
# Annex
# A14.10 Compressor Train Engineering Justification Paper

As a part of the NGGT Business Plan Submission

nationalgrid

## Executive Summary

### Introduction

To maintain the ongoing safe, secure and reliable operation of the UK Gas National Transmission System (NTS) it is imperative that the health of the assets that constitute the NTS is carefully managed.

Our Asset Health programme is an ongoing plan of works that assures, and consists of 7 core asset themes of work. This document outlines our approach to the management of our Compressor Train assets to meet desired regulatory, stakeholder and financial outcomes. A 10-year view has been taken, covering the RIIO-2 and RIIO-3 regulatory periods to ensure a balanced, lifecycle approach to asset management. The overarching fleet strategy for our compressor assets is aligned to Network Capability, ensuring we carry our asset health interventions only where it is appropriate.

Our asset strategy is to ensure a good consistent level of unit availability and reliability for the fleet. To maintain these assets, we follow the original equipment manufacturers (OEM) recommendations and our policy is consistent across all European compressor operators. Our plan is the minimum number of interventions required and least whole life cost, to maintain availability and reliability for customers.

The Compressor Train asset health programme has 4 sub-themes. In total, we propose to spend £113.69m (18.5% of the 7 themes that comprise the overall asset health plan) ensuring risk levels are maintained on our Compressor Train assets during RIIO-2.

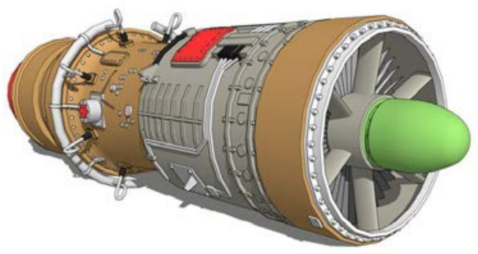
| Sub-theme | Intervention Volumes | Cost |
|---|---|---|
| Compressor | 20 | £7,075,528 |
| Gas Generator Power Train | 305 | £89,392,120 |
| Variable Speed Drive | 21 | £15,793,266 |
| Vent System | 25 | £1,424,709 |
| **Total** | **371** | **£113,685,623** |

The profile of Compressor Train asset health investment for the 10-year period, derived from the volumes of work and the unit costs, is shown in the table below:

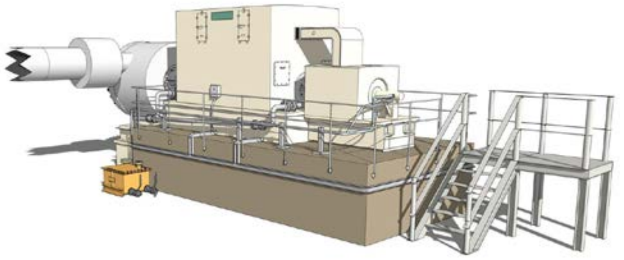
| Investment (£ 000's) | RIIO-2 | | | | | RIIO-3 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 |
| Total | 50,026 | 29,312 | 7,317 | 9,111 | 17,920 | 27,262 | 21,212 | 14,282 | 29,220 | 28,699 |
| | **113,686** | | | | | **120,682** | | | | |

### The Assets

There are 61 Gas Generator powered Compressors Trains and 9 Electrically powered Compressors Trains across the NTS. Compressor trains are made up of a centrifugal **Compressor** that pressurises the gas in the NTS. This may be powered by an **Electric Drive** or a **Power Turbine**. The latter is driven by a **Gas Generator** which, in turn, requires a **Starter Motor** to commence operation. Under certain circumstances the gas containing pipework around the compressor is depressurised through a **Vent System**. The body of this document covers each of these highlighted aspects.

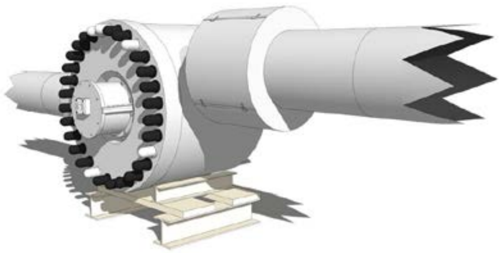


**Gas Generator**



**Variable Speed (Electric) Drive (VSD)**

**Starter Motor**



**Centrifugal Compressor**

**Vent System**

Due to the pattern of gas flows required by our customers and consumers becoming increasingly variable across the network, the patterns of gas movement across the network have changed with increased, and much more complex, demand on the compression fleet. This has increased the stress on compressor machinery due to greater frequency of start-stop cycles and more volatile running hour periods.

Changes in usage, especially increasing start-stop cycles, of the compressors has resulted in the need to increase the number of overhauls. These interventions ensure that compression assets remain supported by the manufacturer and continue to operate at an acceptable level of availability. The frequency of overhauls and general maintenance on the compressors can be further increased by the poor performance of the associated assets. The overhaul of a compressor train can typically take 13 to 26 weeks.

There is evidence of increased defects and failures on the compressor train leading to compressor unit trips and the associated unavailability of the compressor unit for the duration of any investigation and repair. There is also a decreasing start reliability meaning Gas Generators fail to achieve stable running on demand.

## Impacts of no investment

Compression balances the flow of gas and linepack levels across the network, ensuring that all terminals and offtakes are maintained at the right pressure. This requirement is routinely tested and analysed by the System Operator and the Network Capability required by our customers underpins the need for these assets. The loss of compression in sections of the NTS has significant impact on customers putting gas on and off the network. This has knock-on effects for the operation of gas production facilities, power generation, and domestic and industrial consumers.

These impacts are currently managed by ensuring that there is redundancy in the compressor fleet, allowing loss of a compressor to be compensated for by another machine. However, this means maintaining a large fleet of aging machines at a constant state of readiness.

## Proposal Development

In defining our proposed intervention approach, we have focussed our effort on developing a least whole-life cost option with a minimum level of intervention in line with OEM guidance and expected machine running requirements. Significant expert challenge and review has underpinned the level of interventions and the proposed phasing ensures we meet the desired engineering and stakeholder outcomes, whilst smoothing out this workload and aligning outages across our fleet.

Gas Generators are complex machines that require careful maintenance and operation which comes at a cost. Due to the degree of redundancy in the fleet, the consequences of losing a single machine are minimised, but a high proportion of the fleet must be maintained at readiness to provide that redundancy.

Although Electric Drives are considerably more cost beneficial, replacing Gas Generators with these devices requires providing high voltage power supplies to remote locations, with considerable cost and time impacts that have not proved to be efficient to pursue in RIIO-1.

Much of the cost associated with Gas Generators is derived from duty profiles (run hours and number of start stops) that have been agreed with other EU-based gas generator operators. These are described in best practice integrity management policies based on Original Equipment Manufacturer (OEM) guidelines which we always aim to adhere to as a safety requirement for operating these machines.

It is vital for the supply of gas to our customers that our compressors remain available and resilient to the demands and changes on the NTS and investment in our Compressor Trains is essential to ensuring this availability is not compromised.

The table below summarises the key considerations when developing this theme of work.

| To deliver these outcomes…. |
| --- |
| • Maintaining a resilient level of compression availability that responds to flow requirements without causing network constraints<br>• Ensuring that any defects and associated outages can be resolved quickly avoiding impact on availability<br>• Meeting strict emissions regulations without compromising network capability |

- Building a compressor fleet that will continue to deliver the required Network Capability into the future in a cost-effective manner
- Maintain reliable energy supplies across the NTS
- Meeting the expectations of our customers and stakeholders and keeping risk stable

**…by intervening like this…**

- Continuing to proactively manage the condition of Gas Generators, Power Turbines and Compressors in partnership with OEMs.
- Resolving the specific unreliability and obsolescence issues with the electric drives
- Making increasingly active use of condition monitoring to support data-led decision making and stretch overhaul intervals.
- Replacing the compressor fleet where this is shown to be cost beneficial.
- Maintaining the condition and function of vent systems to ensure the safe depressurisation of equipment
- Ensuring compliance with legal requirements and all relevant regulations and approved codes of practice

**…based on this knowledge:**

- An asset-specific risk-based review of the results of routine inspections, maintenance and investigations already undertaken
- Knowledge of the compressor assets that will reach maximum life-time hours during the investment period.
- A forecast of the defects and associated risks following routine interventions
- An evaluation of the impact of changing emissions legislation on the Gas Generator fleet.
- An assessment of the changes in customer behaviour and the impact on network capability.

## RIIO-2 Compressor Train Asset Health Investment Proposal Summary

Compressor Train Asset Health investment proposal headlines

- The total RIIO-2 proposed expenditure for this theme is £113.69m
- 83% of our Compressor Train programme is based upon interventions to address known defects (7%) and high confidence work volumes based on historical trends (76%).
- 99% of this asset health work is condition driven and delivers NARMs outputs. Only the work associated with vents falls outside of NARMs measures.
- 71% of this work is driven by OEM guidance to overhaul gas generators and compressors at predetermined trigger points (e.g. running hours, No. of starts).
- £16.3m of the Compressor Train costs relate to the compressor breakdown budget and fleet management (engine swap-out and strategic spares) and this represents an annual run rate based on historic performance.

The least cost option (do minimum) has been proposed to maintain compliance with OEM guidelines and associated internal policy to maintain our fleet at expected levels of reliability and therefore stable risk:

| Sub-theme | RIIO-2 Plan (£) | Percentage of Theme | Options considered | Option summary / considerations |
|---|---|---|---|---|
| Gas Generator Power Train | £89,392,120 | 78.6% | 1 | Least whole-life cost option to maintain compressor capability in line with OEM / Safety guidelines to overhaul at preset running hour quantity with additional budget for breakdown in line with historic costs |
| Compressor | £7,075,528 | 6.2% | 1 | Least whole-life cost option proposed to resolve known defects and running hour interventions in line with manufacturers guidelines and internal policy |
| Electrical Variable Speed Drives | £15,793,266 | 13.9% | 1 | Least whole-life cost blend of interventions to meet the minimum requirements to maintain risk and therefore operating reliability. Proposal is built on known defects and largely driven by OEM guidelines |
| Vent Systems | £1,424,709 | 1.3% | 4 | Least whole-life cost option proposed to resolve known defects through lowest cost refurbishment approach. |

We have estimated unit costs across all our proposed Compressor Train interventions either from historical outturn data points, from supplier quotations or from other estimation methods (such as extrapolation to similar types of work or from reviewing industry benchmarking data). Our approach has been primarily based top down from final actual costs combined with bottom up from estimating procedures and supplier rates or quotations. We have challenged our costs through internal benchmarking review with current supply chain partners combined with use of benchmarking data where this exists.

All the unit costs include the efficiencies resulting from bundling delivery programmes across asset classes and within available outages and efficiencies resulting from our innovation projects where these are proven to deliver benefits and can be utilised in the planned investments.

40% of costs for the Compressor Train assets in our plan are supported by outturn costs which provides a medium level of confidence overall. The remaining 60% is supported by supplier quotations where obtainable or other estimation methods. There are cost differentiators (e.g. ground conditions and intervention type) and unique factors (e.g. access requirements and work mix) that influence the degree of certainty, which are presented in this report.

The table below summarises the evidence used to produce the Compressor Train unit costs.

| Investment sub-theme | Secondary Asset Class | RIIO-2 Business Plan | Evidence | | |
|---|---|---|---|---|---|
| | | | Outturn | Estimated - Quotation | Estimated - Other |
| Gas Generator Power Train | Gas Generator Power Train | [redacted] | 42% | 34% | 24% |
| | Power Turbine | [redacted] | 56% | 15% | 29% |
| Compressors | Compressors | [redacted] | 66% | 16% | 19% |
| Variable Speed Drive | Variable Speed Drive | [redacted] | 0% | 61% | 39% |
| Vent Systems | Vent Systems | [redacted] | 0% | 0% | 100% |
| **Total** | | [redacted] | 40% | 33% | 28% |

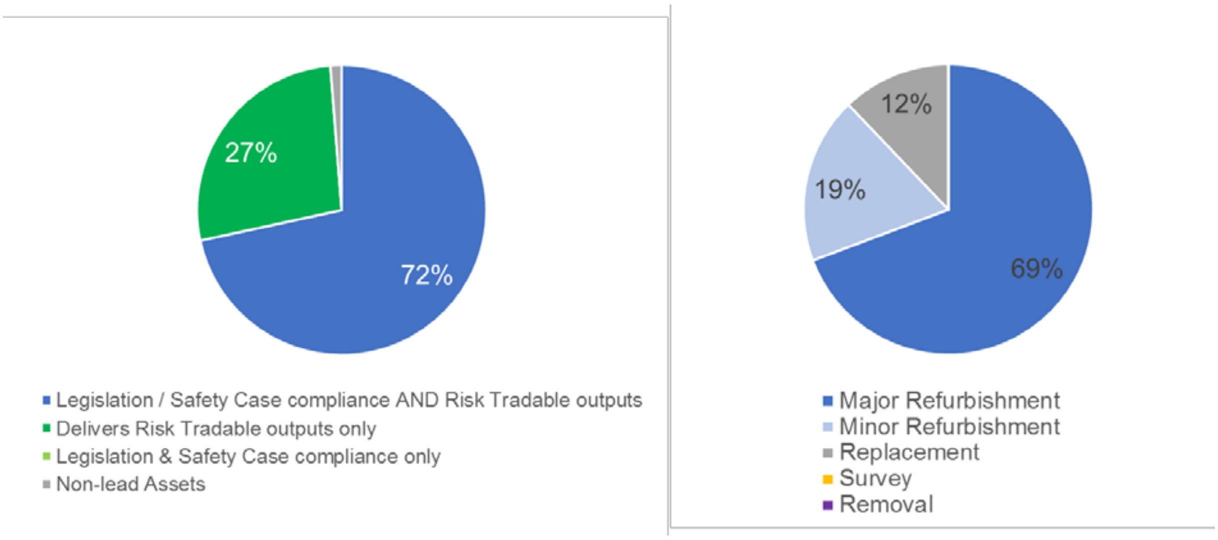
We have set out full details of our process for estimating unit costs across our asset health proposals in our Asset Health Unit Cost Annex.

The RIIO-2 Compressor Train Asset Health theme and intervention costs and volumes by output are provided below. All costs are in thousands (£000).

| Sub-theme & Intervention | RIIO-2 Volumes | Legislation/ Safety Case & Risk Tradable | Risk Tradable | Legislation & Safety Case | Non-lead Assets |
|---|---|---|---|---|---|
| **Compressor** | | | | | |
| Compressor Bearing & Coupling Major Refurb | [redacted] | £0 | £830 | £0 | £0 |
| Compressor Wet / Dry Seal Major Refurb | [redacted] | £0 | £1,065 | £0 | £0 |
| GG/PT/Compressor Oil System Major Refurb | [redacted] | £0 | £360 | £0 | £0 |
| Impeller Major Refurb | [redacted] | £0 | £3,576 | £0 | £0 |
| Instrument Air / N2 System Major Refurb | [redacted] | £0 | £120 | £0 | £0 |
| Instrument Air / N2 System Replacement | [redacted] | £0 | £1,125 | £0 | £0 |
| **Gas Generator Power Train** | | | | | |
| Avon / RB211 Fuel Gas Conditioning Skid Installation | [redacted] | £0 | £4,613 | £0 | £0 |
| Power Turbine Overhauls - Dresser Vectra | [redacted] | £3,904 | £0 | £0 | £0 |
| Power Turbine Overhauls - GE HSPT | [redacted] | £9,759 | £0 | £0 | £0 |
| Power Turbine Overhauls - GEC EAS1 / ERB1 | [redacted] | £2,309 | £0 | £0 | £0 |
| Power Turbine Overhauls - Rolls-Royce RT48 / RT56 | [redacted] | £2,304 | £0 | £0 | £0 |
| Power Turbine Overhauls - Siemens SGT400 | [redacted] | £3,243 | £0 | £0 | £0 |
| Compressor Train Breakdown Budget (inc St Fergus) | [redacted] | £0 | £16,281 | £0 | £0 |
| Gas Generator Overhauls - GE LM2500s | [redacted] | £22,635 | £0 | £0 | £0 |
| Gas Generator Overhauls - Rolls-Royce Avons | [redacted] | £5,749 | £0 | £0 | £0 |
| Gas Generator Overhauls - Rolls-Royce RB211s | [redacted] | £2,293 | £0 | £0 | £0 |
| Gas Generator Overhauls - Siemens SGT400s | [redacted] | £12,857 | £0 | £0 | £0 |
| Solar Titan Overhaul - GT & PT | [redacted] | £3,445 | £0 | £0 | £0 |
| **Variable Speed Drive** | | | | | |
| Electric Drives - Harmonic Filter - Replacement | [redacted] | £928 | £0 | £0 | £0 |
| Electric Drives - HV Motor & Exciter - Major Refurb | [redacted] | £1,237 | £0 | £0 | £0 |
| Electric Drives - HV Motor & Exciter - Minor Refurb | [redacted] | £77 | £0 | £0 | £0 |
| Mopico Motor Compressor Replacement | [redacted] | £6,183 | £0 | £0 | £0 |
| Electric Drives - Auxiliary Systems - Minor Refurb | [redacted] | £0 | £21 | £0 | £0 |
| Electric Drives - Converter Transformer - Major Refurb | [redacted] | £0 | £371 | £0 | £0 |
| Electric Drives - Converter Transformer - Minor Refurb | [redacted] | £0 | £0 | £0 | £0 |
| Electric Drives - Converter Transformer - Replacement | [redacted] | £0 | £2,473 | £0 | £0 |
| Electric Drives - Frequency Converter - Major Refurb | [redacted] | £1,391 | £0 | £0 | £0 |
| Electric Drives - Frequency Converter - Minor Refurb | [redacted] | £0 | £0 | £0 | £0 |
| Electric Drives - Frequency Converter - Replacement | [redacted] | £3,092 | £0 | £0 | £0 |
| Electric Drives - Harmonic Filter - Minor Refurb | [redacted] | £21 | £0 | £0 | £0 |
| Electric Drives - HV Motor & Exciter - Minor Refurb (St Fergus) | [redacted] | £0 | £0 | £0 | £0 |
| Electric Drives - HV Motor & Exciter - Major Refurbish (St Fergus) | [redacted] | £0 | £0 | £0 | £0 |
| Electric Drives - Auxillary Systems - Minor Refurb (St Fergus) | [redacted] | £0 | £0 | £0 | £0 |
| Electric Drives - Converter Transformer Minor Refurb (St Fergus) | [redacted] | £0 | £0 | £0 | £0 |
| Electric Drives - Converter Transformer - Major Refurbish (St Fergus) | [redacted] | £0 | £0 | £0 | £0 |
| Electric Drives - Frequency Converter - Minor Refurb (St Fergus) | [redacted] | £0 | £0 | £0 | £0 |
| Electric Drives - Frequency Converter - Major Refurbish (St Fergus) | [redacted] | £0 | £0 | £0 | £0 |

| | | | | | |
|---|---|---|---|---|---|
| Electric Drives - Harmonic Filter - Minor Refurb (St Fergus) | [redacted] | £0 | £0 | £0 | £0 |
| **Vent System** | | | | | |
| Modulating Vent Valve Overhaul | [redacted] | £0 | £0 | £0 | £939 |
| N2 Snuffing & Molecular Seal Major Refurb | [redacted] | £0 | £0 | £0 | £218 |
| Vent System Pipework Corrosion / P11 Major Refurb | [redacted] | £0 | £0 | £0 | £123 |
| Vent System Pipework Minor Refurb | [redacted] | £0 | £0 | £0 | £57 |
| Modulating Vent Valve Overhaul (St Fergus) | [redacted] | £0 | £0 | £0 | £59 |
| Minor remediation works (St Fergus) | [redacted] | £0 | £0 | £0 | £29 |
| **Total** | [redacted] | **£81,426** | **£30,835** | **£0** | **£1,425** |

