips detailed in Figure 4. In accordance with OEM recommendations.	Capex required. Outage required.	Yes
	Replace flexible hose assemblies	20	Flexible high-pressure hoses are prone to deterioration leading to leaks and splits with consequential safety and environmental risks. Replacing defective hoses ensures they are available to perform their duty.	Ensures integrity of assets to mitigate safety, reliability, and environmental risks.	Capex required. Outage required.	Yes
	Update HMI with HP Recoup Calculations	N/A	Updating the HMI in line with performance tests will prevent trips and faults associated with uncalibrated processes.	Solution to a known issue in accordance with OEM recommendations.	Capex required. Outage required.	Yes
	Rectify Combustion and Air Inlet Drains	N/A	Remediating the failed drains on both units at Felindre will prevent build-up, contamination, and trips.	Solution to a known issue in accordance with OEM recommendations, without which continued trips would occur with resultant impact to compression availability.	Capex required	Yes
	Catalytic Converter Replacement	15	Catalytic converter installed at [redacted] has design life of 5-10 years. Current one is 8 years old and will require replacement during RIIO-GT3.	Solution to a known issue [redacted] in accordance with OEM recommendations to prevent network constraints arising from unavailability. Aligns with required compressor refurbishment.	Capex required	Yes
	Install lube oil conditioning skids	N/A	Installing lube oil conditioning skids on specific CMTs will enable us to proactively assure the quality of the synthetic oil by removing acids and particulate matter. This ensures optimal lubrication of the bearings to maintain life by preventing contaminated oil from encountering bearings.	Ensures asset life is maximised to reduce risk of lengthy outages and costly interventions.	Capex required. Outage required.	Yes
	Replace [redacted] Fuel Gas Valves	20	Replacing the obsolete fuel gas valves installed on the Pressure Reduction Areas at [redacted] Compressor Stations will prevent lengthy unplanned outages leading to reduced compressor availability.	Addresses known obsolescence issue.	Capex required. Outage required.	Yes

Category	Intervention	Benefit (years)	Scope	Positives	Negatives	Taken Forward
	Implement automatic stroking on Fuel Metering Valves	N/A	Implementing automatic stroking on the FMVs on the [redacted] will mitigate issues associated with sticky valves and unexpected shutdowns.	Solution to a known issue in accordance with OEM recommendations.	Capex required. Outage required.	Yes
	Replace Ignitor Box	25	Replacing current ignitor boxes which contain radioactive Krypton will reduce risk and increase availability required as part of the CMT ignition process.	Solution to a known challenge in accordance with OEM recommendations.	Capex required. Outage required.	Yes
	Modify Lube Oil Drain Skid	N/A	Modifying lube oil skid drains with tell-tales will enable easier fault finding as the current drains are combined which prevents leaks from being traced.	Solution to a known issue in accordance with OEM recommendations.	Capex required. Outage required.	Yes
	Install BAM 2.0	N/A	Burner Acoustic Monitor (BAM) installation will enable automatic detection of unhealthy running conditions on the [redacted] fleet to prevent engine damage, therefore mitigating asset health risks.	Solution to a known issue in accordance with OEM recommendations.	Capex required. Outage required.	Yes
	Exhaust Muffler Replacement	N/A	Fitting exhaust bleed mufflers will prevent high velocity bleed air blowing through the flexible exhaust duct, thereby prolonging the life of the exhaust bellows.	Ensures asset life is maximised to reduce risk of outages and costly interventions.	Capex required. Outage required.	Yes
	Replace Exhaust Lagging	20	Lagging on the compressor exhausts ensures the heat emitted does not increase the ambient temperature of the compressor cab which could cause damage to instrumentation. The lagging at Aberdeen is inadequate and requires replacement.	Solution to a known issue in accordance with OEM recommendations. Will mitigate against further damage arising and meet safety requirements.	Capex required. Outage required.	Yes
	Replace PT bearing sump chip detector	10	Replacing faulty PT bearing sump chip detectors with longer ones will ensure bearing failures are detected.	Solution to a known issue in accordance with OEM recommendations aligned to proactive monitoring of assets to prevent consequential unplanned outages.	Capex required. Outage required.	Yes
	Replace Frame mounted Accelerometer	15	Replacing existing accelerometers with suitably certified ones will address the issue with the current ones not meeting EX certification.	Ensures operational assets meet required certification to ensure safety of people, plant and equipment as required by HSE and wider process safety stipulations aligned to policy.	Capex required. Outage required.	Yes
	Implement Anti-Choke System	N/A	Installing software to prevent unit ramping to full speed whilst compressor in choke will mitigate compressor damage associated with operating in choke.	Proactive intervention to mitigate safety, financial, availability and environmental risks.	Capex required. Outage required.	Yes
	Rectify HMI and Communications issues on [redacted]	N/A	Implementing a fix to the Human-Machine Interface (HMI) at [redacted] to ensure communications are maintained between unit and GNCC even when local HMI fails.	Solution to a known issue in accordance with OEM recommendations, without which would result in suboptimal operation with wider NTS implications.	Capex required. Outage required.	Yes
	Enhanced Emissions Control	N/A	Installing enhanced controls to improve turndown to increase compressor operating window.	Compressor efficiency improvements. Solution to a known issue in accordance with OEM recommendations.	Capex required. Outage required.	Yes
	[redacted] Thrust Unloader Survey	N/A	An engineering survey and design scheme shall determine suitable action to rectify the issue which occurs when the thrust unloader operation causes lube oil collected in the vent pipe to be vented out to atmosphere.	Solution to a known issue in accordance with OEM recommendations. Will establish way forward to mitigate environmental and safety risks.	Capex required. Does not directly resolve issue.	Yes
	Purchase and Installation of [redacted] Motor	N/A	Purchase and installation of [redacted] Compressor Station to facilitate overhauls. Without	Increases unit availability and reliability in line with fleet strategy.	Capex required	Yes

Category	Intervention	Benefit (years)	Scope	Positives	Negatives	Taken Forward
			[redacted] 1 in 20 license obligation cannot be met. See Appendix 7: [redacted] Compressor Station.			
	Cooling System Replacement	50	Replace cooling system to rectify overheating issues having confirmed that refurbishment was unable to address problem.	Solution to a known issue in accordance with OEM recommendations.	Capex required	Yes
	Verification and Re-validation of HV Motor EX'p' pressurisation System	40	Ex 'p' protection concept forms a layer of protection incorporated into the motor design to reduce the risk of causing harm and damage by fire and/or explosion as detailed on the motor ATEX EC type examination certificates. An inspection of the EX 'p' protection system required to ensure compliance with Dangerous Substances and Explosive Atmospheres Regulations (DSEAR) and associated standards such as BS EN 600079-14 and BS EN 60079-17.	Ensures system maintains compliance with ATEX certification requirements as part of DSEAR and industry standards to enable it to continue to operate and provide compression to the NTS.	N/A	Yes
	Harmonic Filter - Minor Refurb	30	Replace obsolete consumable parts and individual components within the Harmonic filter.	Solution to a known obsolescence issue in accordance with OEM recommendations.	Capex required	Yes
	Power Cables Remediation and Earthing	30	Remediate cables and earthing issues as detailed in Appendix 4: [redacted] VSD HV Power cable damage report.	Solution to a known issue in accordance with recommendations.	Capex required	Yes
	Motorhood Gasket Replacement	50	Replace gasket to ensure correct sealing.	Solution to a known issue in accordance with OEM recommendations.	Capex required, requires unit outage	Yes
	Cooling Systems Survey	N/A	Survey all VSD units to assess cooling system requirements aligned to issues elsewhere on the network.	Proactive option to assess condition and establish solutions.	Does not directly address extant tripping problems	Yes
	Cables Testing	N/A	Testing cables to ensure safety, integrity, and reliability.	Proactive option to assess condition and establish solutions to mitigate safety risks.	Capex required	Yes
	Mopico Motor Compressors Remote Condition Monitoring	30	Install remote condition monitoring to enable early detection of impending defects and condition-based maintenance.	Proactive approach to reduce downtime and deliver value for money.	Capex required	Yes

Volume Derivation

4.5.6 Overhaul volumes have primarily been derived based on scheduled repeatable interventions required in line with defined time periods and/or forecast fleet running hours aligned to the Compressor Fleet EJPs[54,55,56,57]. Only those due within the RIIO-GT3 period are included within this funding request. Volumes to address known faults and defects are based on extant issues, defects, condition reports and ALERT trip data. For future unplanned defect remediation, the volume of interventions is based on the run rate experienced during RIIO-T2, equivalent to an extra overhaul per year. Intervention volumes identified from the RAM model are also included (e.g., Compressor Oil System Major Refurbishments). More information on the RAM model can be found in the Compressor Fleet EJPs[58596061].