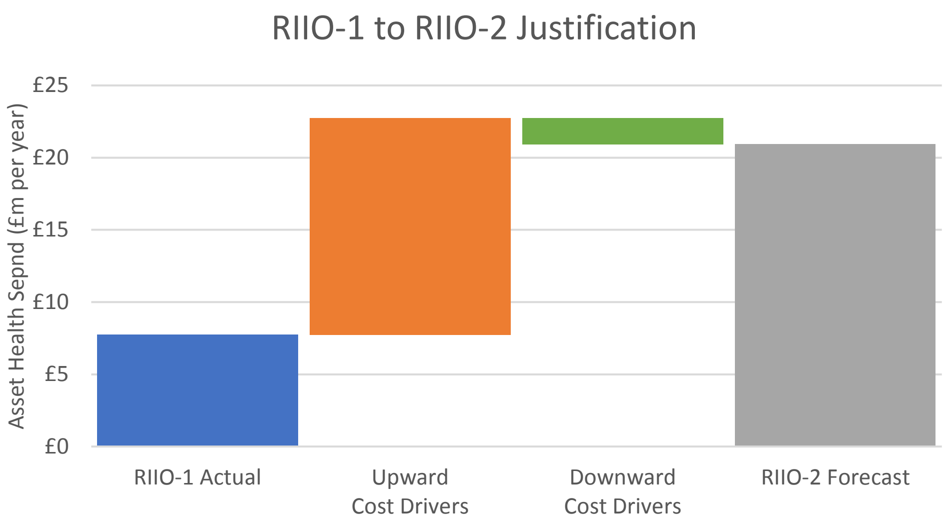
Compressor Train Asset Health theme outputs and intervention categories:




## Comparing our RIIO-2 proposal to our RIIO-1 programme

The annualised RIIO-2 spend has increased when compared to RIIO-1 from £7.7m to £20.9m for the Compressor Train Asset Health theme.

Note that this cost information is annualised to provide a comparative cost per year and the total RIIO-2 forecast below also includes the application of our agreed efficiency target within the downward drivers



### Upward Drivers

A significant proportion of compressor unit gas generators are now at or beyond the guideline running hours and in need of major overhaul work by the OEM. Virtually all the Compressor asset health plans for RIIO-2 are driven from known defects.

A significant increase in compressor overhaul work has been undertaken during RIIO-1 already, with further increases in the final 2 years of RIIO-1 to ensure we can continue to operate a resilient network. Total RIIO-1 forecast spend in this area is now forecast to be almost double that was forecast at the start of RIIO-1. This increase in activity must continue into the RIIO-2 period.

Our fleet is old and we have needed to keep a significant level of capability on the network throughout RIIO-1 to manage the risk of highly volatile supply patterns. This has led to increases in spend throughout RIIO-1 and a continued investment throughout RIIO-2 and RIIO-3 to enable compressor and network outages to accommodate vital upgrades to aging NTS assets.

Our RIIO-2 plans also include much more work on our electric drive compressor assets when compared to RIIO-1. These assets were commissioned in the run up to RIIO-1 and are now requiring overhaul and upgrades to assure continued good reliability and availability.

### Downward Drivers

In preparing our Compressor Train asset health plans we have ensured consistency with Network Capability and our fleet strategy. This has resulted in lower overall costs by avoiding spend at units planned for decommissioning and driving down interventions and costs at low use units in RIIO-2 and RIIO-3.

Most the cost efficiencies in this area are driven through our business change programme “Richmond”. Better asset data, enhanced planning tools and a sharp focus on unit costs all enable longer term overhaul programmes with which to engage OEMs on. In turn we have overlaid efficiency forecasts onto our fleet overhaul programme on the basis that we can achieve lower overall cost to delivery through enhanced, longer term delivery contracting.

## Table of Contents

## 1. Summary Table

| | |
|---|---|
| **Name of Scheme/Programme** | *Compressor Train* |
| **Primary Investment Driver** | *Asset Health* |
| **Scheme reference/ mechanism or category** | *A22.10* |
| **Output references/type** | - |
| **Cost** | *£113.7m* |
| **Delivery Year** | *2022-2026* |
| **Reporting Table** | *3.03b* |
| **Outputs included in RIIO-1 Business Plan** | - |

## 2. Introduction

2.1. This document sets out our Asset Health Plan for Compressor Trains. There are 61 Gas Generator powered Compressors Trains and 9 Electrically powered Compressors Trains across the NTS. Compressor trains are made up of a centrifugal Compressor that pressurises the gas in the NTS. This may be powered by an Electric Drive or a Power Turbine. The latter is driven by a Gas Generator which, in turn, requires a Starter Motor to commence operation. Under certain circumstances the gas containing pipework around the compressor is depressurised through a Vent System. The body of this document covers each of these highlighted aspects.

### Overview of the Compressor Train Assets

2.2. The purpose of the compressor train is to ensure that gas compression can be applied at different points on the network to move gas from entry points at the right pressures through the NTS to the exit points. Across the 24 sites, there are 70 operational compressor trains, each consisting of:

**Gas Generator** – Generates hot, pressurized gas that is used to drive the power turbine;

**Power Turbine** – The power turbine converts energy in the hot, pressurised gas from the gas generator into a rotary drive that is used to drive the compressor;

**Electric Drives -** HV variable speed electric motor used to drive the gas compressor. These require an HV electrical supply and associated variable speed drive;

**Compressor** – High pressure centrifugal device used to increase the pressure of the process gas stream. Driven by the power turbine or electric motor. Includes ancillary systems such as lubrication and seal systems;

**Vent System -** allow a controlled safe release of contained high pressure gas to atmosphere from transmission plant within agreed noise limits.

2.3. There are also a further 5 compressor trains that have been retired from use in RIIO-1, with a further 2 units at Warrington that are expected to be retired before the start of RIIO-2. An additional 4 new units are currently under construction at Peterborough and Huntingdon.

2.4. Compression ensures that gas flows through the NTS effectively to enable intake gas from the shippers to be conveyed to customers/consumers at obligatory minimum offtake pressures. These assets are essential for fulfilling our licence and commercial obligations to receive, transport and provide gas at agreed pressures.

### Structure of the Case

2.5. This document summarises the justification for the required investment in our Compressor Train assets. All the assets have been assessed using a consistent overall risk based analytical framework.

2.6. The case for compressor train investment is organised into four groups of assets. The groups enable the assets with similar drivers, purpose and impacts to be discussed and assessed collectively.

- Gas Generator and Power Turbine
- Electric Drives
- Compressors
- Vent Systems

2.7. For each group the following structure has been followed:

- **Introduction** – this section with the structure of the case and an overview of the assets and their effective management
- **Equipment summary** – which provides a summary and profile of the asset base
- **Problem statement** – the issues facing the assets, drivers for investment and impact of no investment
- **Probability of failure and Probability of consequence** – sections which set out the way the assets fail and the subsequent stakeholder impacts
- **Options considered** – the potential mix of interventions to be considered for each of the assets within a range of programmes with differing objectives
- **Business case outline and discussion** – the preferred programme option and reasons, given the cost benefit analyses and assessment of other drivers, stakeholder requirements and business objectives
- **Preferred option and plan** – the final selected option restated, along with the spend profile. This document summarises the justification for the required investment at St Fergus. All the site has been assessed using a consistent overall risk based analytical framework.

# Gas Generator Power Train (£89.4m)

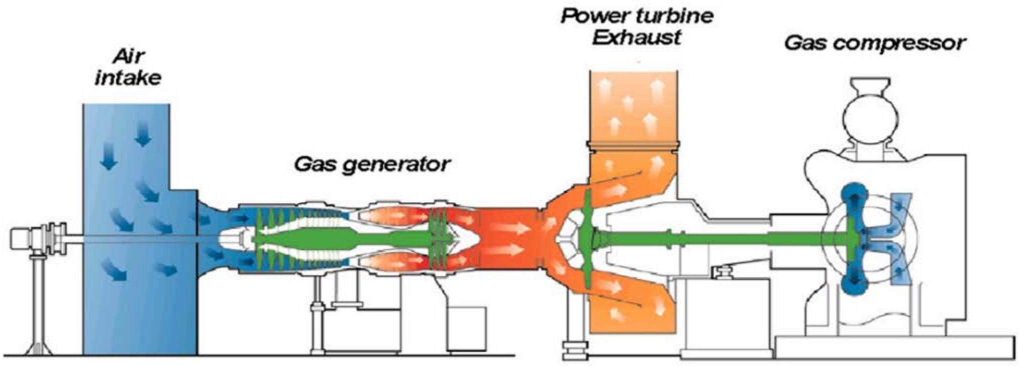
## 3. Gas Generator Power Train - Equipment Summary

3.1. The gas generator power train provides the power to drive the compressor and raise the pressure of the gas to drive its flow through the National Transmission System. It is made up of the Gas Generator, Starter Motors and Power Turbine:

- The gas generator produces high pressure, high temperature exhaust gases to drive the power turbine.
- The starter motor is used to start the gas generator
- The Power turbine converts the energy in the high velocity exhaust gas from the gas generator into the mechanical energy required to power the gas compressor

3.2. These assets are shown in the diagram below:

**Power Train Assets**




3.3. The fuel to drive the gas generator is provided directly from the NTS via associated assets that ensure it is provided at the appropriate pressure, temperature and condition. The efficient and effective monitoring, control and protection of the gas generator power train is provided by the compressor control and safety systems. The gas generator power train is housed within a specifically designed 'cab', the primary purpose of which is to provide noise attenuation to ensure that the relevant environmental permit limits are met. The cab infrastructure provides an element of weather protection but by enclosing the gas generator within a cab, a cab ventilation system together with fire and gas detection and fire protection systems are required. These assets are dealt with in detail in the cab infrastructure paper.

3.4. Each Compressor Unit and the associated fuel, control and cab infrastructure assets are designed to accommodate one specific type of gas generator power train. Assets of one type cannot be utilised in a compressor unit that was designed for another.

### Location and Volume

3.5. As of December 2018, there is a total of 61 operational Gas Generator Power Trains across 23 sites. NG have the following types of gas generator within each power train:

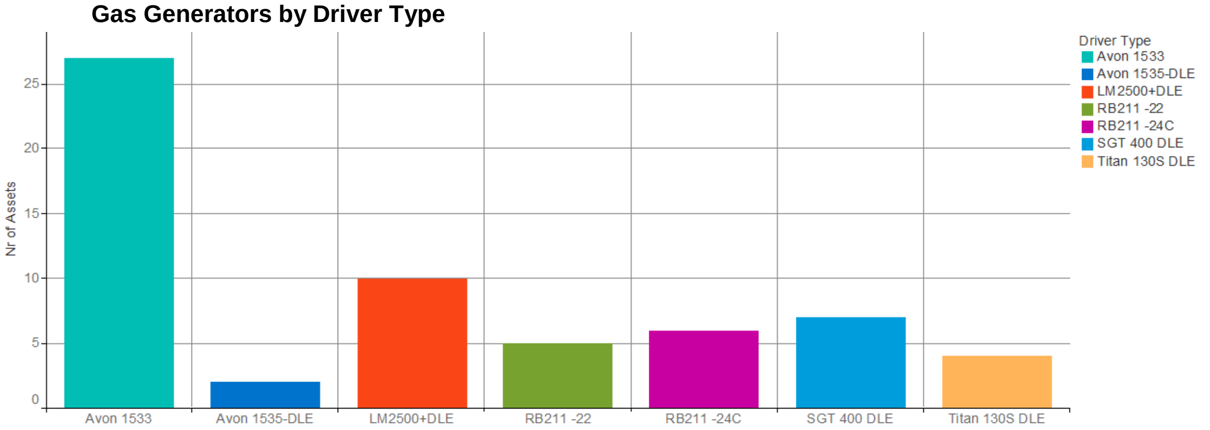
**Generator types within each power train**

| Manufacturer and Type | Volume | Description |
|---|---|---|
| **Siemens Avon (was Rolls-Royce)** | [redacted] | 1970s aero-derivative model, affected by MCPD[1] |
| **Siemens RB 211 (was Rolls-Royce)** | [redacted] | 1980s aero-derivative model, affected by LCPD[2] |
| **Siemens SGT 400** | [redacted] | Modern industrial DLE[3] unit |
| **Solar Titan 130** | [redacted] | Modern industrial DLE unit – 4 more under construction |
| **BHGE LM2500** | [redacted] | Modern aero-derivative DLE unit |
| **Siemens AVON DLE (was Rolls-Royce)** | [redacted] | DLE variant of Avon |

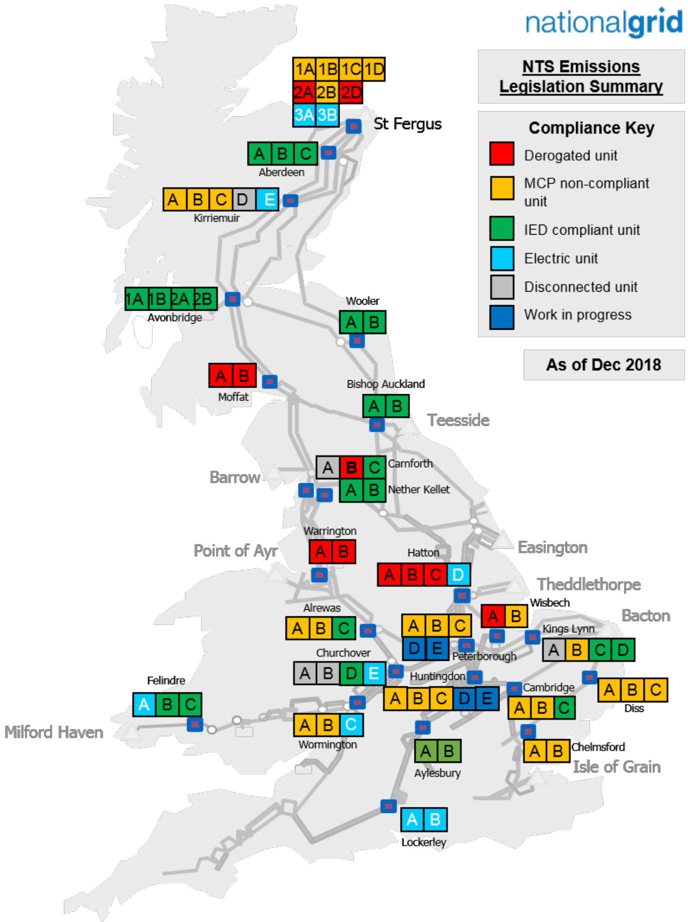
Notes

1. MCPD - Medium Combustion Plant Directive, defines maximum allowable emissions of NOx from combustion plant having a net thermal input of up to 50 MW (thermal)
2. LCPD – Large Combustion Plant Directive, defines maximum allowable emissions of NOx and CO from combustion plant having a net thermal input of more than 50 MW (thermal)
3. DLE - Dry Low Emissions, Emissions control technology applied to gas generators to minimise emissions of NOx and CO

**Gas Generators by Driver Type**



**NTS Emissions Compliance – Compressor Unit Summary**




3.6. To manage availability during overhauls and unexpected failures several spare gas generators are held and maintained as follows, 1 x RB211, 5 x Avon, 2 x LM2500 and 1 x SGT 400. A spare Solar Titan is not held currently, but it may be worth investing in one when the newly commissioned units at Peterborough and Huntingdon start to approach their overhaul interval in RIIO-3 although the OEM (Solar turbines) do offer a service exchange scheme which may be preferable.

## Redundancy

3.7. Compression of gas to enable the management of its pressure and flow through the NTS is essential to delivering the gas at the right pressures and volumes to NG customers. To provide the level of compression and redundancy that is required there is more than one compressor unit on each site. Redundancy is required to enable overhaul of the compressor assets and to mitigate the effects of compressor failure (this is our N+1 design basis). The capacity and number of compressors is designed along with the configuration of the NTS to allow the levels of redundancy and duty required to deliver the contracted levels service to our customers in line with our approach to managing Network Capability.

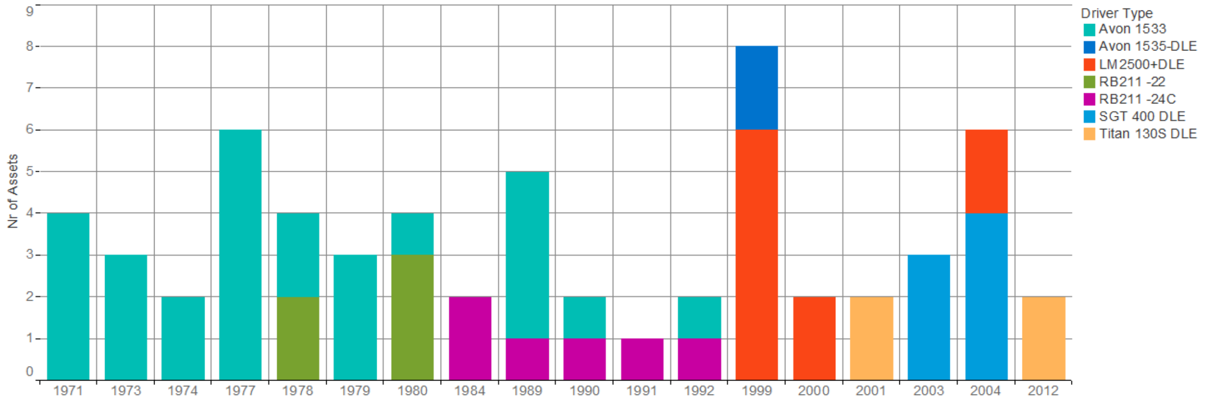
3.8. There is only one gas generator power train within each compressor unit. Therefore, overhaul or failure of the asset results in the unavailability of the compressor train. Due to the extreme temperatures and pressures within gas generators they are a high maintenance item, which is why spares are managed to allow quick return to service when required.