[54] NGT_EJP13_Compressor Fleet – Network Investments and Zone 1 (Scotland)_RIIO-GT3
[55] NGT_EJP14_Compressor Fleet - Zones 2 and 3 (Central)_RIIO-GT3
[56] NGT_EJP15_Compressor Fleet - Zones 4 and 5 (South Wales and South West)_RIIO-GT3
[57] NGT_EJP16_Compressor Fleet - Zones 6 and 7 (East Midlands and South East)_RIIO-GT3
[58] NGT_EJP13_Compressor Fleet – Network Investments and Zone 1 (Scotland)_RIIO-GT3
[59] NGT_EJP14_Compressor Fleet - Zones 2 and 3 (Central)_RIIO-GT3
[60] NGT_EJP15_Compressor Fleet - Zones 4 and 5 (South Wales and South West)_RIIO-GT3
[61] NGT_EJP16_Compressor Fleet - Zones 6 and 7 (East Midlands and South East)_RIIO-GT3

4.5.7 Table 13 summarises how the bottom-up intervention volumes have been developed.

Table 13: Development of bottom-up volumes for RIIO-GT3

Intervention	Volume	Unit of Measure	How this volume has been developed
Compressor Breakdown Budget	[redacted]	Per Year	Volume to cover RIIO-GT3 period aligned to RIIO-T2 run rate.
Compressor [redacted]	[redacted]	Per Asset	Consumed hours is the principal method used to determine overhaul requirement within the overhaul planning tool which is managed by [redacted]. Volumes based on forecast running hours.
Upgrade gas powered starter motors to electric	[redacted]	Per Asset	Rectifying issues on specific units at [redacted].
Compressor Overhauls ([redacted]	[redacted]	Per Asset	Consumed hours is the principal method used to determine overhaul requirement within the overhaul planning tool which is managed by [redacted] Volumes based on forecast running hours.
Compressor Overhauls ([redacted]	[redacted]	Per Asset	Consumed hours is the principal method used to determine overhaul requirement within the overhaul planning tool which is managed by [redacted] Volumes based on forecast running hours.
Upgrade fuel metering valves to [redacted]	[redacted]	Per Asset	Addresses known issues on specific Fuel Metering Valves.
Inlet Strainers Removal	[redacted]	Per Asset	Based on known locations with strainers that have not yet been removed that should be removed.
Install fuel gas conditioning skids	[redacted]	Per Asset	Continuation of existing programme to install skids on all [redacted] units expected to stay past 2030.
GG/PT/Compressor Oil System Major Refurb	[redacted]	Per Compressor Unit	Volumes derived from the output of the RAM model.
Compressor Overhauls ([redacted]	[redacted]	Per Asset	Consumed hours is the principal method used to determine overhaul requirement within the overhaul planning tool which is managed by [redacted]. Volumes based on forecast running hours.
Compressor Overhauls ([redacted]	[redacted]	Per Asset	Consumed hours is the principal method used to determine overhaul requirement within the overhaul planning tool which is managed by [redacted]. Volumes based on forecast running hours.
Compressor Overhauls [redacted]	[redacted]	Per Asset	Consumed hours is the principal method used to determine overhaul requirement within the overhaul planning tool which is managed by [redacted] Volumes based on forecast running hours. This was due in RIIO-T2; however it shall be conducted once the Safe Working Load (SWL) of the crane has been upgraded to lift the PT as detailed in the Cab Infrastructure EJP[62].
Replace Inconel Bolts for Exhaust to transition piece	[redacted]	Per Compressor Unit	Specific to certain units with known issue.
Implement Slow Roll System and install staging valve monitoring	[redacted]	Per Compressor Unit	Specific to certain [redacted] assets with 'hot trip' issues.
Replace flexible hose assemblies	[redacted]	Per Compressor Unit	Known defects on specific assets.
Update HMI with HP Recoup Calculations	[redacted]	Per Compressor Unit	Specific assets with incorrect HP calcs identified.
Rectify Combustion and Air Inlet Drains	[redacted]	Per Compressor Unit	Known defect on specific asset.
Catalytic Converter Replacement	[redacted]	Per Asset	Known defect on specific asset.
Install lube oil conditioning skids	[redacted]	Per Asset	Known defect on specific asset.
Replace [redacted] Gas Valves	[redacted]	Per Compressor Unit	Specific to certain units with known issue.
Implement automatic stroking on Fuel Metering Valves	[redacted]	Per Compressor Unit	Specific to certain units with known issue.
Replace Ignitor Box	[redacted]	Per Compressor Unit	Specific to certain units with known issue.
Modify Lube Oil Drain Skid	[redacted]	Per Compressor Unit	Specific to certain units with known issue.
Install BAM 2.0	[redacted]	Per Asset	Specific to certain units with known issue.
Exhaust Muffler Replacement	[redacted]	Per Asset	Specific to certain units with known issue.
Replace Exhaust Lagging	[redacted]	Per Compressor Unit	Specific to certain units with known issue.
Replace PT bearing sump chip detector	[redacted]	Per Compressor Unit	Specific to certain units with known issue.
Replace Frame mounted Accelerometer	[redacted]	Per Compressor Unit	Specific to certain units with known issue.
Implement Anti-Choke System	[redacted]	Per Compressor Unit	Specific to certain unit with known issue.
Rectify HMI and Communications issues on [redacted]	[redacted]	Per Compressor Unit	Specific to certain unit with known issue.
Enhanced Emissions Control	[redacted]	Per Compressor Unit	Specific to certain units with known issue.
[redacted] Thrust Unloader Survey	[redacted]	Per Asset	Specific to certain unit with known issue.
[redacted] Compressor Overhaul Including New Stator	[redacted]	Per Compressor Unit	Time based in accordance with Management Procedure T/PM/MAINT/11.

[62] NGT_EJP03_Cabs_RIIO-GT3

Intervention	Volume	Unit of Measure	How this volume has been developed
HV Stator Motor Rewind	[redacted]	Per Asset	Known defect on [redacted] during ELCID (Electromagnetic Core Imperfection Detection) test. See Appendix 3: Felindre A Decision Paper .
Purchase & Installation of [redacted]	[redacted]	Per Compressor Unit	Continuation of RIIO-T2 strategy at [redacted] Compressor Station – see Appendix 7 [redacted] Compressor Station
Frequency Converter – Major Refurb	[redacted]	Per Asset	Units [redacted] were the only units not done during RIIO-T2.
Cooling System Replacement	[redacted]	Per Asset	Address known issues to address motor temperature trips.
Verification and Re-validation of HV Motor EX'p' pressurisation System	[redacted]	Per Asset	Required to verify that compliance to the ATEX certificate is maintained. Due on all units apart from those completed in RIIO-T2. See Appendix 5: [redacted] LDA inspection quality report (77PO-10883).
Harmonic Filter - Minor Refurb	[redacted]	Per Asset	5 Units in scope.
Power Cables Remediation and Earthing	[redacted]	Per Asset	Remediation of known faults following integrity testing completed at specific stations.
Motorhood Gasket Replacement	[redacted]	Per Asset	Time based replacement due on two units.
HV Motor Overhaul	[redacted]	Per Asset	Overhaul based on running hours/time interval schedules set by OEM.
Cooling Systems Survey	[redacted]	Per Asset	All sites not already surveyed.
Cables Testing	[redacted]	Per Asset	Required on all units apart from those completed in RIIO-T2.
[redacted] Compressors Remote Condition Monitoring	[redacted]	Per Site	Applicable to [redacted] motors only.

Unit Cost Derivation

4.5.8 Unit costs for the above interventions have been developed using a mix of Estimated Cost at Completion (ECC) data from similar projects and first principal estimations which have been derived using known rates associated for the above scopes of work and caveated supplier quotes (e.g., with assumptions, valid for limited timeframe etc.). A summary is provided in Table 14 with a further breakdown in Appendix 8: Cost Breakdown.

Table 14: Intervention unit cost summary (£m, 2023/24)

Intervention	Unit of Measure	Unit Cost (£m)	Cost Accuracy	No of Data Points	Source Data
Compressor Breakdown Budget	Per Year	[redacted]	+/- 10%	1	Estimated Cost at Completion
Purchase & Installation of Lockerley [redacted]	Per Compressor Unit	[redacted]	+/- 10%	0	First principles
Compressor Overhauls [redacted]	Per Asset	[redacted]	+/- 10%	4	Estimated Cost at Completion
Compressor Overhauls [redacted]	Per Asset	[redacted]	+/- 30%	1	Estimated Cost at Completion
[redacted] Motor Compressor Overhaul Including New Stator	Per Compressor Unit	[redacted]	+/- 10%	0	First principles
Compressor Overhauls [redacted]	Per Asset	[redacted]	+/- 50%	1	Estimated Cost at Completion
Compressor Overhauls [redacted]	Per Asset	[redacted]	+/- 30%	2	Estimated Cost at Completion
Upgrade gas powered starter motors to electric	Per Asset	[redacted]	+/- 10%	0	First principles
HV Stator Motor Rewind	Per Asset	[redacted]	+/- 30%	0	First principles
Compressor Overhauls [redacted]	Per Asset	[redacted]	+/- 30%	2	Estimated Cost at Completion
Compressor Overhauls [redacted]	Per Asset	[redacted]	+/- 10%	3	Estimated Cost at Completion
Rectify Combustion and Air Inlet Drains	Per Compressor Unit	[redacted]	+/- 10%	0	First principles
Frequency Converter - Major Refurb	Per Asset	[redacted]	+/- 50%	0	First principles
Catalytic Converter Replacement	Per Asset	[redacted]	+/- 10%	0	First principles
Cooling System Replacement	Per Asset	[redacted]	+/- 50%	0	First principles
Implement Slow Roll System and install staging valve monitoring	Per Compressor Unit	[redacted]	+/- 10%	0	First principles
Upgrade fuel metering valves to [redacted]	Per Asset	[redacted]	+/- 10%	0	First principles
Install fuel gas conditioning skids	Per Asset	[redacted]	+/- 50%	0	First principles
Replace Inconel Bolts for Exhaust to transition piece	Per Compressor Unit	[redacted]	+/- 10%	0	First principles
GG/PT/Compressor Oil System Major Refurb	Per Compressor Unit	[redacted]	+/- 50%	0	First principles
Replace flexible hose assemblies	Per Compressor Unit	[redacted]	+/- 10%	0	First principles
Implement Anti-Choke System	Per Compressor Unit	[redacted]	+/- 10%	0	First principles
Replace [redacted] Fuel Gas Valves	Per Compressor Unit	[redacted]	+/- 10%	0	First principles
Verification and Re-validation of HV Motor EX'p' pressurisation System	Per Asset	[redacted]	+/- 10%	0	First principles

Intervention	Unit of Measure	Unit Cost (£m)	Cost Accuracy	No of Data Points	Source Data
Power Cables Remediation and Earthing	Per Asset	[redacted]	+/- 10%	0	First principles
HV Motor Overhaul	Per Asset		+/- 10%	0	First principles
Replace Exhaust Lagging	Per Compressor Unit		+/- 10%	0	First principles
Inlet Strainer Removal	Per Asset		+/- 10%	0	First principles
Motorhood Gasket Replacement	Per Asset		+/- 10%	0	First principles
Modify Lube Oil Drain Skid	Per Compressor Unit		+/- 10%	0	First principles
Install BAM 2.0	Per Asset		+/- 10%	0	First principles
Rectify HMI and Communications issues on [redacted]	Per Compressor Unit		+/- 10%	0	First principles
Implement automatic stroking on Fuel Metering Valves	Per Compressor Unit		+/- 10%	0	First principles
Harmonic Filter - Minor Refurb	Per Asset		+/- 10%	0	First principles
Update HMI with HP Recoup Calculations	Per Compressor Unit		+/- 10%	0	First principles
Install lube oil conditioning skids	Per Asset		+/- 10%	0	First principles
Enhanced Emissions Control	Per Compressor Unit		+/- 10%	0	First principles
Replace Ignitor Box	Per Compressor Unit		+/- 10%	0	First principles
Replace Frame mounted Accelerometer	Per Compressor Unit		+/- 10%	0	First principles
Exhaust Muffler Replacement	Per Asset		+/- 10%	0	First principles
Replace PT bearing sump chip detector	Per Compressor Unit		+/- 10%	0	First principles
Cooling Systems Survey	Per Asset		+/- 30%	0	First principles
Cables Testing	Per Asset		+/- 10%	0	First principles
[redacted] Compressors Remote Condition Monitoring	Per Site		+/- 50%	0	First principles
[redacted] Unloader	Per Asset		+/- 10%	0	First principles

4.5.9 Cost accuracies are determined based on types and availability of data including quantities (i.e., the number of data points) and the similarity of the scope of work performed versus the RIIO-GT3 investment programme.