## Pressure Ratings

3.9. The assets within the compressor power train typically operate at the following pressures:

- Gas Generator – 20 bar
- Power Turbine – Atmospheric Pressure

**Gas Generator Drives by Type – Age Profile**



## 4. Gas Generator Power Train - Problem Statement

4.1. The Gas Generator Power Train assets are an extremely complex aging asset base. All elements of the power train assets are subject to increasing failures and NG are seeing increasing trips of compressor units. Many of the gas generators and ancillary equipment are now obsolete and not supported by the OEM. Many of the gas generators are reaching the end of their service lives.

4.2. Environmental legislation (LCPD and MCPD) is impacting the use of some of the compressor types, limiting the number of annual hours that they can be run. Further information can be found in our Compressor Emissions Compliance Strategy Document. Due to the LCPD legislation each RB211 train is limited to either;

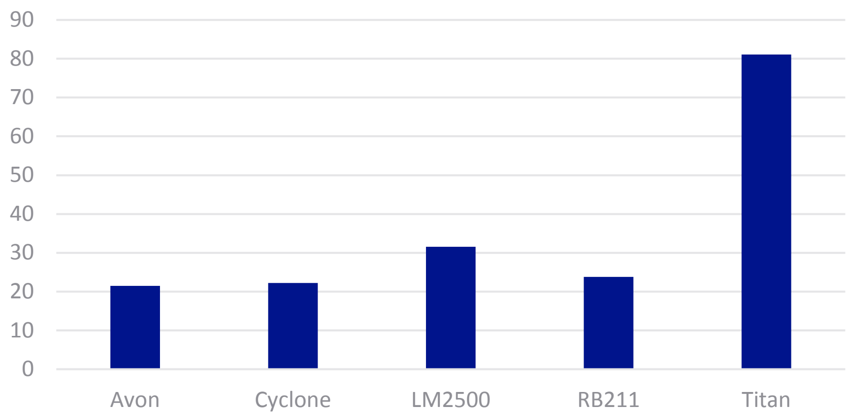
- Maximum of 500 hours per year emergency use or
- Maximum of 17,500 run hours or until then end of 2023, whichever comes first

4.3. The MCPD legislation is expected to apply the same principle to the Avon driven compressor trains by 2030 but is expected only to offer an Emergency Use Derogation allowing operation for an average of 500 hours per year over a 5-year period. Refer to our Compressor Emissions Compliance Strategy (CECS) document for more information.

4.4. The compressor train assets are maintained and overhauled according to the duty they have undertaken (run hours and number of start stops). The levels of duty are set by the manufacturers and are accepted best practice across the EU.

4.5. These overhauls ensure that compression assets remain supported by the manufacturer and continue to operate safely and at an acceptable level of availability. Gas turbines, and particularly industrial gas turbines, are designed to operate continuously at optimum load, but NTS operation often demands short running times and many starts, stops, and load changes because of customer behaviour. This has resulted in the need to increase the number of overhauls, particularly on the Siemens SGT400 fleet. Siemens recommended overhaul interval is 24,000 run hours or 500 starts, whichever comes sooner. The graphic below shows that SGT gas generators (labelled cyclone) are running an average of 22 run hours per start, which means that the start limit is reached when the gas generator has used less than half of its available run hours.

**NTS Fleet average run hours per start by GG Type**



4.6. The frequency of overhauls and general maintenance on the compressors (such as gas generator washing) can be further increased by the poor performance of the associated assets such as air intake filters and fuel gas conditioning skids.

4.7. The overhaul of a compressor train can typically take 13 to 26 weeks.

4.8. The power turbines are specialist items of equipment and although not operating at conditions that are as arduous as those in the gas generator, still require regular overhaul to maintain their integrity.

4.9. The power turbines are bespoke items of equipment tailored to the individual gas generator and compressor application. Many are now obsolete.

## Drivers for Investment

4.10. The key drivers for investment in the Compressor Power Train are:

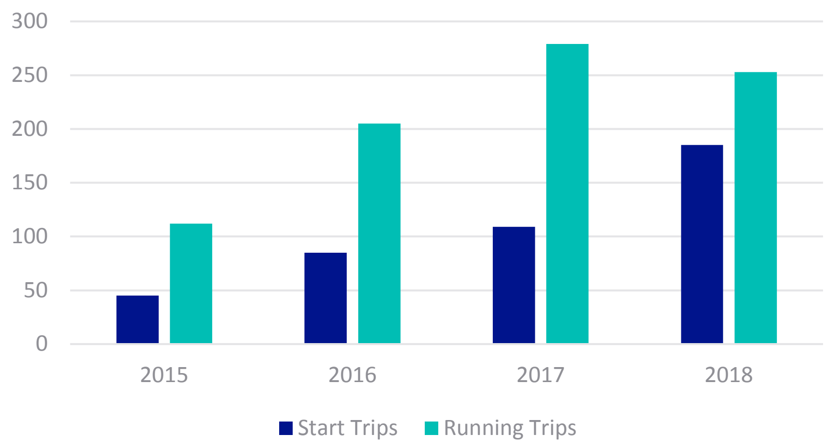
- Asset Duty and Deterioration
- Customer Demand Patterns
- Environment
- Increasing Costs

### *Asset Deterioration and Duty*

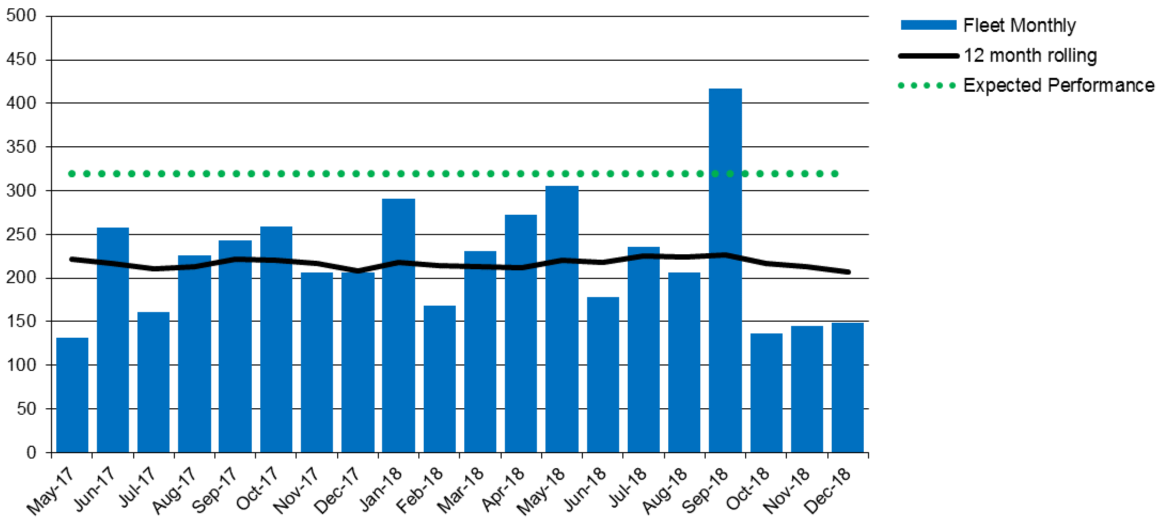
4.11. Gas generators and power turbines deteriorate due to age and wear from use. Factors affecting rates of deterioration include the quality and condition of the fuel and combustion air, and number of starts, stops and load changes. There can also be significant degradation when left unused for extended periods of time, dependent on the environment that they operate within.

4.12. There is evidence of increased defects and failures on the compressor train leading to compressor unit trips or failures to start, although most these do not result in an outage. The increasing number of defects will ultimately lead to increasing unavailability of the compressor unit for the duration of any investigation and repair. In some cases, failures of plant have occurred with significant implications for plant damage and safety.

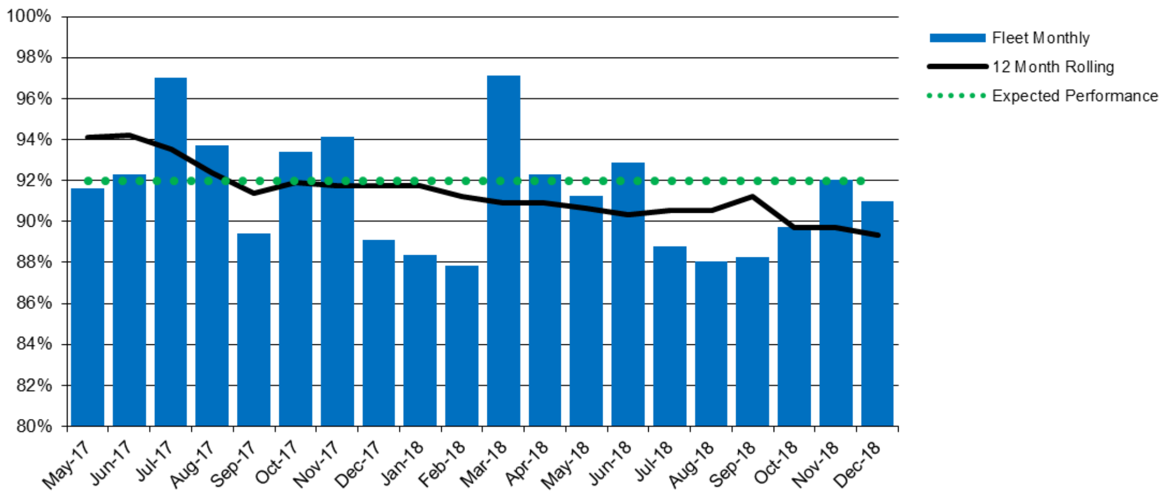
**Historic Compressor Trips**



**Compressor unit Mean Time Between Failure (MTBF)**



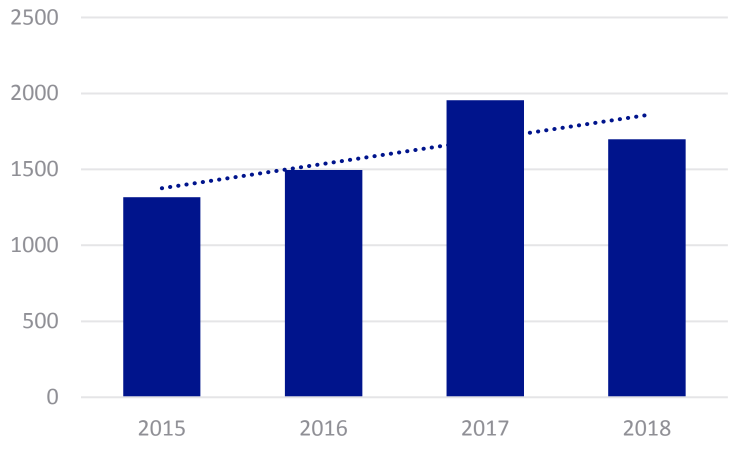

**Compressor Unit Start Probability**



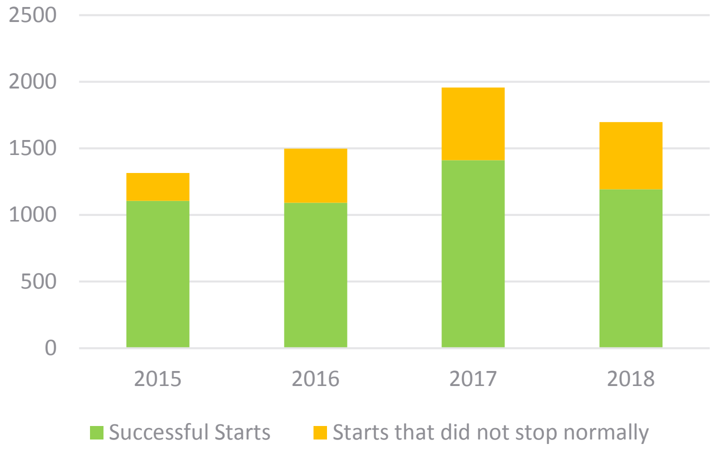

*Asset Deterioration – Unplanned Overhauls*

4.13. More recent experience has found that due to changing demand patterns, gas generators on the NTS are turned on and off more frequently, increasing the rate of deterioration, and causing significantly increased probability of breakdowns.

**Compressor Unit Start Annual Totals**




**Successful Compressor Unit Start Annual Totals**




*Customer Demand Patterns*

4.14. In recent years, the pattern of gas flows required by NG's customers and consumers has become much more variable and much less predictable across the network because of changes in supply patterns and the impact of increasing levels of renewable electricity generation impacting on the demand pattern from gas fired power generation plant.

4.15. Because of this, more compression is required to be available overall, this can be required at different points in the network than was historically the case. The variability of demand has increased the duty required from, and the stresses on, the compressor machinery, for example through greater frequency of starting up and stopping of compressors and shorter run times when loaded. We are also seeing summer running of compressors which have historically only ever operated in the winter months.

4.16. The changing customer driven flow and demand patterns are leading to a change in duty on the compressors, over that for which they were originally designed, in terms of an increased frequency of starts and stops. This is showing in increasing failures and driving an increased frequency of maintenance and overhaul.

*Environment*

4.17. Stringent environmental emissions legislation (Large and Medium Combustion Plant Directives) has reduced the amount of compressor fleet that can be used, concentrating this extra duty on a smaller number of emissions compliant compressors.

4.18. Under the Large Combustion Plant Directive, 8 of the RB 211 generator run hours are restricted to a maximum of 500 hours per year. The remaining 4 RB 211 units are subject to a limited life derogation, allowing continued unrestricted operation until the end of 2023 or until 17,500 operating hours have been consumed from the start date of the derogation, whichever comes sooner, at which point the unit must be decommissioned.

4.19. The Medium Combustion Plant Directive (MCPD) will restrict the operation of any unabated Avon gas generators to an average 500 hours per annum over a 5-year period post 31st December 2029.

4.20. Specific justification must be provided to the Environment Agency for any operation of Avon/RB211 driven compressor trains where there is a DLE or electric drive compressor train on the site. This recently caused an extended site unavailability at Alrewas where consent was not given by the EA to run the available Avon driven compressors during an outage affecting on the DLE Solar driven compressor unit.

## Impact of No Investment

4.21. Compression ensures that gas flows through the NTS effectively to enable gas from the shippers input to the network at entry points to be conveyed to customers/consumers at obligatory minimum offtake pressures, without exceeding the design pressure of the pipeline at the entry points. These assets are essential for fulfilling NG's licence and commercial obligations to receive, transport and provide gas at agreed pressures.

4.22. Failure to adequately invest in maintaining good compressor fleet availability and reliability will undermine our ability to meet the network capability our customers require and expect.

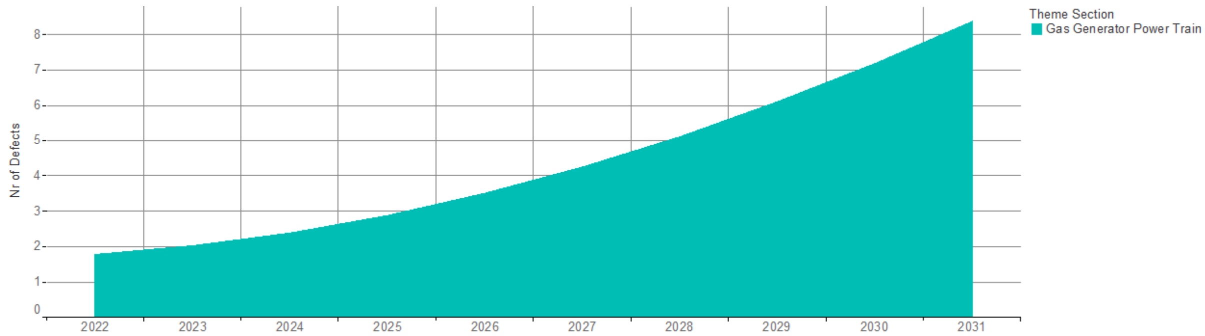
4.23. In the event of a loss of compression, flows of gas across the network are severely restricted. For example, in Scotland this could result in shippers who inject gas at the St Fergus terminal having to restrict or cease their operation due to an inability to move that gas away from St Fergus. At a recent St Fergus stakeholder event the operators said that if we had to constrain St Fergus they would have to begin flaring gas to the atmosphere and may have to shut down production of gas and oil coming in from the North Sea which would have significant environmental and supply consequences.

4.24. Whilst site and network redundancy is designed to manage the effects of single outages, increasing the frequency and duration of these outages impacts on the ability to undertake scheduled maintenance of other units thereby further reducing compression capacity and leading to the potential for network constraints. This has significant negative cost implications on direct and indirect National Grid maintenance costs.

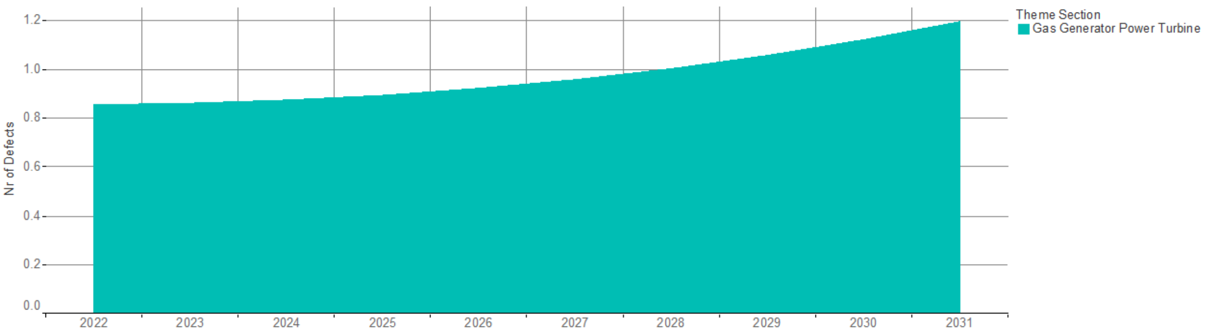
4.25. Without investment, poor condition and safety precautions would result in the compressors being unfit to use, which would then result in an inability to move gas through the network at the required rate. Eventually restrictions at entry points and not meeting agreed offtake pressures at some exit points which in some conditions may lead to disruption to consumer gas supplies.