4.5.10 Interventions Table 14 with less accuracy (i.e., +/-30% and +/-50%) are predominantly due to variances previously experienced in costs, for example an overhaul may require more or less work once the asset has been stripped down and inspected. Additionally, immature scopes due to needing more detailed design work have been assessed as less accurate forecasts. This is also the case for interventions where suppliers were unable to provide accurate estimates due to fluctuations in markets and the protracted procurement time from initial rough order of magnitude cost to future design, fabrication, delivery, installation, and commissioning as applicable.

4.5.11 A specific example for how unit costs have derived can be explained using the cost for "Compressor Overhauls [redacted] - [redacted] which has been produced using two data points across two compressor units. In this example, although costs at [redacted] and [redacted] were higher in comparison to other sites, the approach of using the OEM supplier to undertake the overhaul activity provided a higher standard of service in comparison to lower cost alternatives. This included superior guarantees and a report on all components (including life expectancy). It was, therefore, decided to utilise these data points as they reflect the preferred overhaul strategy moving forwards.

4.5.12 Furthermore, the unit cost for "Compressor Overhauls [redacted] has been derived using three data points across three compressor units. In this example, unit costs ranged from £[redacted] to over £[redacted] In the upper range, it was established that spare parts had been purchased/manufactured as part of the works and, in some cases, kept as strategic spares. It was agreed with business that this scenario is likely to occur in the future and, therefore, an average cost across the three data points (including where the spares had been purchased) was appropriate to be used.

5 Centrifugal Compressors - £15m (2023/24)

5.1 Introduction

5.1.1 This section covers centrifugal compressors which use the rotary drive from gas driven power turbine or electric drive to raise the pressure of the gas to flow it through the NTS. The scope includes the compressor, its supporting structure, coupling to power turbine/electric drive, seals, lubrication oil and oil/nitrogen seal supply systems. An equipment summary is below with additional information such as health score at the beginning and end of the price control and monetised risk provided in the accompanying NGT_IDP14_Portfolio EJP Rotating Machinery_RIIO-GT3.

5.2 Equipment Summary

5.2.1 Compressors installed on the NTS are either of single stage or multistage centrifugal type which are directly coupled to a power turbine or an electric motor. The machinery has been designed so that the power turbine operating speed range and required compressor speed range match, which removes the need for gearboxes.

5.2.2 The rotating element of a centrifugal compressor rotates at between 5,000 and 10,000 rpm to deliver high flow capacity.

5.2.3 There is one compressor per operational compressor train. Appendix 6: Installed Compressor Units, shows the operational compressors by location and the various types and manufacturers (OEMs).

5.2.4 The coupling between the drive and compressor transmits the rotating power to the compressor impeller. Bearings within the compressor carry the load of the rotating elements. These moving parts are served by lubrication systems which supply oil to the power turbine bearings, gas compressor bearings and seals.

5.2.5 Seals prevent the escape of high-pressure gas around the rotating shaft of the compressor where it passes through the compressor casing. Seal technologies in use include dry gas seals and wet gas seals depending on the type of compressor drive.

5.2.6 Dry gas seals (DGS) utilise filtered high pressure gas from the compressor discharge to feed the DGS. There is also a separation seal which uses nitrogen to ensure oil from the bearings cannot contaminate the DGS.

5.2.7 Wet gas seals are an older technology and use oil as the medium within the seal and require an oil system. There is typically one nitrogen/air or one oil system for each compressor. Replacing wet seals with alternative options to reduce emissions is considered in the Network Decarbonisation EJP[63].

5.3 Problem Statement

Why are we doing this work and what happens if we do nothing?

5.3.1 Centrifugal compressors are fundamental assets of CMTs. The components in this group are integral to operations and must be managed to achieve the required reliability, availability, and maintainability of our compressor fleet.

Table 15: Centrifugal compressor problem statement

Driver Category	Description
Asset Deterioration	Compressors are subject to degradation with use and are severely affected by changes in gas conditions. Wear components such as bearings will always need to be replaced as part of their inevitable asset lifecycle, however this can be influenced by optimal lubrication. Similarly, components such as couplings wear with duty and must be managed to ensure continued functionality and integrity. Seals are subject to deterioration, particularly through repeated pressurisation and depressurisation and during suboptimal conditions.
Reliability and Availability	Unit availability is dependent on all parts of CMTs working together which requires the compressor to be functional. The Reliability Availability Maintainability (RAM) model detailed in the Compressor Fleet EJPs[64,65,66,67] considers the necessary Asset Health interventions aligned to network capability requirements.

What is the outcome that we want to achieve?

5.3.2 The primary outcome sought to be achieved is enabling availability of compression assets across the NTS as required to meet forecasted and actual demand including resilience allowances.

How will we understand if the spend has been successful?

[63] NGT_EJP21_Network Decarbonisation_RIIO-GT3
[64] NGT_EJP13_Compressor Fleet – Network Investments and Zone 1 (Scotland)_RIIO-GT3
[65] NGT_EJP14_Compressor Fleet - Zones 2 and 3 (Central)_RIIO-GT3
[66] NGT_EJP15_Compressor Fleet - Zones 4 and 5 (South Wales and South West)_RIIO-GT3
[67] NGT_EJP16_Compressor Fleet - Zones 6 and 7 (East Midlands and South East)_RIIO-GT3

5.3.3 Success shall be measured by CMT, including centrifugal compressor, availability within all constraints. Additionally, ALERT trip data, fleet issues and defects will be measurable metrics against the RAM model for this spend.

Narrative Real Life Example of Problem

5.3.4 Compressor impeller failure occurred on both [redacted] units around the same time due to operating in choke for sustained periods. The compressor was a [redacted] with 20 years of operation and 19,000 hours completed when the vanes cracked.

5.3.5 The significant damage shown in Figure 5 required a new impeller to be installed which was subject to a long lead time of over 12 months impacting compressor availability. The work required the supporting manufacturer (Siemens) designing and fabricating a new impeller involving machining to the compressor bundle in Germany. It was essential that the impeller was suitably matched to the operating conditions of the CMT to ensure compatibility and full capability.

Compressor vane in discharge section. View from inside Compressor looking into discharge pipe.

Impeller failure

Figure 5: Cracked compressor vane and failed impeller.

5.3.6 A very similar occurrence happened on [redacted] in 2017 following suboptimal running conditions associated with NTS demands which also had a significant impact to availability to remediate the issue. The outage lasted from November 2017 to February 2019 due to needing to diagnose the fault and the long lead time to manufacture the new impeller before returning the unit to service.

Project Boundaries

5.3.7 The boundaries of spend are limited to centrifugal compressors. In some situations, shared lubrication systems and nitrogen systems may be required to be intervened on which may not directly impact the centrifugal compressor.

5.3.8 The same elements are out of scope as the previous chapter, including St. Fergus. Re-wheeling compressors to change the envelope for capability enhancements are in the Compressor Fleet EJPs[68,69,70,71].

5.4 Probability of Failure

Failure Modes

5.4.1 Probability of failure (PoF) has been assessed utilising historical defects, results from surveys and utilising our Network Asset Risk Metric (NARMs) model. This model is built within our copperleaf asset management decision support tool to assess the forward-looking probability of failure. This provides a different lens to consider in addition to looking at historically captured defects.

5.4.2 Not all modelled failures will result in real-world asset failure and this forecast is not a prediction of how many defects will be identified.

5.4.3 Likely failure modes for centrifugal compressors with an average proportion of failures of 0.5 or above are provided in Table 16, the full list of failure modes is available in the NARMS methodology.

Table 16: Centrifugal compressor failure Modes

Failure Mode	Average Proportion of Failures

[68] NGT_EJP13_Compressor Fleet – Network Investments and Zone 1 (Scotland)_RIIO-GT3
[69] NGT_EJP14_Compressor Fleet - Zones 2 and 3 (Central)_RIIO-GT3
[70] NGT_EJP15_Compressor Fleet - Zones 4 and 5 (South Wales and South West)_RIIO-GT3
[71] NGT_EJP16_Compressor Fleet - Zones 6 and 7 (East Midlands and South East)_RIIO-GT3

Corrosion no oil leak	0.59
Failure of compressor gas seal	0.59
Oil spill from wet seal	0.56
Corrosion no leak	0.55

When applied to the asset count with an assumption that no investment is made, a forecast of failures across the RIIO-GT3 period is produced, shown in Table 16. The average failure rate represents the proportion of that asset type with an unresolved failure. The forecast failures per year shows the quantity of new failures modelled to occur each year.