**Predicted Gas Generator Defects with No Investment**

**Power Train**




**Power Turbine**




4.26. Continuing to run compressor train equipment beyond its recommended service interval increases the risk of a catastrophic failure. NG and the wider industry have experience in managing this type of failure. An example of this happened at St Fergus, when a gas generator turbine disc failed, and the disc and high velocity metal fragments were ejected from the casing. Further occurrences like this could lead to, greatly increased safety risk, reduced reliability and availability, and considerable scrutiny from the HSE. Any failure of a gas generator where components were significantly beyond the manufacturer's recommended overhaul interval would result in serious post-event scrutiny from the HSE.

4.27. A loss of compression in the East of England could result in constraints at Easington terminal, or gas supplies to power stations being compromised, which in turn compromises electricity supplies across the country. It could also have a knock-on effect compromising supplies to the south east of England.

4.28. A loss of compression in the south east could result in supplies to London being disrupted as the Isle of Grain LNG terminal doesn't usually have the injection capacity to supply all demand of London and the south east continuously. It could also result in constraints at Bacton as compression in the east takes gas to and from Bacton terminal to be distributed around the country and into Europe.

4.29. A loss of compression in Wales and/or the West of England could result in gas supplies to Birmingham, Manchester and the South West of the UK being compromised, and supply constraints at Milford Haven.

## Examples of Problem

**Aluminium stator vanes corrosion**

## Spend Boundaries

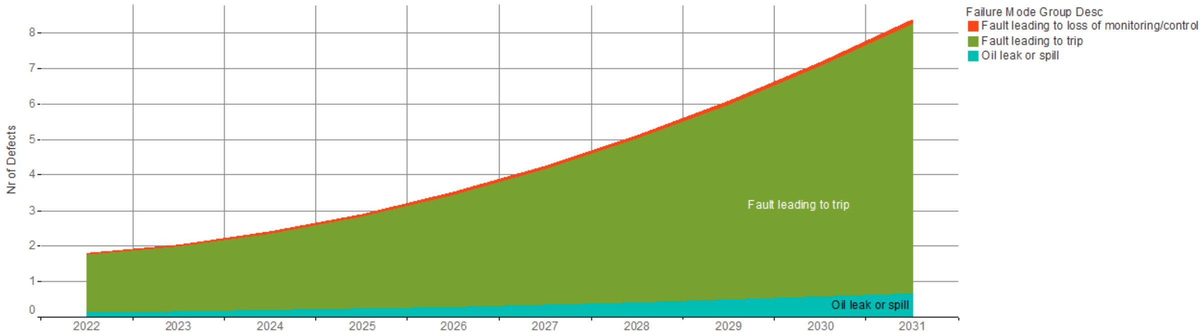
4.30. The air intake and power turbine exhaust are not included in this investment case and are covered in the Engineering Justification Report – Asset Health, Compressor Cab Infrastructure. All Unit Control and Safety Systems are included in the Cyber Resilience Plan (A23.07). The proposed investment includes any ‘no-regrets’ investment at St Fergus to keep it safe and operational whilst the separate funding mechanism for the proposed project is progressed via an Uncertainty Mechanism.

## 5. Gas Generator Power Train - Probability of Failure

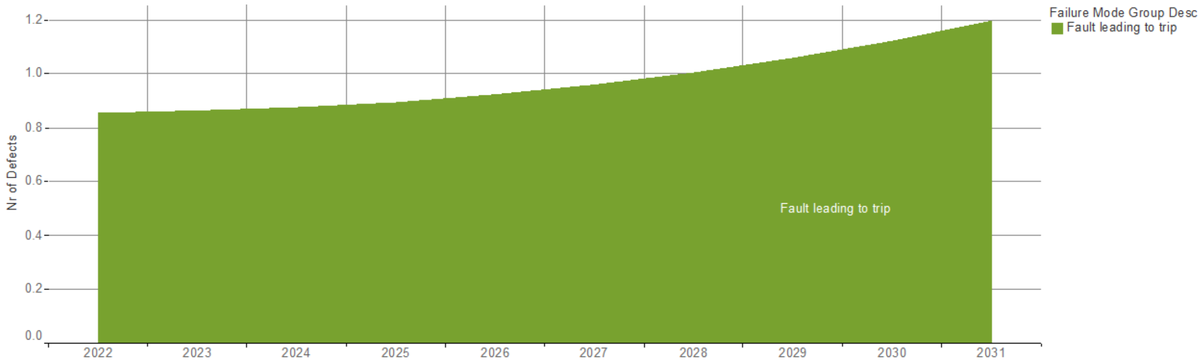
5.1. The probability of failure is modelled using our NOMs methodology. The charts below show the predicted frequency of failures split by failure mode.

**Predicted number of defects by failure mode**

**Gas Generator Power Train**




**Power Turbine**




5.2. The charts show that the failure modes that contribute most to the failure of these assets are:

- Fault leading to trip

### Probability of Failure Interventions

5.3. The table below shows the drivers for Compressor Train investment that are related to the current and future Probability of Failure (PoF). This includes investments that are driven by future PoF deterioration.

**NARMs Interventions**

| NARMs Asset Intervention Categories | Secondary Asset Class |
|---|---|
| **Extension of Expected Asset Life**<br>Includes Minor Refurbishments | Gas Generator<br>Power Turbine |
| **Asset Refurbishment (PoF Driven)**<br>Included Major Refurbishments | Gas Generator<br>Power Turbine |

5.4. These are defined as PoF driven investments as the risk change delivered through investment is modelled as a direct consequence of replacing or refurbishing the asset. The benefits delivered through these investments will be reported as a Network Asset Risk Metric (NARM) as a reduction in monetised risk, arising from a lower PoF delivered through investment. Investment benefits vary depending on the intervention category and are consistent with the Cost Benefit Analysis (CBA) accompanying this Justification Report.

## Consequential Interventions

5.5. Several Compressor Train assets are defined as only delivering Consequential Interventions based upon the following definitions:

*"Any intervention on a network asset, or other infrastructure asset, that modifies the probability of failure, or consequence of failure of* ***another network asset****. A consequential asset can include, for example:*

- *installation or removal of physical infrastructure designed to prevent damage to adjacent assets in the event of an asset failure (e.g. installation of a blast wall),*
- *addition or disposal that increases or decreases the resilience of a local or regional network and hence modifies the consequence of failure of other asset(s) in the locality or region."*

5.6. The SACs that are considered to deliver Consequential Interventions are listed in the table below:

**NARMs Interventions**

| NARMs Asset Intervention Category | Secondary Asset Class |
|---|---|
| **Consequential Interventions (Non-risk tradeable)** | Starter motor (no current interventions) |

## Gas Generator Power Train Interventions

5.7. The interventions in gas generator power trains are shown in the table below:

| Intervention | SAC | Intervention Category |
|---|---|---|
| A22.10.2.1 / Avon / RB211 Fuel Gas Conditioning Skid Installation | Gas Generator | Minor Refurbishment |
| A22.10.2.11 / Power Turbine Overhauls - Dresser Vectra | Power Turbine | Major Refurbishment |
| A22.10.2.12 / Power Turbine Overhauls - GE HSPT | Power Turbine | Major Refurbishment |
| A22.10.2.13 / Power Turbine Overhauls - GEC EAS1 / ERB1 | Power Turbine | Major Refurbishment |
| A22.10.2.14 / Power Turbine Overhauls - Rolls-Royce RT48 / RT56 | Power Turbine | Major Refurbishment |
| A22.10.2.15 / Power Turbine Overhauls - Siemens SGT400 | Power Turbine | Major Refurbishment |
| A22.10.2.2 / Compressor Train Breakdown Budget | Gas Generator | Minor Refurbishment |
| A22.10.2.3 / Gas Generator Overhauls - GE LM2500s | Gas Generator | Major Refurbishment |
| A22.10.2.4 / Gas Generator Overhauls - Rolls-Royce Avons | Gas Generator | Major Refurbishment |
| A22.10.2.5 / Gas Generator Overhauls - Rolls-Royce RB211s | Gas Generator | Major Refurbishment |
| A22.10.2.6 / Gas Generator Overhauls - Siemens SGT400s | Gas Generator | Major Refurbishment |
| A22.10.2.8 / Solar Titan Overhaul - GT & PT | Gas Generator | Major Refurbishment |

## Data Assurance

5.8. All PoF and CoF values are taken from the National Grid Gas Transmission ‘Methodology for Network Output Measures’ (the Methodology). The Methodology was originally submitted for public consultation in April 2018, with three generally favourable responses received in May 2018. On this basis, Ofgem were happy to provisionally not reject the Methodology pending further work to:

- Produce a detailed Validation Report, confirming the validity of data sources used in the Methodology

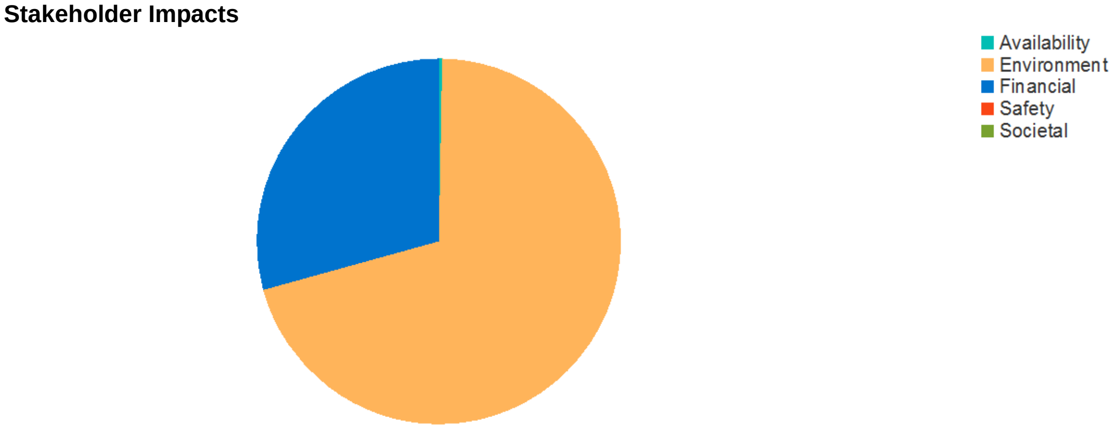
- Test a range of supply and demand scenarios and incorporate an appropriate scenario to best represent Availability and Reliability risk

5.9. A review of the Methodology by independent gas transmission experts has been carried out and several improvements identified and incorporated.

5.10. At the time of writing, the final Validation Report has been submitted to Ofgem. We understand that once this work is complete Ofgem will formally “not reject” the Methodology and a License change progressed to restate our RIIO-1 targets in terms of monetised risk commenced.

## 6. Gas Generator Power Train - Consequence of Failure

6.1. The chart below shows the expected stakeholder impacts because of failure occurring on the Gas Generator Power Train assets. The charts show the relative numbers of consequence events, not relative monetised risk.




6.2. Risk for the Gas Generator (GG) Power Train can be explained as follows, in order of significance:

- **Environmental risk** is associated with the loss of gas through trips and vents of the unit caused by GG asset failure. This is an indirect effect and only a small proportion of GG asset failures will generate a unit trip and associated vent of gas. The NOMs Methodology assumes that all emissions relating to the GG are from vents of unburned gas.

- **Financial risk** is mostly associated with the costs of operating and maintaining the asset at the current level of risk, including routine maintenance and repair. Overhauls are considered as Major Refurbishments (proactive interventions) and are not considered in this category

6.3. The risk associated with other service risk measures for the GG Power Train is negligible, based on the assigned failure modes. Safety risk is associated with the ignition of escaping gas in confined spaces and is not a major risk for the GG asset itself.

6.4. Historically, availability risk due to the loss of a unit is quantified but considered small due to the assumed ability of alternative units to be used in the event of an extended outage of a compressor unit, however limitations on running hours and aging plant means that whilst this has been the case historically it will not necessarily be the case in the future.

6.5. Fuel gas (unburned) is not considered, as the decision to use or not use a compressor unit is largely based on operational requirements or legislative constraints. Therefore, the level of fuel gas use is only indirectly linked to the condition of the asset (e.g. engine efficiency) and is not modelled.

## 7. Gas Generator Power Train - Options Considered

7.1. The following options have been considered for the compressor train assets.

7.2. **Monitoring** - The gas generator and power turbine assets are managed using a comprehensive monitoring, inspection and condition based intervention programme. The assets are fitted with sensors to continually monitor all relevant characteristics such as vibration, temperature, performance etc. Gas generator assets that are used for more than 1000 hours per year are also subject to annual internal visual inspections via a borescope, whilst assets that run less than 1000 hours per year receive a borescope inspection every 2 years.

7.3. The results of this monitoring are analysed every month and together with the results of the inspections and the run hours determine whether intervention is required.

7.4. **Replacement –** Except for those units on service exchange contracts, gas generators and power turbines are only overhauled, never replaced. This is because overhauls provide the high performance required at a lower lifetime cost.

7.5. **Overhauls** – An overhaul will return an asset to 'as new' condition and performance. There is currently an issue developing in Avon overhauls, in that many of the components are now so old that returning to 'as new' condition requires a much more intrusive intervention, with many more complete part replacements than was historically the case which is directly contributes to increased costs. For these assets, the overhauls are based on duty of the asset in terms of:

- the hours they have been run (gas generators, power turbines)
- number of start/stops (starters, gas generators, power turbines)
- time since installation (gas generators, power turbines)

7.6. **Planned Overhaul** – The duty at which the overhauls occur are based on OEM specifications, and are comparable to industry best practice across European Gas Transmission.

7.7. Service exchange of gas generators, currently used for LM2500 & Solar Titan (& potentially SGT400 in the future), is a type of overhaul, the only difference being that a life expired GG is exchanged for a newly overhauled GG rather than waiting for the same one to be overhauled and returned.

7.8. **Upgrade –** Enhancements to planned overhauls to achieve longer service life, particularly LM2500 XTend and HSPT PIP, both of which double the overhaul interval.

7.9. **Unplanned Overhauls / Breakdowns** – 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

7.10. **Maintenance –** maintenance activities include oil filter changes, emissions mapping, engine washing etc.

7.11. **Repairs -** Some gas generator and power turbine repairs are carried out in cases where minor issues appear but a full overhaul would be excessive. There are also smaller components that may occasionally fail and require repair. This includes minor starter motor breakdowns and instrumentation problems.

7.12. Management of Gas Generator Duty – The expensive nature of the overhauls can make it economically viable to balance the run hours of the fleet through swapping gas generators between compatible compressor units.

7.13. Spares – Gas generator and power turbine spares are used to minimise the outage times on the compressor fleet. Rather than waiting for a unit to be overhauled before returning it to the berth, a spare is installed to maintain availability and the overhauled unit then becomes the fleet spare.

7.14. Provision of new fuel gas conditioning units - One of the proposed gas generator investments for the period is the installation of fuel gas conditioning skids for the 14 Avon's & RB211s that are expected to remain in service beyond 2030. This is driven by the deterioration and performance of these assets and the impact of this deterioration on the performance and safety of the gas generator. All the installed low emission gas generators already have enhanced fuel gas conditioning skids installed, and similar skids are being retrofitted across the remainder of the fleet to manage this risk.

7.15. Associated Assets – Interventions on the associated assets will be identified and undertaken as part of the normal defect identification, assessment and remediation process. These are relatively low value, and will only be instigated when a problem arises, never planned.

### Overall Options for the Management of the Gas Generator Fleet

7.16. In the long term, a proactive approach to managing condition is required, which involves investment in the machines, rationalisation of the fleet, better use of condition monitoring, and optimising machine usage across the network. In the short term, there are a number reactive stances that can be taken, but they are not viable long term solutions:

7.17. **Reactive - Fix on Fail Critical Units Only -** Repair critical units, when they fail, and defer planned maintenance on other non-critical units. This increases availability/reliability risk on the units that have had planned maintenance deferred and can only be used as a temporary 'one-off' solution.

7.18. **Reactive - Fix on Fail using Available Spares** - Install a fleet spare and repair the failed unit whenever investment is available. Note that once the fleet spare is installed this involves operating without a fleet spare for some time which means if another unit were to fail the outage window for replacement increases. This increase is from 2 weeks to 4-6 months in most cases, but up to 12 months in some cases where spare parts or OEM workshops have long lead times.

7.19. Neither of the above is a sustainable way to manage assets in the long term because as more maintenance is deferred, and fleet spares are used up, the risk of an asset failure causing an extended outage that could cause network restrictions continuously increases.

7.20. **Maintain Available Spares –** The preferred option is therefore to maintain the inventory of spares to ensure that quick return to service of units is always possible. Funding proposals to repair a spare SGT400 have been included in the plan. RB211's will be managed by fleet rotation, and as units are decommissioned a stock of spares will be maintained that is consistent with the number and expected use of RB211s remaining in service. NG currently hold 5 x Avon spares in good condition.

7.21. These spares will allow effective management of the fleet until decommissioning begins in 2024 for the RB211s and 2030 for the Avon's.

7.22. The 2 spare LM2500s are currently mid-life and will be able to support the fleet through RIIO-2. A spare Solar Titan isn't owned but may become a requirement after RIIO-2 when the new Peterborough and Huntingdon units get closer to their service interval. Any decision will depend on the economics of the service exchange programme.

7.23. When it is beneficial to delay a gas generator overhaul, units can be swapped between berths. For example, with the RB211s that will be decommissioned in the next few years the fleet is being managed so that a minimal number of overhauls are required. Units that have run a lot and are close to requiring overhauls are being transferred into 500 hour per year berths, and the units that have been in 500 hour per year berths and therefore have low run hours are being moved to berths that are expected to run more often.

## Intervention Unit Costs

7.24. The total RIIO-2 investment for Gas Generator Power Train represents 79% of the Compressor Train investment theme. The unit costs that support the Gas Generator Power Train investment were developed using historical outturn costs for 45% of the spend. Obtaining more unit cost information has been inhibited by the low frequency of the works occurring meaning, therefore, no recent actual cost information is available. The remaining 55% of costs, 30% have been estimated from supplier quotations and the remaining 25% have been estimated by other methods, 18% of which relates to the Compressor Breakdown budget which is undergoing further cost analysis and justification post cut-off for this submission.

7.25. Overhauls are considered highly specialist works and cannot be interchanged between manufacturers due to the speciality, know-how and warranties meaning works can only be practically completed by the manufacturer of the equipment.