Table 17: Centrifugal compressor PoF

Asset Type	No. of Assets	Cumulative Average Failure Rates					Forecast Failures per Year				
		2027	2028	2029	2030	2031	2027	2028	2029	2030	2031
Rotating (A.2.2)-Compressors-Centrifugal	[redacted]	0.81	0.81	0.81	0.81	0.81	0.37	0.26	0.24	0.28	0.27
Utilities (A.2.11)-Nitrogen Supply Equipment-Nitrogen Generator	[redacted]	0.91	0.91	0.91	0.92	0.92	0	0.01	0.01	0.01	0.01

5.4.4 Generally, the probability of failure is relatively stable. However, operating in sub optimal conditions such as operating close to the edge of the envelope increases the probability of failure as shown by the examples which occurred when operating in choke conditions. To ensure probability of failure is managed, compressors are inspected, seals tested for leaks and regular oil sampling is conducted to assess bearing condition where possible.

Historic Defects

5.4.5 Defects are raised through inspection and maintenance activities and captured within the Maximo defect management system. This defect data has been used as part of assessing compressor assets within the RAM model detailed in the Compressor Fleet EJPs[72,73,74,75]. Defects include amber or red oil samples which can indicate worn bearings or couplings, instigating further investigation. Depending on findings, oil change or refurbishment action proceeds.

5.4.6 Previous safety bulletins have also resulted in the need to intervene. Specifically, three [redacted] compressors required overhauling [redacted]

5.4.7 To address defective dry gas seals, seals are replaced. Figure 6 shows the quantity of dry gas seals which have been replaced annually to date.

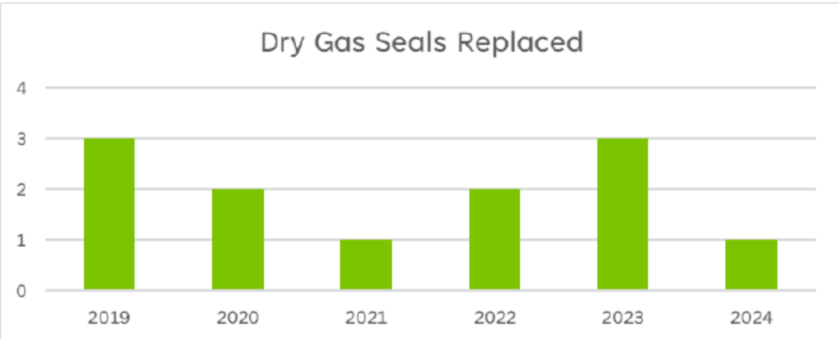


Figure 6: DGS refurbishments per year

Probability of failure Data Assurance

5.4.8 An extract from the defect management system was undertaken on 21st August 2024, with data analysis undertaken based on the columns of data exported from the system including quantities of dry gas seal replaced. Engineering assessment was completed to validate the data, giving high confidence.

5.4.9 The NARMS Probability of Failure data was sourced from a Power BI dashboard, with data supplied from our Copperleaf asset management decision support system.

[72] NGT_EJP13_Compressor Fleet – Network Investments and Zone 1 (Scotland)_RIIO-GT3
[73] NGT_EJP14_Compressor Fleet - Zones 2 and 3 (Central)_RIIO-GT3
[74] NGT_EJP15_Compressor Fleet - Zones 4 and 5 (South Wales and South West)_RIIO-GT3
[75] NGT_EJP16_Compressor Fleet - Zones 6 and 7 (East Midlands and South East)_RIIO-GT3

5.5 Consequence of Failure

5.5.1 The consequence of failure for centrifugal compressors is presented in Table 18 mapped against the NARMS service risk measures.

Table 18: Centrifugal compressor consequence of failure summary

Impact / Consequence			
Environment	**Financial**	**Availability**	**Safety**
Seals which are ineffective will lead to gas leaks.	Without proactive asset management, repairs could be more costly as damage may be more severe.	Failed centrifugal compressors would directly impact CMT availability. Although redundancy is built into the NTS, the RAM model has been used to identify optimal levels of reliability and availability, requiring asset health investment.	Centrifugal compressors operate at high rpms. Any uncontained failure would result in risk to safety of people, plant, and equipment.

5.6 Interventions Considered

5.6.1 Table 19 shows the interventions considered for centrifugal compressor assets. These interventions have been developed based on working knowledge of the assets and OEM input.

Intervention Summary

Table 19: Centrifugal compressor interventions considered

Option	Benefit (years)	Scope	Positives	Negatives	Taken Forward
Counterfactual	N/A	Continue routine maintenance activities to meet statutory obligations and enhanced maintenance.	Least cost	Does not address asset health or meet RAM model requirements. .	No
Replace Compressor	40	Wholesale replacement of Centrifugal Compressor.	Maximum age benefit. May increase compressor functionality.	Not cost beneficial due to high cost. Potential compatibility issues. Outage required. Would not negate need to undertake the other interventions considered.	No
Impeller Major Refurbishment	30	Strip impeller from compressor and recover it to ensure continued optimal running of the unit and component integrity. Depending on the condition and type, compressor impellers can be refurbished or replaced.	Condition based. Prevents further damage from occurring. Opportunity to align with revised operations (e.g., gas flows). Helps to deliver the required reliability, availability and maintainability.	Capital expenditure required, planned outage required.	Yes
Bearing and Coupling Refurbishment	10	Based on proactive monitoring and monthly sampling to inform when more detailed inspections and investigation are required. In most cases, couplings can be rebalanced and recoated with corrosion protection, but may require remanufacturing if damage is found.	In line with RAM model indicates proactive refurbishment to achieve reliability, availability and maintainability requirements.	Capital expenditure required, planned outage required.	Yes
Dry Gas Seal Refurbishment	10	Replace dry gas seals using refurbished assets. Rectifies failures including sticking and inoperative seals and when higher than expected flow out of the seal vents occurs.	In line with RAM model indicates proactive refurbishment to achieve reliability, availability and maintainability requirements.	Capital expenditure required, planned outage required	Yes
Seal Gas Booster	20	Install seal gas booster to extended time that pressurised hold can be used.	Proactive intervention to mitigate against premature seal failures (involving outages, installation costs and use of lifting equipment).	Capital expenditure required.	Yes

Volume Derivation

5.6.2 Volumes are derived from historic run rates to forecast expected refurbishments. Additional, proactive, volumes are included from the output of the RAM model. Generally, where specific assets were both forecast and required by the RAM model, only one volume has been included to avoid duplication. Investments concerning re-wheeling compressors to change the envelope of compressors are covered in the Compressor Fleet EJPs[76,77,78,79] comprising of impeller refurbishments, seal refurbishments and bearing and coupling refurbishments.

Table 20: Development of bottom-up volumes for RIIO-GT3

Intervention	Volume	Unit of Measure	How this volume has been developed
Impeller Major Refurbishment	[redacted]	Per Asset	Using RAM model where improved asset health is required.
Compressor Bearing & Coupling Major Refurb	[redacted]	Per Asset	Using historic run rate plus RAM model where improved asset health is required.
Compressor Dry Gas Seal Major Refurb	[redacted]	Per Asset	Using historic run rate plus RAM model where improved asset health is required.
Install Seal Gas Booster	[redacted]	Per Compressor Unit	Based on feasibility studies and surveys completed at [redacted] to address asset health.

Unit Cost Derivation

5.6.3 Unit costs for the above interventions have been developed using a mix of Estimated Cost at Completion (ECC) data from similar projects and first principal estimations which have been derived using known rates associated for the above scopes of work and caveated supplier quotes (e.g., with assumptions, valid for limited timeframe etc.). A summary is provided in Table 21 with a further breakdown in Appendix 8: Cost Breakdown.

Table 21: Intervention unit cost summary (£m, 2023/24)

Intervention	Unit of Measure	Unit Cost	Cost Accuracy	Number of Data Points	Source Data
Impeller Major Refurbishment	Per Asset	[redacted]	+/- 50%	2	Estimated Cost at Completion
Compressor Bearing & Coupling Major Refurb	Per Asset	[redacted]	+/- 30%	2	Estimated Cost at Completion
Compressor Dry Gas Seal Major Refurb	Per Asset	[redacted]	+/- 10%	4	Estimated Cost at Completion
Install Seal Gas Booster	Per Compressor Unit	[redacted]	+/- 10%	0	First principles

5.6.4 Cost accuracies are determined based on types of cost data available, the quantity of this data (i.e., the number of data points) and the similarity of the scope of historical data points against our RIIO-GT3 investment programme.

5.6.5 Interventions with a +/-50% accuracy include those which have incurred fluctuating costs depending on specific scopes, manufacturers, and suppliers. Some contractors were unable to provide accurate estimates due to fluctuations in markets and availability of specialist vendors and/or components.

[76] NGT_EJP13_Compressor Fleet – Network Investments and Zone 1 (Scotland)_RIIO-GT3
[77] NGT_EJP14_Compressor Fleet - Zones 2 and 3 (Central)_RIIO-GT3
[78] NGT_EJP15_Compressor Fleet - Zones 4 and 5 (South Wales and South West)_RIIO-GT3
[79] NGT_EJP16_Compressor Fleet - Zones 6 and 7 (East Midlands and South East)_RIIO-GT3

6 Vent Systems - £6m (2023/24)

6.1 Equipment Summary

6.1.1 Vent systems allow a controlled, safe, and environmentally effective release of contained high pressure gas to atmosphere from transmission plant at compressor stations and terminals (does not include pipeline venting). They allow localised de-pressurisation to prevent integrity issues, damage to machinery and to facilitate maintenance. Further information such as health score at the beginning and end of the price control and monetised risk is provided in the accompanying NGT_ADP14_Portfolio EJP Rotating Machinery_RIIO-GT3.

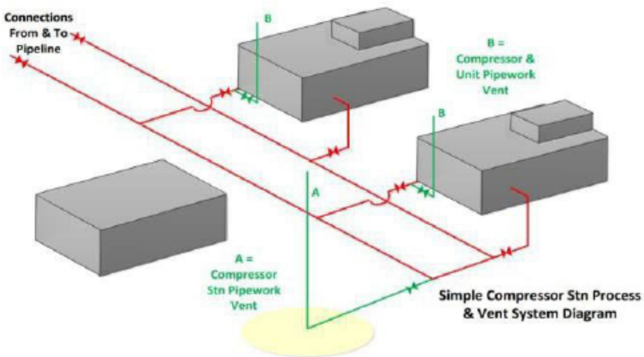
6.1.2 Vent systems have two primary duties:

- An automatic or manually actuated response to a plant safety scenario venting gas inventory to remove the potential of fire or explosion.
- Manual gas evacuation in conjunction with process isolations to facilitate safe access for maintenance or other equipment invasive needs.