7.26. The table below provides the unit costs for all the potential Gas Generator Power Train interventions.

**Intervention Unit Costs – Gas Generator Power Train**

| Intervention | Cost (£) | Unit | Evidence | Data Points | Overall value in BP |
|---|---|---|---|---|---|
| **Gas Generators** | | | | | |
| A22.10.2.2 / Compressor Train Breakdown Budget | [redacted] | Per asset | Estimated - Other | 0 | £16,281,032 |
| A22.10.2.1 / Avon / RB211 Fuel Gas Conditioning Skid Installation | [redacted] | Per asset | Estimated - Quotation | 1 | £4,613,294 |
| A22.10.2.3 / Gas Generator Overhauls - GE LM2500s | [redacted] | Per asset | Outturn | 1 | £22,635,145 |
| A22.10.2.4 / Gas Generator Overhauls - Rolls-Royce Avons | [redacted] | Per asset | Outturn | 3 | £5,748,868 |
| A22.10.2.5 / Gas Generator Overhauls - Rolls-Royce RB211s | [redacted] | Per asset | Estimated - Quotation | 1 | £2,292,997 |
| A22.10.2.6 / Gas Generator Overhauls - Siemens SGT400s | [redacted] | Per asset | Estimated - Quotation | 1 | £12,857,156 |

| | | | | | |
|---|---|---|---|---|---|
| A22.10.2.8 / Solar Titan Overhaul - GT & PT | [redacted] | Per asset | Estimated - Quotation | 1 | £3,444,953 |
| **Power Turbine** | [redacted] | | | | |
| A22.10.2.11 / Power Turbine Overhauls - Dresser Vectra | [redacted] | Per asset | Estimated - Other | 0 | £3,903,553 |
| A22.10.2.12 / Power Turbine Overhauls - GE HSPT | [redacted] | Per asset | Outturn | 3 | £9,758,883 |
| A22.10.2.13 / Power Turbine Overhauls - GEC EAS1 / ERB1 | [redacted] | Per asset | Estimated - Other | 0 | £2,309,373 |
| A22.10.2.14 / Power Turbine Overhauls - Rolls-Royce RT48 / RT56 | [redacted] | Per asset | Outturn | 1 | £2,303,914 |
| A22.10.2.15 / Power Turbine Overhauls - Siemens SGT400 | [redacted] | Per asset | Estimated - Quotation | 1 | £3,242,952 |

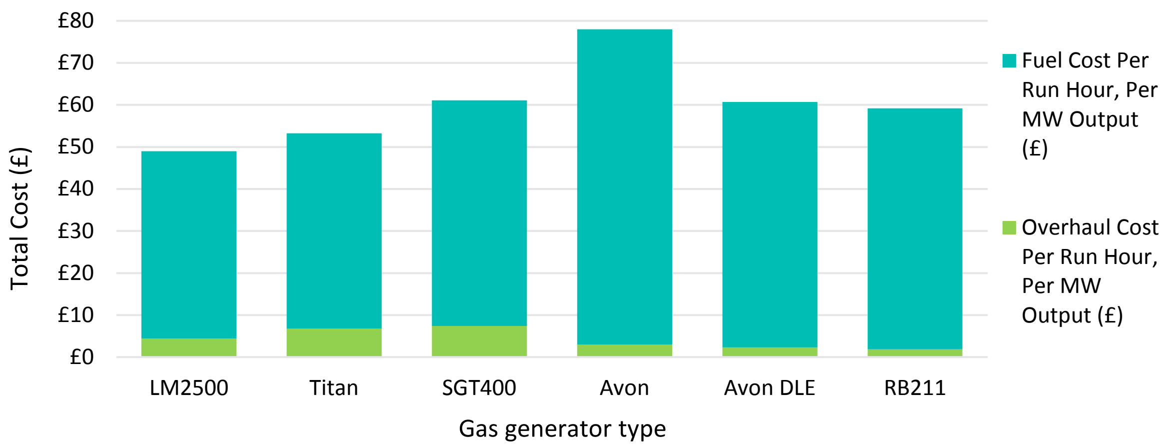
7.27. The Environment Agency (EA) and Scottish Environment Protection Agency (SEPA), are now encouraging reduced use of the Avon driven compressor trains, which results in nearly all compressor use being on the low emission compressor trains. Whilst we fully support this, the capital cost to overhaul the low emission gas turbines is much higher than for Avons and RB211s, and this will result in future overhauls of the compressor trains being more expensive.

7.28. The table and chart below show the overhaul cost and fuel cost per run hour per MW power output of each engine type.

7.29. It can be observed that although the low emission compressor train types (LM2500, Titan, SGT400) are more expensive to overhaul, due to their high fuel efficiency they are the more cost effective compressor trains to use in comparison to Avons.

7.30. RB211 and Avon DLE are cost effective compared to Avons, and are similar in total cost to SGT400s, but the high CO emissions from RB211s renders them non-compliant with the LCPD legislation. The Avon DLE units at Aylesbury are prototypes and are the only 2 of that type ever built, so they cannot be realistically compared to other engine types.

**Cost Comparison Chart For Use Of Different Gas Generator Types**



**Cost Comparison Table For Use Of Different Gas Generator Types**

| OEM | Model | Overhaul Cost (£) | Fuel Efficiency | Fuel cost per run hour, per MW output (£) | Overhaul cost per run hour, per MW output (£) | Total cost per run hour, per MW output (£) |
|---|---|---|---|---|---|---|
| **GE** | LM2500 | £3,772,524 | 45% | £45 | £4 | £49 |
| **Solar** | Titan | £3,444,953 | 43% | £46 | £7 | £53 |
| **Siemens** | SGT400 | £2,571,431 | 37% | £54 | £7 | £61 |
| **Rolls-Royce** | Avon | £958,145 | 27% | £75 | £3 | £78 |
| **Rolls-Royce** | Avon DLE | £1,146,498 | 34% | £58 | £2 | £61 |
| **Rolls-Royce** | RB211 | £1,146,498 | 35% | £57 | £2 | £59 |

7.31. The compressor campaign approach adopted during RIIO-1 has been a successful way to deliver savings on the RB211 and Avon overhauls. This was achieved by tendering for several overhauls over several years in a single work package. This has also helped with staff resourcing as the successful contractor provided a 'value add' into the contract to supply labour for the removal and reinstallation of gas generators that would otherwise have to be done by National Grid staff.

7.32. For LM2500 gas generators, a fixed price service exchange contract is now being used in place of overhauling gas generators that were owned by National Grid. This ensures that all LM2500 gas generators have the latest technology, which improves availability, reliability and safety. It also reduces the capital risk required for an LM2500 mid-life overhaul, which have seen project outturn costs of greater than 150% of expected cost because of additional damage being discovered once the gas generator has been stripped in the OEM's workshop. Lessons learned from this will be able to be applied in RIIO-2. There is the potential to put a similar contract in place for Solar Titan and Siemens SGT400 driven compressor trains

7.33. Avon and RB211 gas generators have been in existence since the early 1970s, and there are a variety of suppliers who are licensed to overhaul gas generators and power turbines on these trains. Given the age of these machines and the lack of OEM supply chains, most overhauls and repairs rely on remanufactured parts (to original OEM specifications).

7.34. Choice of supplier for overhaul is much more restricted for the DLE compressor trains as the OEM retains the IP. These are driven by GE LM2500, Solar Titan, or Siemens SGT400 gas generators. Overhauls on all equipment in these compressor trains are in a closed market, and once the compressor train has been built it is not possible to change the type of gas generator or power turbine that is used. GE and Siemens trade in euros, and Solar trade in American dollars, so the exchange rate has a significant effect on the prices.

## Innovation

7.35. During RIIO-1, we have continued to develop a dynamic portfolio of projects aligned to the Gas Network Innovation Strategy which deliver real value to our customers, stakeholders and the wider industry. We will be continuing to focus on the implementation of innovation into business as usual to drive value throughout everything we do. We will also remain committed to sharing these ideas and best practice across the wider industry to deliver a safe, reliable and efficient network that benefits gas consumers across the UK.

7.36. For the gas generator power train, we developed and implemented several projects in the RIIO-1 period which will be brought forward into this investment period:

- **Compressor Data Analytics & Remaining Useful Life (1 & 2),** a series of projects which look to use previous and trend data to predict failures and other associated problems, both in the long and short term. If successful, this should give greater unit reliability and availability and allow more effective and efficient maintenance planning on compressor assets.

- **Constrained Layer Damping -** Investigation into the use of constrained-layer damping, a project which is looking at mitigating vibrations and the potential problems associated with them, such as unit trips and pipework damage. It does this by examining if the constrained layer damping technique is suitable for use on NTS pipework, which will reduce the potential impact that vibrations can have on compressor availability.

7.37. We are also looking to continue to develop the following projects and deliver benefit from them in this investment period:

- **Novel vibration measurement technologies**, study which explored novel techniques for monitoring vibration, which demonstrated a range of sensors and applications that will inform future vibration monitoring.

- **Selective Catalytic Reduction (SCR) Pre-FEED Environmental and Technical Study**, looked at a catalytic solution for mitigating harmful pollution from non DLE gas generators, which will be considered when designing future compressors if it passes a BAT assessment.

- **Architectural Design of Compressor Site,** provided a series of environmentally sensitive designs for future compressor sites, which will inform future work on compressor sites, helping to mitigate the impact that compressors have on the environment.

- **Variable Envelope Compressors (VEC),** this project explored the potential use of VEC on the NTS, from both a technical and economic point of view. The benefit to the VEC is it allows the compressor's envelope to be more readily varied to match requirements. The results of this project showed that there was potential for using VECs on the NTS, the economics made it unfeasible, although this could change in the future.

- **Next Generation Predictive Emission Monitoring Validation (PEMS),** examined the potential of using the PEMS methodology for NOx and CO emissions, at a range of operating conditions and validating the results against actual emissions measurements. This predictive technique has potential for use in the future when building or upgrading new compressors, or if environmental legislation changed.

- **Compressor Balance of Plant Environmental Study,** delivered a tool for helping to balance technical needs with environmental benefit, which looked at 15 areas of site design. Due to the wide-reaching scope of the tool, the benefit depends on which of 15 areas it looks at and the decision that is made from it, as there is no standard answer for each of the 15 areas.

*Cost Efficiency Innovations:*

7.38. HSPT performance improvement package (PIP) upgrade – This is an OEM recommended power turbine upgrade that increases run hours between overhauls by 100% for an increased overhaul cost of approximately 10%. There is potential to apply to Aberdeen C, Avonbridge 1A, and Avonbridge 2A throughout RIIO-2.

7.39. Solar Titan overhaul interval- Solar Titan gas generators are made with resilient materials that are designed to operate with 'dirty' gas, such as is available on production vessels offshore. Due to the ‘cleanliness’ of the gas on the NTS it may be possible to increase the run hours between overhauls for Solar Titans. These are early discussions with the OEM at present, and the increased risk of continuing to run after the recommended overhaul interval is not yet known

*Performance Innovations:*

7.40. LM2500 trip predictor – An ongoing NIA project that aims to produce a tool that can be used to predict when an LM2500 gas generator will trip. If successful results are achieved, this will help to improve network resilience as remedial action can be taken before the engine trips.

7.41. RUL – An ongoing NIA project that aims to monitor gas generator running conditions and provide warnings if similar conditions as those experienced by the failed engine at St Fergus occur.

7.42. Trip reduction programme – To improve compressor train availability and reliability by investigating common root causes of trips to drive focussed investment.

7.43. GE online condition monitoring – As above, but with OEM support to monitor running conditions and suggest changes to operating patterns to improve reliability. This also allows condition prediction by comparing operating patterns to other GE engines across the world to understand when problems may be arising in each engine.

7.44. OxyCat (Feed study only) – Will potentially allow gas generators that are outside LCPD & MCPD limits continue to run by reducing CO emissions. This has been implemented successfully at Aylesbury and could potentially be applied to Avons / RB211s if proven to work and be financially viable.

7.45. The cab infrastructure theme refers to HEPA filter upgrade, this will potentially extend engine life therefore reducing maintenance costs in the future. It is also claimed by the suppliers that improved filters improves the fuel efficiency of the engine, which leads to reduced fuel costs.

## 8. Gas Generator Power Train - Programme Options

8.1. Our aim in developing the investment plan is to deliver value to our consumers and stakeholders.

8.2. As described in the section below ‘Gas Generator Power Train - Business Case Outline and Discussion – Investment Decision Approach’ these assets are maintained as recommended by OEM guidance that aligns with industry practice. This means that the work involved does not have genuine optionality as the assets must be maintained in a particular way and at predictable points in their lifecycle. Our plan incorporates the minimum number of interventions required to deliver this and therefore we do not consider that there are other credible options that ensure the intended asset performance and safe operation of gas generator and power turbine assets.

8.3. The proposed programme is therefore based on current OEM best practice guidance and represents the lowest whole life programme of investment to deliver the outcomes over RIIO-2 and RIIO-3.

8.4. As a result, we have therefore not considered any further programme options as any of those would be an increase in initial investment and overall whole life cost from this proposed position.

## 9. Gas Generator Power Train Business Case - Outline and Discussion

9.1. In this section, we set out our overall investment plan for the gas generator power trains. This section demonstrates why the proposed investment levels for gas generator power trains are the right levels to ensure the health and reliability of these assets for the investment period and beyond.

### Key Business Case Drivers Description

9.2. In developing our risk forecasts and proposed plans we have considered the impact of the following drivers for investment on these assets:

- Asset Duty and Deterioration
- Customer Demand Patterns
- Obsolescence
- Environment
- Increasing Costs

### Business Case Summary

9.3. In appraising asset health investment, we have considered how our assets can impact on several outcomes:

- Reliability risk
- Environmental risk
- Safety risk
- Societal risk

9.4. Failure of gas generator power trains can affect these outcomes.

9.5. The outcome of this investment is to:

- Ensure we deliver against our stakeholder priority: "I want to take gas on and off the system when and where I want"
- Ensure that the compressor fleet can continue to provide a level of compression availability and reliability both efficiently and economically

*Stakeholder Support*

9.6. Consumer and stakeholder research and engagement has been integral to the development of our asset health investment plans. Early discussions realised that to engage in meaningful dialogue, our plan outputs should be presented at a programme rather than asset level of detail. This is due to the integrated nature of our Asset Health plan which makes it challenging to disaggregate and engage on individual elements. For details of our stakeholder engagement approach please refer to 'I want to take gas on and off the system where and when I want' [Chapter 14 of the GT submission].

### Interventions Scope

9.7. The gas generator and power turbine assets are managed using a comprehensive monitoring, inspection and condition based intervention programme. The assets are fitted with sensors to continually monitor all relevant characteristics such as vibration, temperature, performance etc. The assets are also subject to annual internal visual inspections via a borescope.

9.8. The results of this monitoring are analysed every month and together with the results of the inspections and the run hours determine whether intervention is required.

9.9. Interventions are applied only when performance is observed to deteriorate or run hour limits are reached.

*Overall*

9.10. The compressor train fleet will need to be maintained based on the current policy as this aligns with industry practice and OEM guidance. In RIIO-1 5 units have been retired from use so far, and 2 more at Warrington are scheduled to be decommissioned. In RIIO-2 the fleet size will decrease slightly as some RB211 and Avon driven compressor trains are decommissioned and new compressor trains are commissioned. Ongoing Network Capability work is challenging the need for each compressor unit, and following the completion of compressor builds for GT07, the fleet will have more reliable units that aren't restricted by emissions legislation which will allow the fleet size to be further reduced.

9.11. The inspections and monitoring regime will be continued throughout the investment period as this drives the lowest whole life risk cost for the management of assets of this type.

9.12. The overhaul expenditure for Gas Generators and Power Turbines is driven by:

- The number of equivalent hours - calculated using; run hours, starts, trips, and time since installation
- Number of unexpected breakdowns leading to overhaul
- The number of spare gas generators to minimise outage time
- Overhauls on starters are driven by the number of start operations they perform

*Gas Generator Planned Overhauls*

9.13. Gas Generator inspection and overhaul will be undertaken based on manufacturers recommendations. The table below shows the inspection overhaul intervals for each type.

**Gas Generator Overhaul Intervals**

| Manufacturer and Type | Overhaul interval |
|---|---|
| Avon | 25,000 hours |
| RB 211 | 25,000 hours |
| SGT 400 | 25,000 hours |
| Titan | 30,000 hours |
| LM2500 | 25,000 hours |
| AVON DLE | 25,000 hours |

9.14. Gas generators are required to be overhauled after 25,000 except for Titans which are overhauled after 30,000 hours. There are also reduced scope overhauls available for RB211s and Avons which recertify the machines for 10,000 hours. These are currently being used for RB211 overhauls, and as we approach 2030 they will start to be used on Avons as well.

9.15. Overhaul run-hours are based on manufacturers recommendations and are consistent with overhaul intervals applied by other European Gas Transmission operators.

9.16. The existing fleet of spare Avon / SGT400 / LM2500 gas generators will be retained to provide the ability to maintain compression during overhauls.

9.17. The existing strategy of utilising a service contract that overhaul the Titan and LM2500 gas generators will be retained. The contract provides for an overhauled engine to be provided as the existing is taken for overhaul. So, the management of the spare engines required to undertake this lies with the supplier.

### *Power Turbine Planned Overhauls*

9.18. Power turbine inspection and overhaul will be undertaken based on manufacturers recommendations. The table below shows the inspection overhaul intervals for each type.

**Power Turbine Overhaul Intervals**

| PT type | Mid-life inspection interval | Overhaul interval |
|---|---|---|
| **EAS1 / ERB1** | 25,000 hours | 50,000 hours |
| **RT48 / RT56** | 50,000 hours | 100,000 hours |
| **SGT400** | N/A | 48,000 hours |
| **Solar Titan** | Integral to the gas generator, so overhauled at the same time | |
| **Vectra** | N/A | 50,000 hours |
| **PGT25** | N/A | 25,000 hours |
| **PGT25 PIP (Not yet installed)** | N/A | 50,000 hours |

### *Starter Overhauls*

9.19. Overhaul for gas powered starters will be undertaken based on manufacturers recommendations, which is every 500 starts. However, as these are on the low use compressor units it is unlikely that any of the NG gas fired starter motors will reach 500 starts in their lifetime.

9.20. Electric and hydraulic starter motors do not have a service interval and aren't expected to fail in the lifetime of the compressor unit.

9.21. Starter motor overhaul costs are currently included within the Fleet Management costs for Gas Generator assets

### *Unplanned Gas Generator and Power Turbine Overhauls*

9.22. The number of unplanned gas generator overhauls has been based on historic performance. This indicates 2 overhauls will be required on the Avon or RB211 generators or 1 overhaul on the other generator types per year. This also includes all small ancillary equipment such as starter motor and lube oil pump repairs.

9.23. This estimated number of unplanned overhauls may differ as gas flow/demand patterns are expected to increase the number of stop/starts required of the gas generators. However, we have accounted for this increase to be mitigated by the investment on some of the supporting plant and equipment such as fuel gas conditioning.

*Fuel Gas Condition Systems*

9.24. It is proposed to undertake 14 replacements of Fuel Gas Condition Systems. This is to Improve safety, performance, and reduce overhaul costs by combatting deterioration of components and enable the continued running of the Avon / RB2111 500 hour limited standby units past 2030.

*Summary*

9.25. In determining the volumes of work full account has been taken of the gas generator and power turbine assets being decommissioned as part of the MCP Programme.

9.26. There are no credible programme options to assess that ensure the intended asset performance and safe operation of gas generator and power turbine assets. These assets are maintained as recommended by OEM guidance and aligns with industry practice. Any failure of a Gas Generator/Power Turbine where components are significantly beyond the manufacturer's recommended overhaul interval would result in serious post-event scrutiny from the HSE. The proposed strategy therefore delivers the outcomes at lowest whole life cost based on current OEM best practice guidance.

9.27. The impact of no investment in our Compressor Train assets is a significant increase in service risk over a 10-year period, the most significant impact being a doubling in the volume of gas released to atmosphere every year through trips and vents caused by Gas Generator or VSD asset failures. There is also an equivalent increase in the number of potential outages every year caused by these same assets failing, resulting in isolations of the NTS. This option includes the reactive only investment across all the Compressor Train assets and is the option against which all the other options are compared.

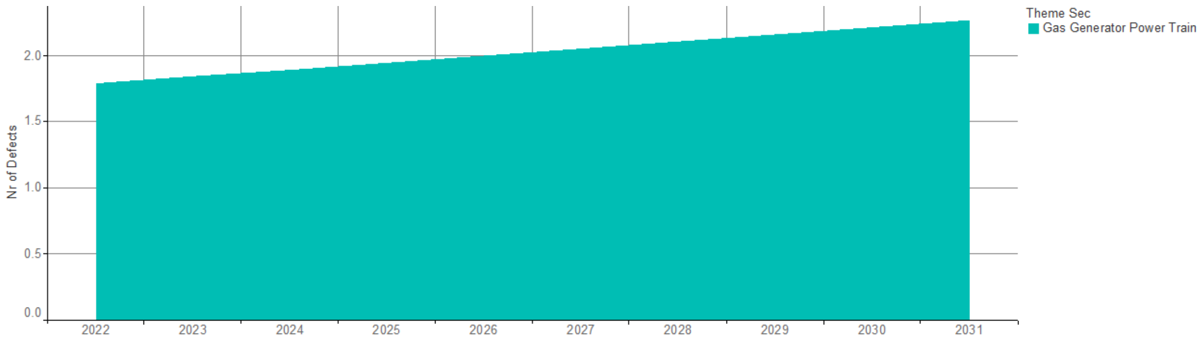
## Benefits of Investment

*Defects*

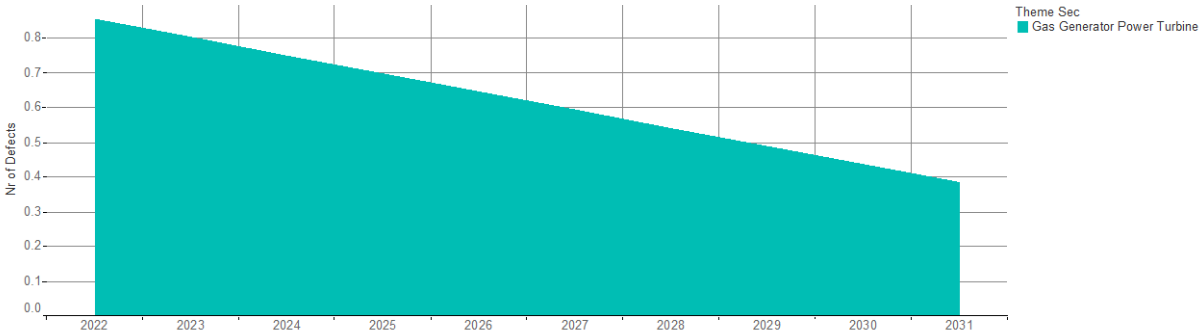
9.28. The charts below show the predicted defects following the preferred programme of investment for gas generator power trains by asset type.

**Predicted Defects with preferred investment option**

**Gas Generator Power Train**




**Power Turbine**


Theme Sec
Gas Generator Power Turbine
Nr of Defects
0.0
0.1
0.2
0.3
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2022
2023
2024
2025
2026
2027
2028
2029
2030
2031

## Preferred Option

9.29. To deliver the required outcomes for all our stakeholders we have developed the most effective combination of efficient interventions. These form the programme of work for the gas generator power train assets in the investment period. [redacted]:

**Intervention Volumes**

[redacted]

## Asset Health Spend Profile

9.30. The profile of investment in the gas generator power train assets, driven from the derived volumes of work and the efficient unit costs, for the period is shown is the table below:

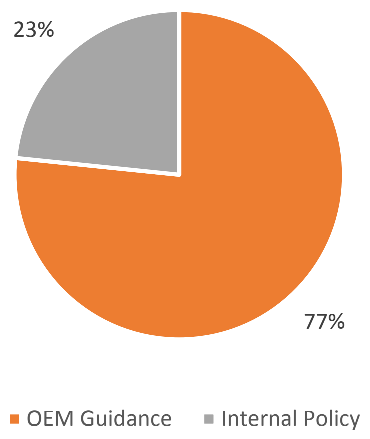
**Spend Profile**

| Investment (£ 000's) | RIIO-2 | | | | | RIIO-3 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 |
| **Gas Generator** | 27,310 | 17,006 | 5,688 | 7,301 | 10,568 | 22,995 | 17,148 | 7,602 | 21,163 | 16,020 |
| **Power Turbine** | 7,856 | 9,759 | 0 | 0 | 3,904 | 2,322 | 2,322 | 3,092 | 5,814 | 10,899 |
| **Total** | 35,167 | 26,765 | 5,688 | 7,301 | 14,472 | 25,317 | 19,470 | 10,694 | 26,977 | 26,920 |
| | **89,392** | | | | | **109,378** | | | | |

## Intervention Drivers

9.31. The following chart shows the breakdown of investment across each of the intervention drivers. This shows that the majority of the investment consists of interventions that are based on OEM Guidance with the remainder based on internal policy.

**RIIO-2 Gas Generator Power Train Intervention Drivers**[1]




## Preferred Programme CBA

9.32. We are targeting an appropriate level of asset health investment in gas generator power trains to mitigate the reliability, safety and environmental risks from the ageing asset base.

9.33. In line with HM Treasury Green Book advice and Ofgem guidance we have appraised whether investment in gas generator power trains is value for money. We have considered costs over a 45-year period in a full cost benefit analysis (CBA).

9.34. The CBA for the gas generator power trains investment over the period is shown below.

**CBA Summary**[2]

| | 10 years | 20 years | 30 years | 45 years |
|---|---|---|---|---|
| **Present Value costs (£m)** | £73.25 | £124.32 | £172.82 | £239.65 |
| **Present Value H&S benefits (£m)** | £- | £- | £- | £- |
| **Present Value non H&S benefits (£m)** | £0.54 | £6.14 | £26.01 | £88.61 |
| **Net Present Value (£m)** | £(72.71) | £(118.18) | £(146.81) | £(151.03) |

9.35. The option proposed represents the least non-cost beneficial option even though overall the total NPV is not cost beneficial. However, our overarching compressor strategy identifies the need case for our compressor stations and units and accounts for ongoing asset health costs as part of that CBA process. Moving forwards a robust Network Capability review will reassess these needs on an ongoing basis and our asset health programme for our compressors will continually align to ensure we invest to maintain the reliability of these essential machines.

9.36. We have challenged whether this is the right programme of work. In developing our plans and making our decision we have been fully cognisant of the need to develop plans that are value for money, acceptable, affordable and deliverable.

[1] See Appendix A for intervention driver category definitions
[2] A14.11.2 Gas Generator Power Train CBA

9.37. This level of investment will ensure we successfully manage asset deterioration and obsolescence, whilst meeting our legal obligations. It will ensure we deliver the outcomes that consumers and stakeholder tell us they want us to meet.

*Unit Cost Sensitivity*

9.38. We have used the potential range of unit cost variance to assess the sensitivity of the Cost Benefit Analysis to the upper and lower limits. The graph below shows the results of this compared to the preferred option.

**Net Benefits of Upper and Lower Unit Cost Sensitivity**


9.39. Whilst the level of cost benefit and the payback period changes as the unit costs vary, the investment remains non cost beneficial across the range of unit costs. The potential range of units does not cause our decision to change.

9.40. Across our stakeholders there is little support for keeping the costs the same as in RIIO-1, given the unacceptable consequential increase in risk.

## 10. Gas Generator Power Train Preferred - Option Scope and Project Plan

10.1. The section summarises our preferred investment plan required to deliver acceptable and affordable outcomes for our stakeholders.

### Preferred Option

10.2. To deliver the required outcomes for all our stakeholders we have developed the most effective combination of efficient interventions. These form the programme of work for the gas generator power train assets in the investment period. [redacted]:

**Intervention Volumes**

[redacted]

10.3. A22.10.2.2 / Compressor Train Breakdown Budget and A22.10.2.7 / Fleet Management Minor Refurb are excluded from this list as they relate to all Secondary Asset Classes within the compressor train.

### Asset Health Spend Profile

10.4. The profile of investment in the gas generator power train assets, driven from the derived volumes of work and the efficient unit costs, for the period is shown is the table below:

**Spend Profile**

| Investment (£ 000's) | RIIO-2 | | | | | RIIO-3 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 |
| Gas Generator | 27,310 | 17,006 | 5,688 | 7,301 | 10,568 | 22,995 | 17,148 | 7,602 | 21,163 | 16,020 |
| Power Turbine | 7,856 | 9,759 | 0 | 0 | 3,904 | 2,322 | 2,322 | 3,092 | 5,814 | 10,899 |
| Total | 35,167 | 26,765 | 5,688 | 7,301 | 14,472 | 25,317 | 19,470 | 10,694 | 26,977 | 26,920 |
| | 89,392 | | | | | 109,378 | | | | |

### Delivery Planning

10.5. At this point in time the delivery of our RIIO-2 and RIIO-3 plans are in principle deliverable based on initial assessments of work. We will regularly review the plan to consider any known or changing constraints, customer impacts and bundling opportunities. In the event of churn our plan must be reoptimised to reflect the impact of the change and provide an opportunity to reconsider the efficient timing of delivery.

10.6. We recognise that many of our asset classes are co-located across the NTS pipe network and sites. Much of our investment delivery also requires outages of the associated pipelines or plant and equipment. The availability of outages is extremely limited across most of the NTS due to the radial nature of the network. It is therefore most efficient from both financial and network risk points of view to bundle investment across asset classes within the same outage period. This maximises the work undertaken in any outage whilst ensuring efficient delivery through minimised project overheads. For cabs and compressor train projects it may be possible to take more localised outages bypassing the unit. This depends on network flow conditions and the availability of local/supporting units. Therefore, the availability and reliability of the supporting units are also critical factors. Our deliverability assessment and phasing of the work has accounted for supporting unit availability and the availability of sites which can provide similar compression requirements. By providing options to "re-direct" gas flows, compression availability also influences the likelihood of outages on other parts of the network.

# Compressor (£7.1m)

## 11. Compressor - Equipment Summary

11.1. The compressor raises the pressure of the gas to drive its flow through the NTS. The rotary drive from the Gas Generator Power Turbine or Electric Drive drives the compressor unit to pressurise the gas.

11.2. The compressor asset comprises all parts of the compressor, its supporting structure, coupling to the power turbine or electric drive, dry gas seal or wet gas seal, lubrication oil and oil/nitrogen seal supply systems.

11.3. Centrifugal compressors deliver high flow capacity, have good reliability, and require significantly less maintenance than reciprocating compressors. However, the performance characteristic of centrifugal compressors is more easily affected by changes in gas conditions and accurate process control is necessary to avoid operation in damaging surge or choke conditions. The rotating element of a centrifugal compressor rotates at between 5,000 and 10,000 rpm.

11.4. A critical part of the compressor from an integrity perspective are the gas seals that prevent the escape of high pressure gas around the rotating shaft of the compressor where it passes through the compressor casing. Several compressor shaft seal technologies are in use, reflecting the different ages of the assets and the preferred technology suppliers of the various OEMs.

11.5. Dry gas seals utilise high pressure gas from the compressor discharge and nitrogen as part of the necessary purge for the mechanical seal. This type of seal needs a nitrogen system to provide the medium to purge the seal. Wet gas seals are an older technology and use oil as the medium within the seal and require an oil system. There is one Nitrogen / Air or one Oil system for each compressor.

11.6. Historically compressor shaft seals were ‘wet’ oil-based systems. These remain in use on many older units on the NTS, but lead to higher natural gas emissions (via the oil degassing vent) than modern ‘dry’ gas-based systems. Dry gas systems also remove the potential for oil leaks into the pipeline.

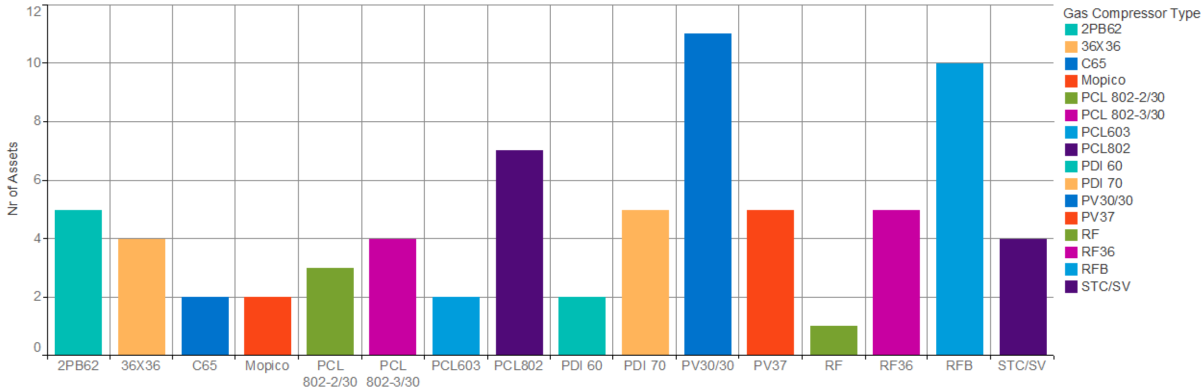
11.7. The coupling between the drive and compressor transmits the rotating power to the compressor. Bearings within the compressor carry the load of the rotating elements.

## Location and Volume

11.8. There are 61 Gas Generator powered Compressors Trains and 9 Electrically powered Compressors Trains across the NTS (excluding St. Fergus).

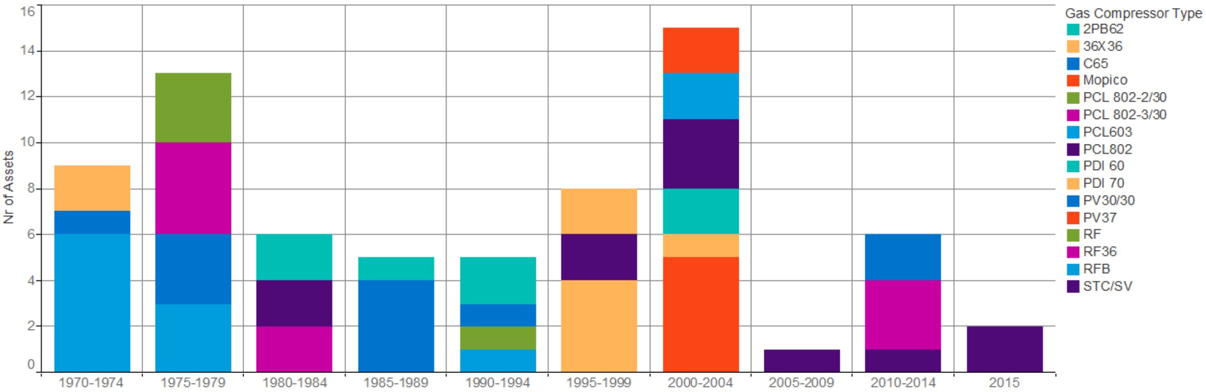
11.9. The chart below shows the numbers of each type of compressor.

**Compressors by Type**




11.10. The chart below shows the age profile of the compressors split by type

**Compressor Age Profile by Type**




## Pressure Ratings

11.11. The compressor assets operate at a range of pressures from 40 to 94 bar with design pressures between 70 and 94 barg.

## Redundancy

11.12. Compression of gas to enable the management of its pressure and flow through the NTS is essential to deliver the gas at the right pressures and volumes to NG customers. To provide the level of compression and redundancy that is required there is more than one compressor unit on each site. Redundancy is required to enable overhaul of the compressor assets and to mitigate the effects of compressor failure. The capacity and number of compressors is designed along with the configuration of the NTS to allow the levels of redundancy required to deliver the contracted levels service to our customers.

11.13. There is only one compressor within each compressor unit. Therefore, overhaul or failure of the asset results in the unavailability of the compressor train.

## 12. Compressor - Problem Statement

12.1. Compressors, their components and associated assets require ongoing intervention to enable them to operate effectively and safely. They are typically low maintenance assets and are subject to a comprehensive and continual monitoring programme. This condition / performance based approach identifies the need for investigation and intervention. Regular intervention is required to manage the whole life cost and performance of this critical asset.

### Drivers for Investment

12.2. The key drivers for investment in the compressor assets are:

- Asset Deterioration
- Obsolescence
- Compressor repurposing

12.3. The assets deteriorate over time and with duty which leads to their inability to perform their required function. This can also result in them presenting a risk to health and safety and damage to associated plant and equipment. The obsolescence of some of the assets can mean, despite a comprehensive spares strategy, a risk of increased impact when they fail.

12.4. **Deterioration and Degradation**– Compressors and the associated assets deteriorate and degrade over time and with the duty they perform.

12.5. The older Wet Gas Seals within most National Grid's Compressor fleet degrade over time and usage. Machinery oil can be lost into the process gas stream affecting downstream customers and compression assets. Deterioration of seals (especially dry gas seals) is increased through particulates and liquids in the seal gas supply. We use coalescing filters to condition the seal gas supply for the dry gas seals to remove liquids and particulates and prevent damage and deterioration of the seals.