6.1.3 Vent systems comprise several elements including: Fixed vent stacks and supporting structures and civils, silencers (where applicable), molecular seals, nitrogen snuffing systems, isolation valves, volume flow control regulators and remote and locally actuated valves.

6.1.4 There is typically one vent stack system for each individual compressor unit and one for the site as shown in Figure 7.

Figure 7 Typical Vent System Configuration



6.2 Problem Statement

Why are we doing this work and what happens if we do nothing?

6.2.1 Vent systems are critical to safe compressor operations and require suitable asset management to address the problems summarised in Table 22.

Table 22: Categories of driver for vent systems

Driver Category	Description
Availability and Reliability	Vent systems form a fundamental part of compressor station safety shut down systems and must be available and fully functional when the compression systems are operating. If the vent system is not functional or fit for purpose, then the facility may be declared non-operational on process safety grounds. This will lead to compressor unit or site unavailability. Similarly, system abnormality which prevents effective inventory evacuation may halt maintenance activity on safety grounds. This impacts the ability to undertake normal or emergency works on other assets further increasing the impact of any failures or extending outage times.
Safety	Compressor station vent stacks have a sterile zone which shows the area where death or serious injury may occur if the plume ignited whilst venting at the emergency rate. All sites require review to ensure that the venting system, including sterile zones, are appropriate for current and future operations in line with network changes (e.g., operating pressures, number/type of compressors installed). Failure to fully evaluate these against the latest regulations and standards could result in sterile zones being unsuitable as part of process safety obligations in line with HSE laws. If zones are compromised when venting takes place, there is a risk of injury or fatality.
Asset Deterioration	Compressor station vent systems are subject to deterioration. For example, vent pipework and associated structural steel work suffer from corrosion due to climate. Lack of investment in the structural elements of the vent stack leads to increased safety risk of structural failure.

What is the outcome we want to achieve?

6.2.2 Safe, reliable, and available vent systems across the NTS as demonstrated by safety records and compression availability statistics.

How will we understand if the spend has been successful?

6.2.3 The spend will have been successful if the defect rate has remained stable and all safety concerns are addressed to fully quantify the risk.

Narrative Real Life Example of Problem

6.2.4 The [redacted] vent stack was identified as having many serious safety risks. A temporary solution was implemented to continue operation [redacted]. It is problematic for reasons including:

- The [redacted] vent design comprises a control valve to regulate flow into the vent. In the event of control valve failure, the design pressure and the lower design temperature of the vent pipework could be exceeded. This could threaten the integrity of the vent (brittle fracture) leading to a Major Accident.
- [redacted]

6.2.5 Some of the inadequacies in the [redacted] vent design are contained within HAZ/19 vent design procedure which requires assessment, especially as [redacted].

6.2.6 The design of all compressor station vents systems should be reviewed and any appropriate modifications to vent stack design implemented in the future. Failure to do this may risk a brittle fracture failure during blowdown which has the potential to cause fatalities.

6.2.7 Replacing the [redacted] vent stack may involve [redacted], or introducing other means to address the problem as determined during more detailed design.

Project Boundaries

6.2.8 The boundaries of the spend proposed by this section are limited to the scopes of the vent system interventions and do not relate to any other parts of the machinery train or compressor station other than the scope of works at Felindre.

6.2.9 The same elements are out of scope as for the previous chapters, including St. Fergus.

6.3 Probability of Failure

Failure Modes

6.3.1 Probability of failure (PoF) has been assessed utilising historical defects, results from surveys and utilising our Network Asset Risk Metric (NARMs) model. Likely failure modes for venting assets are provided in Table 23. The full list of failure modes is available in the NARMS methodology

Table 23: Vent failure modes

Failure Mode	Average Proportion of Failures
Loss of power - gas supply instrument trip	0.53
Corrosion no leak	0.50
Corrosion on pipework - no leak	0.47

6.3.2 When applied to the asset count with an assumption that no investment is made, a forecast of failures across the RIIO-GT3 period is produced, shown in Table 24. The average failure rate represents the proportion of that asset type with an unresolved failure. The forecast failures per year shows the quantity of new failures modelled to occur each year.

Table 24: Forecast vent failures

Asset Type	No. of Assets	Cumulative Average Failure Rates					Forecast Failures per Year				
		2027	2028	2029	2030	2031	2027	2028	2029	2030	2031
Mechanical (A.2.3)-Pipework-Vent	55	0.68	0.69	0.70	0.71	0.71	0.70	0.73	0.45	0.44	0.47

Historic Defects

6.3.3 Defects are raised through inspection and maintenance activities and captured within our Maximo defect management system. Figure 8 shows the analysis of historical defects, with corrosion being the most prevalent defect category. The historic trends of defects on vent valves and snuffing systems indicate the probability of continued defects.

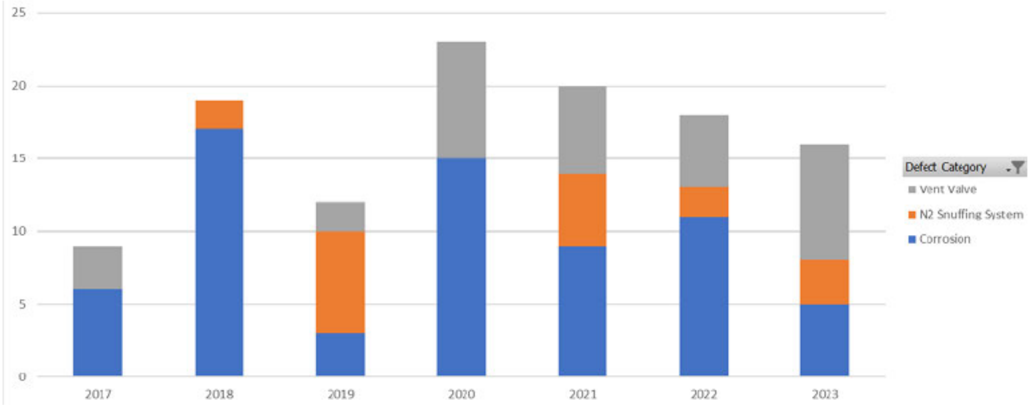


Figure 8: Vent system historic defects

Probability of Failure Data Assurance

6.3.4 An extract from our defect management system was undertaken on 21 July 2024, with data analysis undertaken based on the columns of data exported from the system. The NARMS Probability of Failure data was sourced from a Power BI dashboard, with data supplied from our Copperleaf asset management decision support system.

6.4 Consequence of Failure

6.4.1 The consequence of failure for our vent assets is presented in Table 25 mapped against our NARMS Consequence of Failure service risk measures.

Table 25: Consequence of failure summary

Impact / Consequence			
Environment	**Financial**	**Availability**	**Safety**
Vent system leakage, for example due to lack of investment in the vent valve, could lead to significant volumes of natural gas being discharged to atmosphere with safety and environmental impacts. In cases where silencers are installed, increased noise could result in legal enforcement by environmental regulators. Failure to comply may result in significant fines and prohibition notices (unable to operate legally).	Failure of vent systems presents a risk of non-compliance with legislation including PSR. Consequential HSE action has the potential to lead to uncapped financial impacts.	Vent systems must be reliable and operate as intended. Failure of vent systems may impact compressor unit and station availability with consequences for the wider NTS.	Vent systems are critical to site safety. Failure during use could be catastrophic to people.

6.5 Interventions Considered

6.5.1 Vent System Asset Health interventions include overhauling the modulating vent valve, refurbishing nitrogen snuffing & molecular seal and addressing degraded system pipework.

6.5.2 Interventions considered for specific issues include replacing the vent system at [redacted] to [redacted] and conducting vent system surveys which aim to review all compressor vent stacks across the NTS to determine compliance within design parameters. They shall also [redacted] to determine compliance with policy and identify locations which exceed site boundary and pose a risk to the public. This shall inform what actions need to be taken and the level of risk to determine when further intervention may be required.

Table 26: Vent system interventions technical summary

Option	Investment Design Life	Positives	Negatives	Taken Forward
Counterfactual	N/A	Least cost option.	Reactive only. Does not address problem statement.	No
[redacted] Vent System Replacement	40	Addresses safety, reputational, reliability risks	Cost	Yes
Vent System Surveys	N/A	Proactively quantifies risk for current and future operations in line with changing network operations. Meets safety obligations.	Scope limited to survey (i.e., does not include remediating any findings).	Yes
Modulating Vent Valve Overhaul	30	Maintains integrity of assets. Ensures continued reliability and availability.	Cost	Yes
N2 Snuffing and Molecular Seal Major Refurb	10		Cost	Yes
Vent System Pipework Corrosion / P11 Major Refurb	15		Cost	Yes
Vent System Pipework Minor Refurb	5		Cost	Yes

Volume Derivation

6.5.3 Vent system intervention volumes have been derived based on known issues and historic run rates. Table 27 summarises how the bottom-up intervention volumes have been developed.

Table 27: Development of bottom-up volumes for RIIO-GT3

Intervention	Volume	Unit of Measure	How this volume has been developed
[redacted] Vent System Replacement	[redacted]	Per Site	Known issue following survey at specific site.
Vent System Surveys	[redacted]	Per Site	Known quantity of sites with vent systems.
Modulating Vent Valve Overhaul	[redacted]	Per Asset	RIIO-T2 forecasted run rate.
N2 Snuffing and Molecular Seal Major Refurb	[redacted]	Per Asset	
Vent System Pipework Corrosion / P11 Major Refurb	[redacted]	Per Asset	
Vent System Pipework Minor Refurb	[redacted]	Per Asset	

Unit Cost Derivation

6.5.4 Unit costs for the above interventions have been developed using a mix of Estimated Cost at Completion (ECC) data from similar projects and first principal estimations which have been derived using known rates associated for the above scopes of work and caveated supplier quotes (e.g., with assumptions, valid for limited timeframe etc.) where applicable. A summary is provided in Table 28 with a further breakdown in Appendix 8: Cost Breakdown.

Table 28: Intervention unit cost summary (£m, 2023/24)

Intervention	Unit of Measure	Unit Cost	Cost Accuracy	Number of Data Points	Source Data
[redacted] Vent Stack Replacement	Per Site	[redacted]	+/- 10%	0	[redacted]
Modulating Vent Valve Overhaul	Per Site	[redacted]	+/- 50%	1	[redacted]
Vent System Survey	Per Asset	[redacted]	+/- 50%	0	[redacted]
N2 Snuffing and Molecular Seal Major Refurb	Per Asset	[redacted]	+/- 50%	0	[redacted]
Vent System Pipework Corrosion / P11 Major Refurb	Per Asset	[redacted]	+/- 50%	1	[redacted]
Vent System Pipework Minor Refurb	Per Asset	[redacted]	+/- 50%	1	[redacted]

6.5.5 Our cost accuracies are determined based on the type of cost data available, the quantity of this data (i.e., the number of data points) and the similarity of the scope of these historical data points against our RIIO-GT3 investment programme.

6.5.6 Interventions in our vents with a +/-50% accuracy are either due to them being derived from costs with few data points, or from first principle estimating where more scope definition may be required such as completing detailed design. Additionally, variability in cost is likely to arise owing to the bespoke work required depending on condition and individual circumstances.

6.5.7 A specific example of how we have developed costs for vent system works is the "Vent System Pipework Minor Refurb" intervention. This unit cost has been derived using a single data point from historically delivered works. In this instance, the data point reflected work to cut out and replace a section of 4" vent downstream of [redacted] and valve [redacted]. This has been validated by delivery units as a suitable example for future works.

7 Portfolio Options

7.1 Portfolio Approach

7.1.1 In developing our plans, we focused on value for money and deliverability, while managing the risks of aging assets. We evaluated the cost-effectiveness of our investment program through a full Cost Benefit Analysis (CBA) using the NARMs Methodology within the Copperleaf decision support tool.

7.1.2 We have assessed the benefit from options across the entire rotating machinery portfolio to meet investment drivers, business plan commitments, and consumer priorities. Therefore, a single CBA covers CMT, centrifugal compressors and vent systems.

7.1.3 The options considered combine the interventions discussed previously in varying combinations and volumes to identify the optimal investment for rotating machinery.

7.1.4 In line with HM Treasury Green Book advice and Ofgem guidance, we assessed the value of investing in compressor machinery trains across the RIIO-GT3 period by analysing the cost benefit over a 20-year horizon.

7.1.5 Bottom-up intervention volumes were derived using the engineering assessments described in the previous chapters and aligned to fleet strategy detailed in the Compressor Fleet EJPs[80][81][82][83]. Each investment was assessed via the Ofgem-approved NARMs Methodology embedded in Copperleaf, quantifying risk reduction and Long Term Risk Benefit (LTRB). Analysing this performance, Copperleaf Predictive Analytics selected further NARM driven interventions to create further options to satisfy certain criteria, such as stable risk across the portfolio.

7.1.6 Only interventions assigned to specific assets have been assessed in the CBA, as benefits cannot be applied to interventions that are assigned to various locations (e.g., based on forecast defects). Interventions which have been discounted (i.e., because they do not meet legislative requirements) have also not been modelled.

7.2 Options

7.2.1 Using the Predictive Analytics Optimisation Module (PA) within Copperleaf, our compressor machinery train assets have been optimised against the NARMs Methodology to ensure the portfolio achieves a variety of outcome risk levels, to satisfy stakeholder needs.

7.2.2 All the options described below have been assessed against our Option 0, Counterfactual (Do Nothing) option, which considers no investment over and above maintenance and corrective repairs.

7.2.3 All options (except counterfactual) include investment volumes derived through bottom-up intervention development to address overhaul requirements, known defects and obsolescence issues. A table of these intervention volumes is in Table 36.

Option 1: Risk Stable to RIIO-T2 Start

7.2.4 This option utilised the Copperleaf Portfolio optimisation tool to constrain overall levels of NARMS risk at the end of the RIIO-GT3 period to remain consistent with the levels of risk at the start of RIIO-T2. Individual NARMS service risk measures are not individually constrained, however overall risk outcome is.

7.2.5 The total spend of proposed interventions is £110.70m which addresses known and forecast defects. No additional investment is proposed through predictive analytics model to keep overall NARMS risk stable. The proposed intervention volumes and the associated spend are shown in Table 29.

Table 29: Option 1: Risk Stable to RIIO-T2 Start summary (£m, 2023/24)

Intervention	Volumes	RIIO-GT3 Value
Bottom-Up Interventions	[redacted]	110.70
Total	[redacted]	**110.70**

Option 1A: Post Deliverability

7.2.6 This option includes bottom-up interventions with constraints applied to ensure it is deliverable. This option factors in network outage, resource and supply chain constraints. The total spend of proposed interventions is £109.90m as shown in Table 30 to addresses known and forecast defects with the same impacts to Service Risk Measures.

[80] NGT_EJP13_Compressor Fleet – Network Investments and Zone 1 (Scotland)_RIIO-GT3
[81] NGT_EJP14_Compressor Fleet - Zones 2 and 3 (Central)_RIIO-GT3
[82] NGT_EJP15_Compressor Fleet - Zones 4 and 5 (South Wales and South West)_RIIO-GT3
[83] NGT_EJP16_Compressor Fleet - Zones 6 and 7 (East Midlands and South East)_RIIO-GT3

Table 30: Option 1A: Post Deliverability Summary (£m, 2023/24)

Intervention	Volumes	RIIO-GT3 Value
Bottom-Up Interventions	[redacted]	109.90
Total	[redacted]	**109.90**

Option 2: Additional 10% Risk Reduction

7.2.7 This option utilised the Copperleaf Portfolio optimisation tool to constrain overall level of risk at the end of the RIIO-GT3 period to 10% lower than at the start of RIIO-T2. The option seeks to ensure overall NARMS monetised risk is 10% lower but individual service risk measures are not individually constrained, hence service risk measures achieve a blend of outcomes to overall meet the 10% lower NARMS risk.

7.2.8 The total spend of proposed interventions is £116.77m which addresses known and forecast defects. The proposed intervention volumes and the associated spend for this option are shown in Table 31.

Table 31: Option 2: Additional 10% Risk Reduction summary (£m, 2023/24)

Intervention	Volumes	RIIO-GT3 Value
Bottom-Up Interventions	[redacted]	110.70
PA Volumes	[redacted]	6.07
Total	[redacted]	**116.77**

Option 3: Lowest Whole Life Cost (WLC)

7.2.9 This option utilised the Copperleaf Portfolio optimisation tool to derive a combination of intervention options which achieves the lowest total cost of CAPEX incurred over the operational life of the assets. Individual service risk measures are not individually constrained, however overall risk outcome is.

7.2.10 The total spend of proposed interventions is £123.59m. The proposed intervention volumes and the associated spend are shown in Table 32.

Table 32: Option 3: Lowest Whole Life Cost (WLC) summary (£m, 2023/24)

Intervention	Volumes	RIIO-GT3 Value
Bottom-Up Interventions	[redacted]	110.70
PA Volumes	[redacted]	12.89
Total	[redacted]	**123.59**

Option 4: Health and Safety Risk Stable to T2 Start

7.2.11 This option utilised the Copperleaf Portfolio optimisation tool to constrain the Health and Safety service risk measure to achieve a stable risk at the end of RIIO-GT3 compared to the start of RIIO-T2. No other service risk measures have been constrained and they have been left un-optimised.

7.2.12 The total spend of proposed interventions in this option is £122.73m. The proposed intervention volumes and the associated spend for this option are shown in Table 33.

Table 33: Option 4: Health and Safety Risk Stable summary (£m, 2023/24)

Intervention	Volumes	RIIO-GT3 Value
Bottom-Up Interventions	[redacted]	110.70
PA Volumes	[redacted]	12.03
Total	[redacted]	**122.73**

7.3 Portfolio Options Summary

7.3.1 Table 34 presents the technical summary table.

Table 34: Portfolio options technical summary (£m, 2023/24)

Option	First Year of Spend	Final Year of Spend	Volume of Interventions	Investment Design Life (years)	Value
Option 1: Total Monetised Risk Stable to T2 start	2027	2031	276	15-40	110.70
Option 1A: Post Deliverability	2027	2031	262	15-40	109.90
Option 2: Additional 10% Risk Reduction	2027	2031	316	15-40	116.77
Option 3: Lowest WLC	2027	2031	354	15-40	123.59
Option 4: Health and Safety Risk Stable	2027	2031	341	15-40	122.73

8 Business Case Outline and Discussion

8.1 Key Business Case Drivers Description

8.1.1 In appraising this investment, we have considered how the recommended approach to managing rotating machinery assets can impact on availability and reliability, safety and the environment. The options presented are primarily driven by asset health needs to meet availability requirements, whilst ensuring compliance. We have considered the impact of the following drivers for investment:

- Ensuring suitable compression assets are available to meet system operator demands in support of customers.
- Protecting site operatives working with complex assets in hazardous areas and mitigating members of the public being exposed to catastrophic events.
- Operating in line with best practice within all constraints whilst optimising opportunities for improvements when beneficial.
- Providing value to consumers by targeting interventions based on compression fleet strategy including forecasted running hours and expected out of service dates.

8.2 Business Case Summary

8.2.1 A variety of technical interventions have been considered and combined to create a range of CBA options. The payback period of each option is shown in Figure 9 with the key metrics presented in Table 35.