12.6. **Obsolescence** - Some of the original instrument systems that feed nitrogen to the compressor are now obsolete which increases repair times leading to increased outages when intervention is required.

12.7. **Compressor repurposing -** Another driver is repurposing the compressor for different duty, e.g. Bishop Auckland, where it is designed to help gas flow down from Scotland into England, but in the future, may need to flow from England into Scotland, which requires a different compressor design. This is covered by the impeller refurb investments, but would be called a re-wheel rather than refurb.

### Impact of No Investment

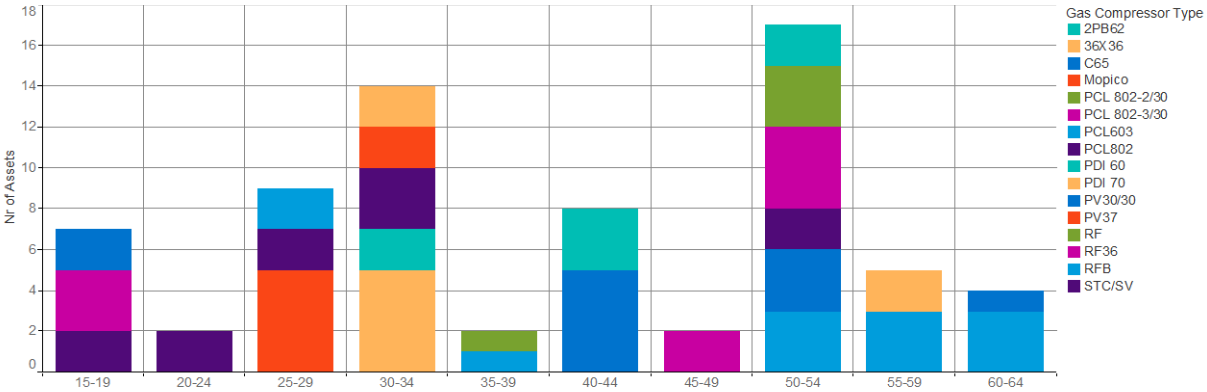
12.8. Lack of investment in the compressor assets will result in the continued deterioration and failure of some of their components. Gas seals can leak high pressure gas with wet seals potentially leaking oil into the main NTS and causing damage to downstream assets. Bearings and couplings can fail leading to failure of the compressor and potential safety issues. Obsolescence of some of the seal air systems will lead to increased repair/replacement time should any failures occur. Obsolescence has caused issues on the dry gas seal nitrogen system at Alrewas, but could affect many other nitrogen systems. It has also occurred on oil pumps, but this doesn't usually cause issues as different types of pump can usually be used, and we'd typically see obsolescence on the RB211/Avon driven units, so decommissioning will help to release some spares.

12.9. Without compression, it would not be possible to supply gas consumers across the UK with the energy they require for industrial processes, generating electricity and heating their homes. Pressures will not be maintained on the network resulting in obligatory minimum offtake pressures not being met, supplies to gas consumers being compromised, and shippers being unable to put gas into the network.

### *Asset Age*

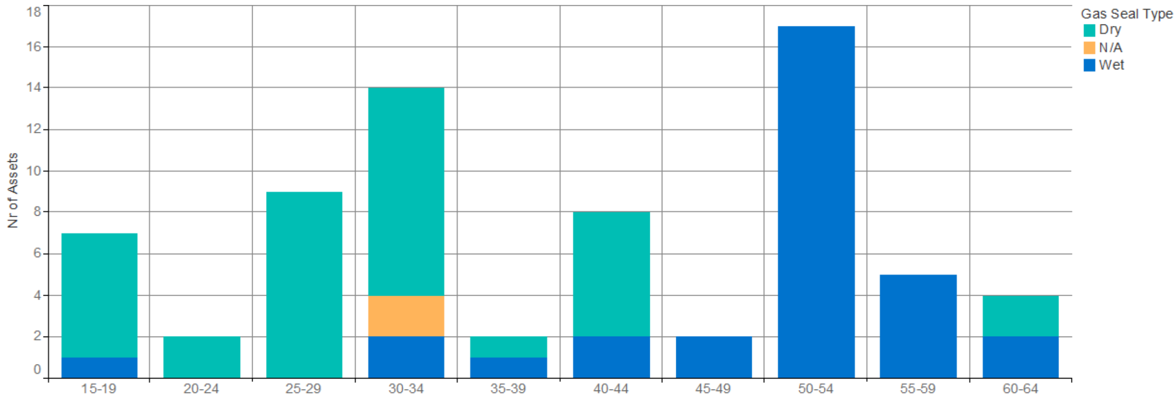
12.10. The chart below shows the age of the compressor assets at end of RIIO-3 without investment.

**Compressors by Type – Age profile by end RIIO-3**




12.11. The chart below shows the age of the compressor assets at end of RIIO-3 without investment split by seal type.

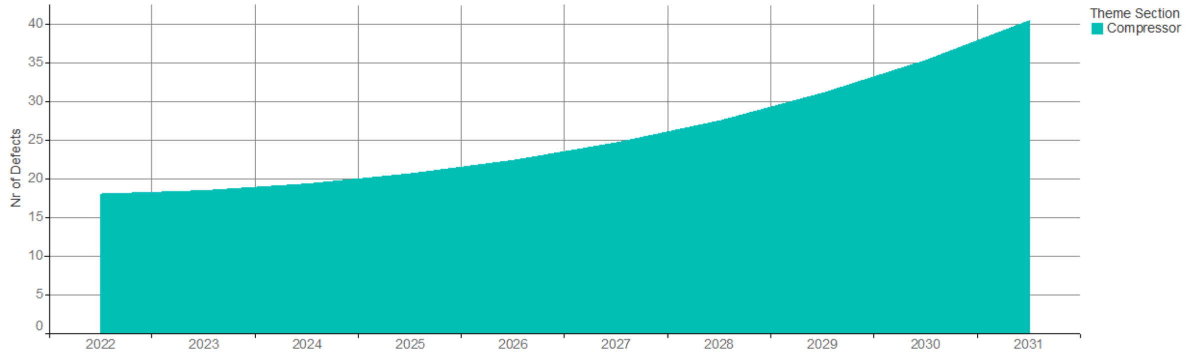
**Compressors Seals by Type – Age profile at end of RIIO-3**




### *Defects*

12.12. The chart below shows the defects predicted for the compressor assets based on defects data recorded in Ellipse and applying our NOMS methodology deterioration models. The deterioration assumes no investment in the compressor assets.

**Predicted Defects with No Investment**




## Examples of Problem

**Compressor Casing Corrosion**

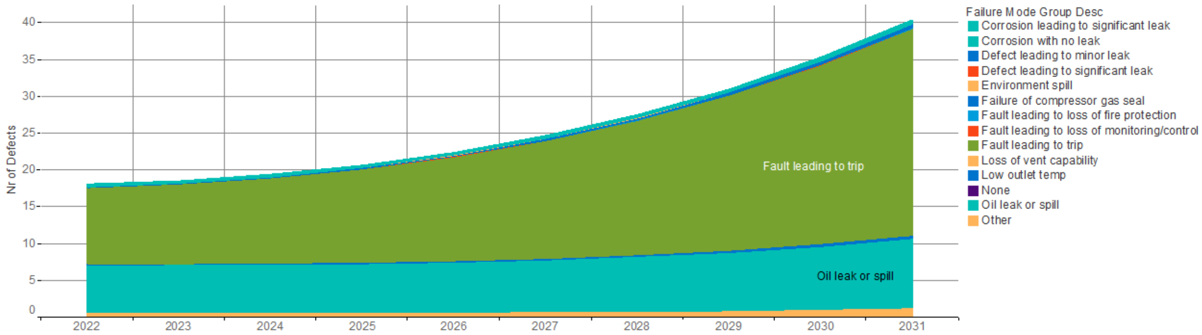
## Spend Boundaries

12.13. The proposed investment includes all Compressor assets on the NTS, including any ‘no-regrets’ site investments at St Fergus to keep it safe and operational whilst the separate funding mechanism for the proposed project is progressed via an Uncertainty Mechanism.

## 13. Compressor - Probability of Failure

13.1. The probability of failure is modelled using our NOMs methodology. The chart below shows the predicted frequency of failures split by failure mode.

**Predicted Failure Modes**




13.2. The chart shows that the failure modes that contribute most to the failure of these assets are:

- Fault leading to trip
- Oil leak or spill

### Probability of Failure Interventions

13.3. The table below shows the drivers for Compressor Train investment that are related to the current and future Probability of Failure (PoF). This includes investments that are driven by future PoF deterioration.

**NARMs Interventions**

| NARMs Asset Intervention Category | Secondary Asset Class |
|---|---|
| **Extension of Expected Asset Life**<br>Includes Minor Refurbishments | Compressor |
| **Asset Replacement (PoF Driven)**<br>Includes Asset Replacements | Compressor |
| **Asset Refurbishment (PoF Driven)**<br>Included Major Refurbishments | Compressor |

13.4. These are defined as PoF driven investments as the risk change delivered through investment is modelled as a direct consequence of replacing or refurbishing the asset. The benefits delivered through these investments will be reported as a Network Asset Risk Metric (NARM) as a reduction in monetised risk, arising from a lower PoF delivered through investment. Investment benefits vary depending on the intervention category and are consistent with the Cost Benefit Analysis (CBA) accompanying this Justification Report.

### Compressor Interventions

13.5. The interventions in Compressors are shown in the table below:

**Compressor Interventions**

| Interventions | SAC | Intervention Category |
|---|---|---|
| A22.10.1.1 / Compressor Bearing & Coupling Major Refurb | Compressor | Major Refurbishment |
| A22.10.1.3 / Compressor Wet / Dry Seal Major Refurb | Compressor | Major Refurbishment |
| A22.10.1.4 / GG/PT/Compressor Oil System Major Refurb | Compressor | Major Refurbishment |
| A22.10.1.5 / Impeller Major Refurb | Compressor | Major Refurbishment |
| A22.10.1.6 / Instrument Air / N2 System Major Refurb | Compressor | Major Refurbishment |
| A22.10.1.7 / Instrument Air / N2 System Replacement | Compressor | Replacement |

### Data Assurance

13.6. All PoF and CoF values are taken from the National Grid Gas Transmission 'Methodology for Network Output Measures' (the Methodology). The Methodology was originally submitted for public consultation in April 2018, with three generally favourable responses received in May 2018. On this basis, Ofgem were happy to provisionally not reject the Methodology pending further work to:

- Produce a detailed Validation Report, confirming the validity of data sources used in the Methodology
- Test a range of supply and demand scenarios and incorporate an appropriate scenario to best represent Availability and Reliability risk

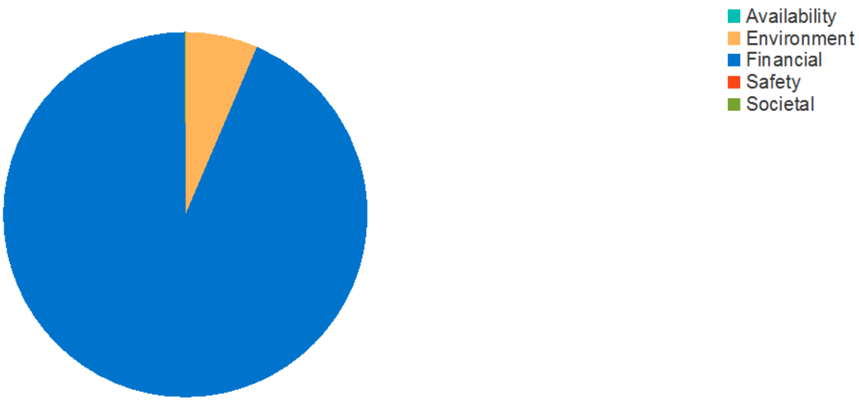
13.7. A review of the Methodology by independent gas transmission experts has been carried out and several improvements identified and incorporated.

13.8. At the time of writing, the final Validation Report has been submitted to Ofgem. We understand that once this work is complete Ofgem will formally "not reject" the Methodology and a License change progressed to restate our RIIO-1 targets in terms of monetised risk commenced.

## 14. Compressor - Consequence of Failure

14.1. The chart below shows the expected stakeholder impacts because of failure occurring on the compressor assets. The charts show the relative numbers of consequence events, not relative monetised risk.

**Stakeholder Impacts**




14.2. The risk for Compressor assets can be explained as follows, in order of significance:

- **Financial risk** is mostly associated with the costs of operating and maintaining the asset at the current level of risk, including routine maintenance and repair. Overhauls are considered as Major Refurbishments (proactive interventions) and are not considered in this category.
- **Environmental risk** is associated with the loss of gas through trips and vents of the compressor unit caused by compressor asset failure. This is an indirect effect and only a small proportion of compressor asset failures will generate a unit trip and associated vent of gas.

14.3. The risk associated with other service risk measures for Compressors is negligible, based on the assigned failure modes. Safety risk is associated with the ignition of escaping gas in confined spaces and is not a major risk for the Compressor asset itself.

14.4. Availability risk due to the loss of a unit is quantified but considered small due to the assumed ability of alternative units to be used in the event of an extended outage of a compressor unit.

## 15. Compressor - Options Considered

### Potential Intervention Options

15.1. The following condition-based interventions have been considered for the compressor and associated assets:

15.2. **Seal Refurbishment** - seals are not repairable and therefore are overhauled or replaced when required. Replacing seals with new is not considered cost effective. A refurbishment of seals usually costs half of that for new seals, but it returns the old seals to an "as new" condition, and therefore the preferred intervention unless there is catastrophic damage that means the original seal must be scrapped.

15.3. **Bearing Replacement –** this includes replacement of the bearings. Regular (monthly) sampling and analysis of the bearing oil together with the analysis of vibration is used to monitor the condition of the bearing. Results of this monitoring instigate an inspection, which may lead to more detailed investigation and potentially the replacement of the bearing.

15.4. **Coupling Refurbishment** – this includes a rebalancing of the coupling and recoating with corrosion protection in most cases, but can require remanufacturing of the coupling if damage is found. It is undertaken during an impellor overhaul.

15.5. **Oil System Refurbishment** - this includes flushing or replacement of pipework, overhaul of pumps, flushing or replacement of tanks, and flushing/refurbishment of oil coolers. This is driven by the regular inspection of the assets as well as the monthly analysis of the oil condition.

15.6. Instrument **Air/Nitrogen System Refurbishment** - replacement of individual elements of the air/nitrogen system to restore the functional performance of the unit.

15.7. Instrument **Air/Nitrogen System Replacement** - replacement of the entire air/nitrogen system.

### Intervention Unit Costs

15.8. The total RIIO-2 investment for Compressors represents 6% of the Compressor Train investment theme. 66% of unit costs that support the Compressors investment are based on historical outturn cost data points. The remaining 34% of costs have been developed using supplier quotations where obtainable (16%), or through other estimation methods (19%) where limited supplier quotations available.

15.9. The table below provides the unit costs for all the potential Compressors interventions.

**Intervention Unit Costs - Compressors**

| Intervention | Cost (£) | Unit | Evidence | Data Points | Overall value in BP |
|---|---|---|---|---|---|
| **Compressors** | | | | | |
| A22.10.1.1 / Compressor Bearing & Coupling Major Refurb | [redacted] | Per asset | Estimated - Other | 0 | £829,845 |
| A22.10.1.3 / Compressor Wet / Dry Seal Major Refurb | [redacted] | Per asset | Outturn | 1 | £1,064,605 |
| A22.10.1.4 / GG/PT/Compressor Oil System Major Refurb | [redacted] | Per asset | Estimated - Other | 0 | £360,328 |
| A22.10.1.5 / Impeller Major Refurb | [redacted] | Per asset | Outturn | 3 | £3,575,982 |

| | | | | | |
|---|---|---|---|---|---|
| A22.10.1.6 / Instrument Air / N2 System Major Refurb | [redacted] | Per asset | Estimated - Other | 0 | £120,109 |
| A22.10.1.7 / Instrument Air / N2 System Replacement | [redacted] | Per asset | Estimated - Quotation | 1 | £1,124,660 |

### *Unit Cost Sensitivity*

15.10. We have used the potential range of unit cost variance to assess the sensitivity of the Cost Benefit Analysis to the upper and lower limits. The graph below shows the results of this compared to the preferred option.

**Net Benefits of Upper and Lower Unit Cost Sensitivity**


15.11. Whilst the level of cost benefit and the payback period changes as the unit costs vary, the investment remains cost beneficial across the range of unit costs.

## Innovation

15.12. During RIIO-1, we have continued to develop a dynamic portfolio of projects aligned to the Gas Network Innovation Strategy which deliver real value to our customers, stakeholders and the wider industry. We will be continuing to focus on the implementation of innovation into business as usual to drive value throughout everything we do. We will also remain committed to sharing these ideas and best practice across the wider industry to deliver a safe, reliable and efficient network that benefits gas consumers across the UK.

- **Novel vibration measurement technologies**, study which explored novel techniques for monitoring vibration, which demonstrated a range of sensors and applications that will inform future vibration monitoring.
- **Variable Envelope Compressors (VEC),** this project explored the potential use of VEC on the NTS, from both a technical and economic point of view. The benefit to the VEC is it allows the compressor's envelope to more readily varied to match requirements. The results of this project showed that there was potential for using VECs on the existing assets on the NTS, the economics made it unfeasible, which could change in the future.

## 16. Compressor - Programme Options

16.1. Our aim in developing the investment plan is to deliver value to our consumers and stakeholders.

16.2. As described in the section below 'Compressor - Business Case Outline and Discussion – Investment Decision Approach' these assets are maintained on a proven condition and performance based approach combined with OEM alerts. This approach aligns with industry practice. The predicted levels of investment are based on historic analysis and known future requirements. There are therefore no credible programme options to assess that ensure the intended asset performance and safe operation of compressor assets.

16.3. The proposed programme is therefore based on the best information available and represents the lowest whole life programme of investment to deliver the outcomes over RIIO-2 and RIIO-3.

16.4. As a result, we have therefore not considered any further programme options as any of those would be an increase in initial investment and overall whole life cost from this proposed position.

## 17. Compressor Business Case - Outline and Discussion

17.1. In this section, we set out our overall investment plan for Compression assets. This section demonstrates why the proposed investment levels are the right levels to ensure the health and reliability of these assets for the investment period and beyond.