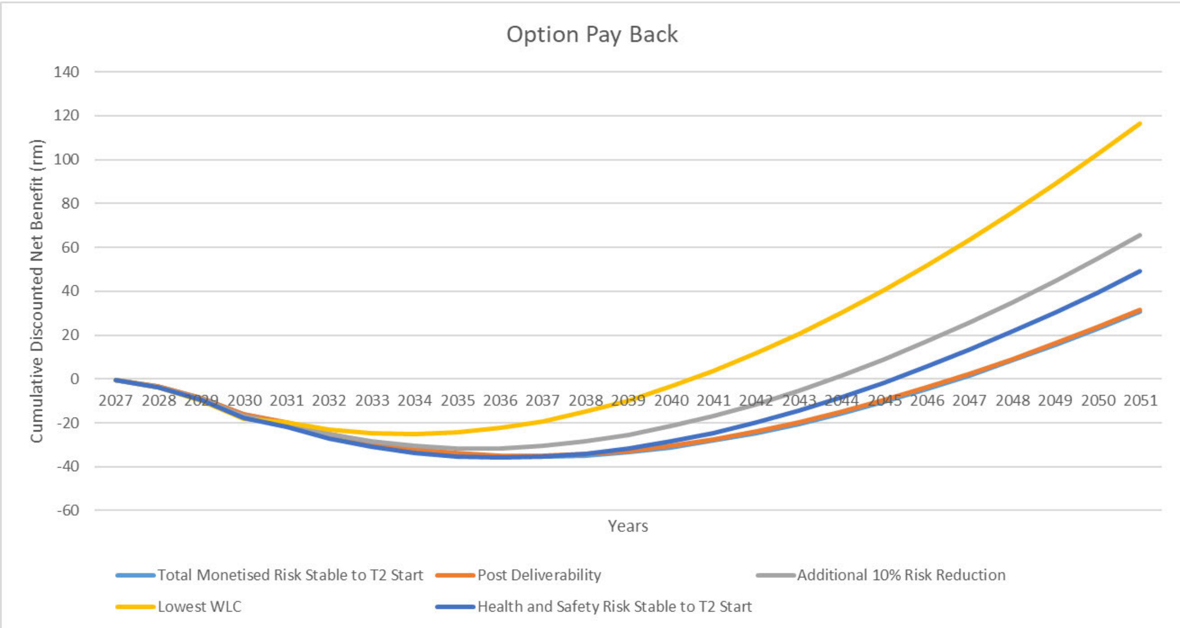


Figure 9: Option payback period

Table 35: Option summary of headline business case metrics (£, 2023/24)

Option	Total Volume of Interventions	Total Spend Request	Outcome Risk End of RIIO-GT3	% change in comparison to start of RIIO-T2	NPV	Payback Period from 2031	% change in service risk measures compared to start of RIIO–T2				
							Financial	Health and safety	Environmental	Availability Reliability	Societal
Option 0: Counterfactual (Do Nothing)	N/A	-	17.86	118.35%	-	-	91.06%	147.21%	110.15%	193.40%	124.14%
Option 1: Total Monetised Risk Stable to RIIO-T2 Start	276	110.70	11.84	78.43%	30.61	20 years	64.76%	111.54%	67.95%	67.51%	74.43%
Option 1A: Post Deliverability	262	109.90	11.84	78.43%	31.42	20 years	64.76%	111.54%	67.95%	67.51%	74.43%
Option 2: 10% Additional Risk Reduction	316	116.77	10.66	70.61%	65.40	17 years	63.38%	89.80%	65.08%	51.13%	74.38%
Option 3: Lowest WLC	354	123.59	8.41	55.74%	116.53	14 years	60.53%	52.17%	56.52%	38.83%	74.20%
Option 4: Health and Safety Risk Stable	341	122.73	10.61	70.28%	49.04	19 years	61.10%	107.21%	56.92%	43.70%	74.35%

9 Preferred Option Scope and Project Plan

9.1.1 The preferred option to manage compressor machinery train assets is Option 1A: Post Deliverability.

9.1.2 The other options have been discounted due to the need to address specific issues and comply with OEM guidance, policy, and legislation rather than a set of interventions to meet service risk measures. Furthermore, the programme of investment on rotating machinery assets has been taken through a deliverability assessment to assesses the programme of works against outputs across our entire capital investment plan.

9.1.3 This has resulted in a deliverable plan which includes a mixture of defect remediation, duty-based overhauls, condition-based refurbishments, and proactive asset health interventions as shown in Table 36.

Table 36: Preferred option summary (£m, 2023/24)

Intervention	Primary Driver	Volume	Unit of Measure	Total RIIO-GT3 Request	Funding Mechanism	PCD Measure
Compressor Breakdown Budget	AH Risk Management	[redacted]	Per Year	[redacted]	Baseline	NARMS
Compressor Overhauls [redacted]	AH Policy	[redacted]	Per Asset	[redacted]	Baseline	NARMS
Upgrade gas powered starter motors to electric	AH Known Defects Secondary	[redacted]	Per Asset	[redacted]	Baseline	NARMS
Impeller Major Refurb	AH Known Defects Primary	[redacted]	Per Asset	[redacted]	Baseline	NARMS
Compressor Overhauls [redacted]	AH Policy	[redacted]	Per Asset	[redacted]	Baseline	NARMS
Purchase & Installation of [redacted]	AH Known Defects Primary	[redacted]	Per Compressor Unit	[redacted]	Baseline	NARMS
Compressor Overhauls [redacted]	AH Policy	[redacted]	Per Asset	[redacted]	Baseline	NARMS
Upgrade fuel metering valves to [redacted]	AH Risk Management	[redacted]	Per Asset	[redacted]	Baseline	NARMS
Install fuel gas conditioning skids	AH Risk Management	[redacted]	Per Asset	[redacted]	Baseline	NARMS
Compressor Dry Gas Seal Major Refurb	AH Known Defects Primary	[redacted]	Per Asset	[redacted]	Baseline	NARMS
Felindre Vent Stack Replacement	AH Policy	[redacted]	Per Site	[redacted]	Baseline	NARMS
Install seal gas booster	AH Risk Management	[redacted]	Per Compressor Unit	[redacted]	Baseline	NARMS
GG/PT/Compressor Oil System Major Refurb	AH Risk Management	[redacted]	Per Compressor Unit	[redacted]	Baseline	NARMS
Bearing & Coupling Refurbishment	AH Risk Management	[redacted]	Per Asset	[redacted]	Baseline	NARMS
Compressor Overhauls [redacted]	AH Policy	[redacted]	Per Asset	[redacted]	Baseline	NARMS
[redacted] Compressor Overhaul Including New Stator	AH Policy	[redacted]	Per Compressor Unit	[redacted]	Baseline	NARMS
Compressor Overhauls [redacted]	AH Policy	[redacted]	Per Asset	[redacted]	Baseline	NARMS
HV Stator Motor Rewind	AH Policy	[redacted]	Per Asset	[redacted]	Baseline	NARMS
Compressor Overhauls [redacted]	AH Policy	[redacted]	Per Asset	[redacted]	Baseline	NARMS
Modulating Vent Valve Overhaul	AH Legislation	[redacted]	Per Asset	[redacted]	Baseline	NARMS
Replace Inconel Bolts for Exhaust to transition piece	AH Known Defects Secondary	[redacted]	Per Compressor Unit	[redacted]	Baseline	NARMS
Vent System Survey	AH Policy	[redacted]	Per Site	[redacted]	Baseline	NARMS
Frequency Converter - Major Refurb	AH Policy	[redacted]	Per Asset	[redacted]	Baseline	NARMS
Implement Slow Roll System and install staging valve monitoring	AH Known Defects Secondary	[redacted]	Per Compressor Unit	[redacted]	Baseline	NARMS
Cooling System Replacement	AH Known Defects Secondary	[redacted]	Per Asset	[redacted]	Baseline	NARMS
Replace flexible hose assemblies	AH Known Defects Secondary	[redacted]	Per Compressor Unit	[redacted]	Baseline	NARMS
Update HMI with HP Recoup Calculations	AH Known Defects Secondary	[redacted]	Per Compressor Unit	[redacted]	Baseline	NARMS
Rectify Combustion and Air Inlet Drains	AH Risk Management	[redacted]	Per Compressor Unit	[redacted]	Baseline	NARMS
Catalytic Converter Replacement	AH Known Defects Secondary	[redacted]	Per Asset	[redacted]	Baseline	NARMS
Install lube oil conditioning skids	AH Known Defects Secondary	[redacted]	Per Asset	[redacted]	Baseline	NARMS
Replace [redacted] Gas Valves	AH Known Defects Secondary	[redacted]	Per Compressor Unit	[redacted]	Baseline	NARMS
Verification and Re-validation of HV Motor EX'p' pressurisation System	AH Legislation	[redacted]	Per Asset	[redacted]	Baseline	NARMS

Intervention	Primary Driver	Volume	Unit of Measure	Total RIIO-GT3 Request	Funding Mechanism	PCD Measure
Implement automatic stroking on Fuel Metering Valves	AH Known Defects Secondary	[redacted]	Per Compressor Unit	[redacted]	Baseline	NARMS
Replace Ignitor Box	AH Risk Management	[redacted]	Per Compressor Unit	[redacted]	Baseline	NARMS
Harmonic Filter - Minor Refurb	AH Policy	[redacted]	Per Asset	[redacted]	Baseline	NARMS
Inlet strainers removal	AH Policy	[redacted]	Per Asset	[redacted]	Baseline	NARMS
Modify Lube Oil Drain Skid	AH Risk Management	[redacted]	Per Compressor Unit	[redacted]	Baseline	NARMS
Install BAM 2.0	AH Risk Management	[redacted]	Per Asset	[redacted]	Baseline	NARMS
Power Cables Remediation and Earthing	AH Policy	[redacted]	Per Asset	[redacted]	Baseline	NARMS
N2 Snuffing & Molecular Seal Major Refurb	AH Legislation	[redacted]	Per Asset	[redacted]	Baseline	NARMS
Motorhood Gasket Replacement	AH Policy	[redacted]	Per Asset	[redacted]	Baseline	NARMS
Exhaust Muffler Replacement	AH Risk Management	[redacted]	Per Asset	[redacted]	Baseline	NARMS
HV Motor Overhaul	AH Policy	[redacted]	Per Asset	[redacted]	Baseline	NARMS
Replace Exhaust Lagging	AH Known Defects Secondary	[redacted]	Per Compressor Unit	[redacted]	Baseline	NARMS
Replace PT bearing sump chip detector	AH Known Defects Secondary	[redacted]	Per Compressor Unit	[redacted]	Baseline	NARMS
Replace Frame mounted Accelerometer	AH Known Defects Secondary	[redacted]	Per Compressor Unit	[redacted]	Baseline	NARMS
Implement Anti-Choke System	AH Known Defects Secondary	[redacted]	Per Compressor Unit	[redacted]	Baseline	NARMS
Cooling Systems Survey	AH Policy	[redacted]	Per Asset	[redacted]	Baseline	NARMS
Vent System Pipework Corrosion / P11 Major Refurb	AH Legislation	[redacted]	Per Asset	[redacted]	Baseline	NARMS
Cables Testing	AH Policy	[redacted]	Per Asset	[redacted]	Baseline	NARMS
Rectify HMI and Communications issues on [redacted]	AH Known Defects Secondary	[redacted]	Per Compressor Unit	[redacted]	Baseline	NARMS
Vent System Pipework Minor Refurb	AH Legislation	[redacted]	Per Asset	[redacted]	Baseline	NARMS
Enhanced Emissions Control	AH Known Defects Secondary	[redacted]	Per Compressor Unit	[redacted]	Baseline	NARMS
[redacted] Motor Compressors Remote Condition Monitoring	AH Policy	[redacted]	Per Site	[redacted]	Baseline	NARMS
[redacted] Thrust Unloader Survey	AH Known Defects Secondary	[redacted]	Per Asset	[redacted]	Baseline	NARMS
Total		**262**		**109.86**		

9.1.4 Costs and volumes have been developed using a formalised methodology including first principle estimating and using estimates at completion from similar scopes of work delivered in RIIO-T2. Therefore, we propose the investment within this EJP is funded via baseline and will be assessed using NARMs methodology.

9.1.5 The outputs from this investment will be included in the Asset Health – NARMS PCD reporting mechanism, and cost variance managed through the TIM mechanism.

Asset Health Spend Profile

9.1.6 The spend profile chart in Figure 10 provides an indicative view on when the above interventions will be carried out. Due to the high number of interventions, not all are shown on the chart key. Further detail is provided in the NGT_IDP14_Portfolio EJP Rotating Machinery_RIIO-GT3.

[redacted]

Figure 10: Rotating Machinery spend profile RIIO-GT3

Investment Risk Discussion

9.1.7 Intervening on compressor machinery train assets usually requires outages which can be planned. However, if unplanned outages are required because of breakdowns, this can have fleet wide consequences as other units may be required to run. In certain situations, this may require units to be brought back online from maintenance, with consequential impacts to any non-critical maintenance activities being postponed.

9.1.8 To mitigate this, the fleet strategy detailed in the Compressor Fleet EJPs[84,85,86,87] aims to ensure sufficient resilience.

9.1.9 Our costs have been built through unit cost analysis and estimates from the market, however there is a risk that costs of materials may increase due to macro-economic conditions and customer and stakeholder demand. This shall partly be mitigated through the CPI-H inflation and real price effect mechanisms within our RIIO-GT3 regulatory framework.

Project Plan

9.1.10 Project delivery has been split into three phases which align with our Network Development Process (ND500) shown in Table 37. Commissioning dates are not relevant to all intervention types but take place at the end of the delivery phase.

Table 37: Delivery phase alignment with ND500

Delivery Phase	ND500 Stage Gate(s)
Preparation	T0, T1, F1 (Scope establishment), T2, F2 (Option selection), T3, F3 (Conceptual Design Development and Long Lead Items Purchase), T4
Delivery	F4 (Execute Project), T5, Available for Commercial Load (ACL), T6
Close Out	F5 (Reconcile and Close)

9.1.11 Table 38 shows the summary plan and provisional delivery phases for rotating machinery interventions within RIIO-GT3. Internal stakeholder engagement has identified when we can obtain required network access to complete these works.

Table 38: Rotating Machinery Portfolio Programme for RIIO-GT3 period

Sanction/Intervention	RIIO-T2		RIIO-GT3					
	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32
T3_Compressor_Overhauls_FY28								
T3_Compressor_Overhauls_FY31								
T3_Sites_AGI_NGS_FY28								
T3_Sites_AGI_NGS_FY31								
T3_Sites_AGI_NGS_FY30								
T3_Compressor_Overhauls_FY29								
T3_Compressor_Overhauls_FY30								

[84] NGT_EJP13_Compressor Fleet – Network Investments and Zone 1 (Scotland)_RIIO-GT3
[85] NGT_EJP14_Compressor Fleet - Zones 2 and 3 (Central)_RIIO-GT3
[86] NGT_EJP15_Compressor Fleet - Zones 4 and 5 (South Wales and South West)_RIIO-GT3
[87] NGT_EJP16_Compressor Fleet - Zones 6 and 7 (East Midlands and South East)_RIIO-GT3

Sanction/Intervention	RIIO-T2		RIIO-GT3					
	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32
T3_Compressor_Electrical Drives								
T3_Compressor_Exhuast Muffler								
T3_Compressor_Overhauls_FY27								
T3_Compressor_Breakdown Budget								
T3_Compressor_AH Cabs_Lot 1								
T3_Sites_AGI_NGS_FY29								
T3_Compressor_AH Cabs_Lot 2								
T3_Compressor_Install BAM 2.0								
T3_Climate Change Adaptation								

9.1.12 Of note, the intervention to purchase and install a new [redacted] has expenditure in FY26. This is due to the long lead time of procuring [redacted] from the OEM and the need for it to be available for load as soon as possible following removal of the existing one in line with the overhaul schedule based on forecasted running hours.

9.1.13 Similarly, overhauls of gas generators, such as the one installed at [redacted] which will be due at the start of RIIO-GT3, are conducted in accordance with set schedules meaning sanction and project can commence in anticipation. Based on the assumed outage, other work has been planned aligned to this, such as the intervention to install fuel gas conditioning skid at [redacted]. This mitigates any delays and limits delivery risk.

9.1.14 Other interventions scheduled for outside the core RIIO-T3 period relate to RAM model investments which are necessary to meet the required reliability, availability, and maintainability levels in line with operational demands. Therefore, it is essential to commence work on these as soon as possible.

9.1.15 All work has been profiled based on a deliverability assessment across the whole plan and compressor running hours aligned to seasonal demand, resource requirements and holistic fleet management.

Key Business Risks and Opportunities

9.1.16 Supply and demand patterns are modelled across different scenarios. If reality differs from the scenarios used to forecast running hours, overhaul interventions may be incorrect. However, this is a minimal risk as running hours would need to be significantly different. More information can be found in the Compressor Fleet EJPs[88,89,90,91].

9.1.17 There is a risk that a transition to hydrogen would require compressor machinery train assets to operate differently or be changed. However, the interventions in this funding request are aligned to the network strategy detailed in the Compressor Fleet EJPs[92,93,94,95] which requires current assets to be managed as discussed in this EJP throughout RIIO-GT3. Therefore, it presents minimal risk to this EJP.

Outputs included in RIIO-T2

9.1.1 There are no outputs from RIIO-T2 plans to be included within RIIO-GT3.

[88] NGT_EJP13_Compressor Fleet – Network Investments and Zone 1 (Scotland)_RIIO-GT3
[89] NGT_EJP14_Compressor Fleet - Zones 2 and 3 (Central)_RIIO-GT3
[90] NGT_EJP15_Compressor Fleet - Zones 4 and 5 (South Wales and South West)_RIIO-GT3
[91] NGT_EJP16_Compressor Fleet - Zones 6 and 7 (East Midlands and South East)_RIIO-GT3
[92] NGT_EJP13_Compressor Fleet – Network Investments and Zone 1 (Scotland)_RIIO-GT3
[93] NGT_EJP14_Compressor Fleet - Zones 2 and 3 (Central)_RIIO-GT3
[94] NGT_EJP15_Compressor Fleet - Zones 4 and 5 (South Wales and South West)_RIIO-GT3
[95] NGT_EJP16_Compressor Fleet - Zones 6 and 7 (East Midlands and South East)_RIIO-GT3

10 Appendices

10.1 Appendix 1: Gas Generator overhaul schedule (hours)

Gas Generator Type	Overhaul Life
[redacted]	25,000 hours
[redacted]	25,000 hours
[redacted]	25,000 hours
[redacted]	30,000 hours
[redacted]	25,000 hours
[redacted]	25,000 hours

10.1.1 NB: Running hours and cycles are taking into consideration when planning overhauls. Specifically, consumed hours is the principal method used to determine overhaul requirement within the overhaul planning tool which is managed by DNV.

10.2 Appendix 2: Power Turbine overhaul schedule (hours)

Power Turbine Type	Mid-life inspection interval	Overhaul interval
[redacted]	25,000 hours	50,000 hours
[redacted]	50,000 hours	100,000 hours
[redacted]		48,000 hours
[redacted]	Power Turbine is integral to the gas turbine	
[redacted]		50,000 hours
[redacted]		25,000 hours
[redacted]		50,000 hours

10.2.1 NB: Running hours and cycles are taking into consideration when planning overhauls. Specifically, consumed hours is the principal method used to determine overhaul requirement within the overhaul planning tool which is managed by [redacted].

10.3 Appendix 3: [redacted]

10.4 Appendix 4: [redacted]

10.5 Appendix 5: [redacted]

10.6 Appendix 6: [redacted]

Table 39: Installed compressor units

Site and Unit	Compressor Station	Unit	Drive	Type	PT Type	Compressor
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
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Site and Unit	Compressor Station	Unit	Drive	Type	PT Type	Compressor
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10.7 Appendix 7: [redacted] [redacted]

10.7.1 [redacted]

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10.8 Appendix 8: Cost Breakdown

10.8.1 Derivation of unit costs are included in the relevant sections of this EJP related to the interventions considered. A further breakdown is shown in Table 40 which includes granular make up of costs where applicable. In some cases, this is not possible, such as when final options or delivery units have not yet fully been determined.

Table 40: Intervention cost breakdown (£m, 2023/24)

Intervention / Location	External Costs	NG Costs	Prebuild/ Engineering	Equipment and Materials	Risk and Contingency	Total Unit Cost
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
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[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Intervention / Location	External Costs	NG Costs	Prebuild/ Engineering	Equipment and Materials	Risk and Contingency	Total Unit Cost
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
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