### Key Business Case Drivers Description

17.2. The key drivers for investment in the Compressor assets are:

- Asset Deterioration
- Legislation
- Obsolescence

*Outcomes Delivered*

17.3. The outcome of this investment is to:

- Ensure we deliver against our stakeholder priority: *"I want to take gas on and off the system when and where I want"*
- Ensure that the compressor fleet can continue to provide a level of compression availability and reliability both efficiently and economically

*Stakeholder Support*

17.4. Consumer and stakeholder research and engagement has been integral to the development of our asset health investment plans. Early discussions realised that to engage in meaningful dialogue, our plan outputs should be presented at a programme rather than asset level of detail. This is due to the integrated nature of our Asset Health plan which makes it challenging to disaggregate and engage on individual elements. For details of our stakeholder engagement approach please refer to 'I want to take gas on and off the system where and when I want' [Chapter 14 of the GT submission].

### Interventions Decision Approach

17.5. The compressor assets are managed using a comprehensive monitoring, inspection and condition based intervention programme. The assets are fitted with sensors to continually monitor all relevant characteristics such as vibration, temperature, performance etc. Sampling of the bearing oil is also undertaken every month. The results of this monitoring are analysed every month and together with the results of the inspections determine whether intervention is required.

17.6. Interventions are applied only when performance is observed to deteriorate or there are specific safety bulletins issued by the manufacturers.

17.7. To deliver the outcomes for the investment period the safe Compressor assets require a mixture of the defined intervention categories. The decision on the volume of each of the interventions required has been determined using the following methodologies.

- **Compressors** - interventions on compressors are infrequent, and therefore, a rate equivalent to the rate of historic interventions has been assumed for the period. On that basis 1 compressor will require overhaul each year of the investment period.

- **Manufacturers Safety Alerts** - In the second half of RIIO-1 there have been multiple compressor overhauls that were driven by a safety alert sent by one of the manufacturers. NG have included in our plan the historic rate of manufacturer required interventions (e.g. safety bulletins).
- **Bearing/Coupling** are all refurbished on the same condition based strategy. Based on historic rates, one refurbishment per year has been forecast for the investment period.
- **Instrument Air/Nitrogen Systems –** again are all refurbished on a condition based strategy. Based on historic rates, one refurbishment per year has been forecast for the investment period.
- There is one Alrewas system that is obsolete and showing increased rates of failure and need to be replaced during the period.
- **Seals** - degradation is monitored through gas leakage from the seal. In most circumstances a compressor train can continue to operate with a slightly leaking seal before the leak becomes a great cause for concern, so once a seal begins to leak, the intervention is usually able to be planned. Based on historic performance 1 or 2 seal refurbishments are expected each year during. The variation is due to some compressors having dual seals.

17.8. The investment proposed in the period is to undertake:

- Refurbishment and replacement of the relevant elements of the compressor in response to the comprehensive condition monitoring regime that is in place.
- Unplanned repairs and responses to manufacturer notifications which will be undertaken efficiently to minimise impact on availability

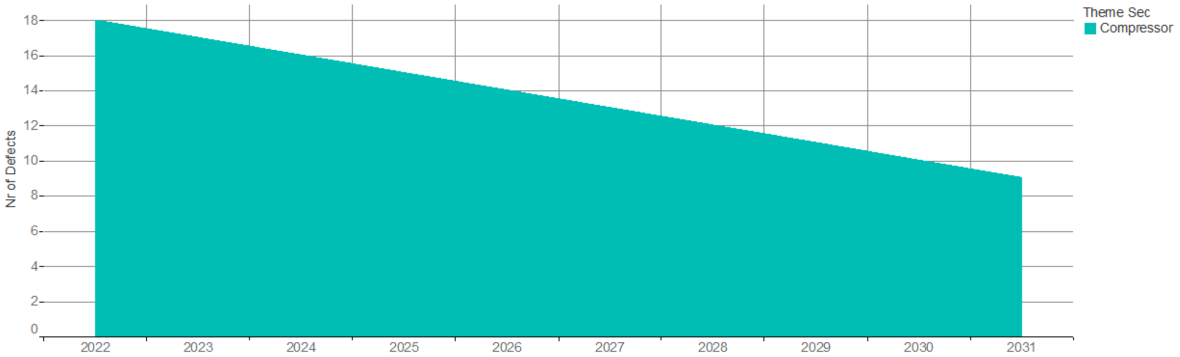
17.9. The investment will achieve the following improvements in the Compressor assets.

## Benefits of Investment

*Defects*

17.10. The chart below shows the defects predicted for the compressor assets based on defects following the investment.

**Predicted Compressor Defects with Preferred Investment Option**



## Preferred Option

17.11. To deliver the required outcomes for all our stakeholders we have developed the most effective combination of efficient interventions. These form the programme of work for the compressor assets in the investment period. [redacted]:

**Intervention Volumes**

[redacted]

## Asset Health Spend Profile

17.12. The profile of investment in the compressor assets, driven from the derived volumes of work and the efficient unit costs, for the period is shown is the table below:

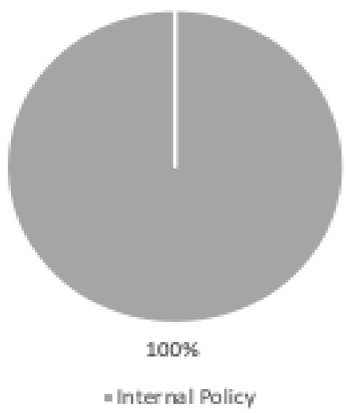
**Spend Profile**

| Investment (£ 000's) | RIIO-2 | | | | | RIIO-3 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 |
| **Compressor** | 1,947 | 1,034 | 1,362 | 1,541 | 1,191 | 1,415 | 1,415 | 1,415 | 1,415 | 1,415 |
| **Total** | 1,947 | 1,034 | 1,362 | 1,541 | 1,191 | 1,415 | 1,415 | 1,415 | 1,415 | 1,415 |
| | **7,076** | | | | | **7,076** | | | | |

## Intervention Drivers

17.13. The following chart shows the breakdown of investment across each of the intervention drivers. This shows all of the investment is based on internal policy.

**RIIO-2 Compressor Intervention Drivers**[3]




[3] See Appendix A for intervention driver category definitions

## Preferred Option CBA

17.14. We are targeting an appropriate level of asset health investment in compressors to mitigate the reliability, safety and environmental risks from the ageing asset base.

17.15. In line with HM Treasury Green Book advice and Ofgem guidance we have appraised whether investment in compressors is value for money. We have considered costs over a 45-year period in a full cost benefit analysis (CBA).

17.16. The CBA for the compressor investment over the period is cost beneficial over the 45-year period. The investment pays back after 23 years. This is shown below.

**CBA Summary**[4]

| | 10 years | 20 years | 30 years | 45 years |
|---|---|---|---|---|
| **Present Value costs (£m)** | £5.24 | £9.84 | £13.71 | £19.48 |
| **Present Value H&S benefits (£m)** | £0.00 | £0.00 | £0.00 | £0.02 |
| **Present Value non H&S benefits (£m)** | £1.79 | £7.81 | £19.94 | £61.12 |
| **Net Present Value (£m)** | £(3.45) | £(2.03) | £6.23 | £41.65 |

17.17. Our overarching compressor strategy identifies the need case for our compressor stations and units and considers ongoing asset health costs as part of that CBA process. Moving forwards a robust Network Capability review will reassess these needs on an ongoing basis and our asset health programme for our compressors will continually align to ensure we invest to maintain the reliability of these essential machines.

17.18. We have challenged whether this is the right programme of work. In developing our plans and making our decision we have been fully cognisant of the need to develop plans that are value for money, acceptable, affordable and deliverable.

17.19. This level of investment will ensure we successfully manage asset deterioration and obsolescence, whilst meeting our legal obligations. It will ensure we deliver the outcomes that consumers and stakeholder tell us they want us to meet.

17.20. We have assessed the sensitivity of the Cost Benefit Analysis to the full range of unit costs. The results of this analysis are presented in the Unit Cost section above.

17.21. Across our stakeholders there is little support for keeping the costs the same as in RIIO-1, given the unacceptable consequential increase in risk.

[4] A14.11.1 Compressor CBA

## 18. Compressor Preferred Option Scope and Project Plan

18.1. The section summarises our preferred investment plan required to deliver acceptable and affordable outcomes for our stakeholders.

### Preferred Option

18.2. To deliver the required outcomes for all our stakeholders we have developed the most effective combination of efficient interventions. These form the programme of work for the compressor assets in the investment period. [redacted]:

**Intervention Volumes**

[redacted]

### Asset Health Spend Profile

18.3. The profile of investment in the compressor assets, driven from the derived volumes of work and the efficient unit costs, for the period is shown is the table below:

**Spend Profile**

| Investment (£ 000's) | RIIO-2 | | | | | RIIO-3 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 |
| **Compressor** | 1,947 | 1,034 | 1,362 | 1,541 | 1,191 | 1,415 | 1,415 | 1,415 | 1,415 | 1,415 |
| **Total** | 1,947 | 1,034 | 1,362 | 1,541 | 1,191 | 1,415 | 1,415 | 1,415 | 1,415 | 1,415 |
| | **7,076** | | | | | **7,076** | | | | |

### Delivery Planning

18.4. At this point in time the delivery of our RIIO-2 and RIIO-3 plans are in principle deliverable based on initial assessments of work. We will regularly review the plan to consider any known or changing constraints, customer impacts and bundling opportunities. In the event of churn our plan must be reoptimised to reflect the impact of the change and provide an opportunity to reconsider the efficient timing of delivery.

18.5. We recognise that many of our asset classes are co-located across the NTS pipe network and sites. Much of our investment delivery also requires outages of the associated pipelines or plant and equipment. The availability of outages is extremely limited across most of the NTS due to the radial nature of the network. It is therefore most efficient from both financial and network risk points of view to bundle investment across asset classes within the same outage period. This maximises the work undertaken in any outage whilst ensuring efficient delivery through minimised project overheads. For cabs and compressor train projects it may be possible to take more localised outages bypassing the unit. This depends on network flow conditions and the availability of local/supporting units. Therefore, the availability and reliability of the supporting units are also critical factors. Our deliverability assessment and phasing of the work has accounted for supporting unit availability and the availability of sites which can provide similar compression requirements. By providing options to “re-direct” gas flows, compression availability also influences the likelihood of outages on other parts of the network.

18.6. The bundling approach is particularly effective when applied at a feeder level or for a whole site. In which case the preparatory inspection, investigation, risk assessment, planning and procurement activities can be completed as far as possible before the outage. This allows the maximum amount of intervention and risk reduction to be bundled into a single ‘campaign’ across the length of the feeder. During RIIO-1 this has proved to be an extremely efficient and effective approach to delivery of our programmes of work. Additionally, where work is necessary on both compressor trains and cabs these projects can be easily/locally bundled where larger scale outages are not available and this could be an option where individual or groups of assets that present a risk to our performance that do not ‘fit’ into the planned ‘campaign’ approach. We will ensure that these risks are remediated as efficiently as possible through individual or small groups of targeted interventions.

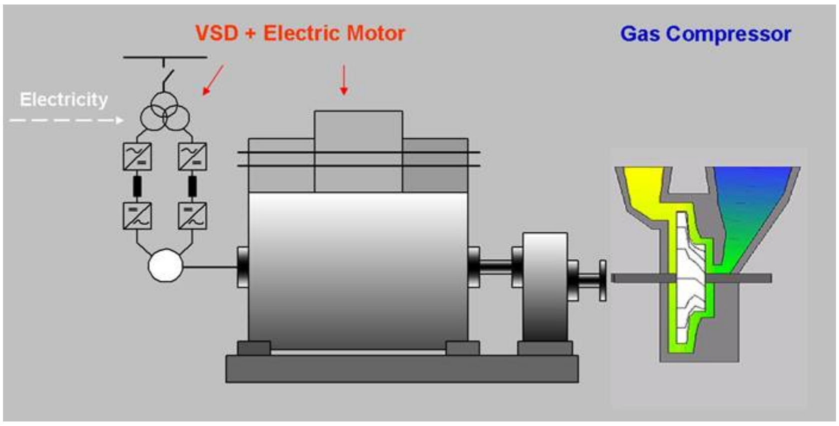
18.7. Where asset interventions do not require outages then the campaign approach will still be applied to maximise the opportunity for delivery of the same type of work across many locations. This enables efficient procurement through significant volumes of common works.

# Electric Variable Speed Drives (£15.8m)

## 19. Electrical Variable Speed Drives - Equipment Summary

19.1. The purpose of the electric drives is to drive a compressor from a high voltage electrical power supply. Electrical variable speed drives are typically broken down into 2 sub assets, electric motor and VSD.

**VSD Overview**




19.2. The assets include HV reactor, converter transformer, inrush limiting resistor, variable frequency drive, harmonic Filter, high voltage motor and exciter, magnetic bearing systems (Lockerley only), converter and motor cooling systems, motor air purge systems, containers, cabling and containment.

19.3. Electric variable Speed Drives allow the compression of gas without the direct emissions and environmental impact associated with the use of gas generators. They are essential in allowing NG to meet our emissions targets.

### Location and Volume

19.4. There is a total of 9 Electric Drives installed at 7 compressor sites:

- 7 - 16-35MW High Voltage Synchronous Electric motor driven compressors with thyristor control frequency converters; converter transformers; harmonic filters and HV switchgear.
    - There are 2 installed at St Fergus, with one at each of Kirriemuir, Hatton, Felindre, Churchover and Wormington
- 2 - 8MW High Voltage Asynchronous Combined Motor/Compressor units with magnetic bearings; thyristor controlled frequency converters; harmonic filters; converter transformers and reactors and HV switchgear. Installed at Lockerley.

### Pressure Ratings

19.5. The motors are not pressure rated.

## Redundancy

19.6. Compression of gas to enable the management of its pressure and flow through the NTS is essential to delivering the gas at the right pressures and volumes to NG customers. To provide the level of compression and redundancy that is required there is more than one compressor unit on each site. Redundancy is required to enable overhaul of the compressor assets and to mitigate the effects of compressor failure. The capacity and number of compressors is designed along with the configuration of the NTS to allow the levels of redundancy required to deliver the contracted levels service to our customers.

19.7. There is only one electric drive within each compressor unit. Therefore, overhaul or failure of the asset results in the unavailability of the compressor train.

## 20. Electrical Variable Speed Drives - Problem Statement

20.1. Components on the electric drives are reaching the end of their life. Some are obsolete and few spares are available; this will lead to extended outage times for the associated compressor. The ability to compensate for the outages using the alternative gas turbine compressors is limited by their environmental impact and NG obligations under the Industrial Emissions Directive.

20.2. There are specific issues identified with these assets that require resolution within the investment period.

### Drivers for Investment

20.3. The key drivers for investment in the Electric Variable Speed Drives are:

- Obsolescence
- Asset Deterioration
- Legislation
- Environment

20.4. **Obsolescence** – electronic parts of the asset are becoming obsolete and there are few spares available leading to long outages.

20.5. **Asset Deterioration** – elements of the assets deteriorate due to duty and corrosion and are liable to cause failure of the asset.

20.6. **Legislation** – the Electric Variable Speed Drives require continued ATEX certification to be used in the potentially explosive environment of a compressor unit.

20.7. **Environment** – the continued use of the electric drives is essential in enabling NG to meet its emissions targets. At sites with a mix of gas generators and electric drives the use of the alternative gas turbine powered compressors is limited due to the environmental impact and there are limits on how many hours they can be run (IED directive).

### Impact of No Investment

20.8. Investment is required in specifically identified issues which if not carried out will lead to the inability to use the electric drives and provide the compression required to provide service to customers on specific parts of the NTS.

20.9. The specific issues are listed below:

20.10. Lockerley

- **Lockerley** – the Variable Speed Drives on two compressor units at Lockerley are life expired (20 years old) and experiencing increased failures and are obsolete with no spares available.

  Lockerley's primary function is to boost pressures in the South West to protect the extremity of the network and store NTS stock. It maintains pressures for various Distribution offtakes; Choakford, Coffinswell, Aylesbeare, Ken South, Ilchester and Mappowder. Without compression, these offtakes would fail leading to a considerable number of domestic customers being without gas, the DNs also have several industrial customers on these offtakes. There is also a power station and an industrial site who are fed at the point of extremity.

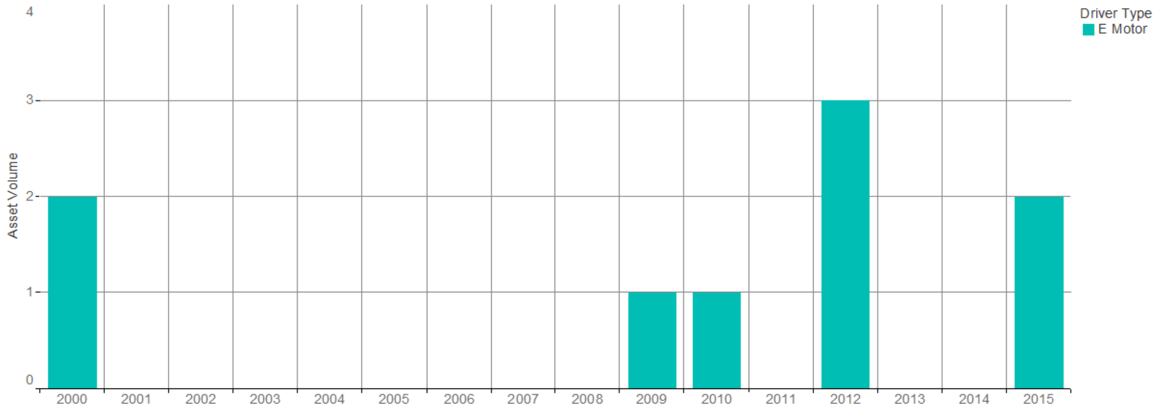
The electric drives at Lockerley have no gas turbine back-up. The backup to Lockerley compressor is Aylesbury. However, it is a much larger unit mainly built for a 1 in 20 winter scenarios. It has scope to be used to support the South West, although because the size of the unit it is not required all the time and starting and stopping it increases its overhaul requirements.

- **Siemens Obsolete Control Systems** – The control systems on the Siemens drives are now obsolete with no spares available.
- **Failing HV Motors at Churchover and Wormington** – The stator winding Resistance Temperature Detectors (RTDs) on the HV motors are failing. Each stator winding has two RTDs 1 main and 1 spare. Several these have failed. If the point is reached where we no longer have enough functioning RTDs to provide temperature protection, then the ATEX certificate for the motor will be invalid and the only available fix would be a motor rewind.
- **Cooling Fin Corrosion** – an emerging issue, experienced at St Fergus during RIIO-1, is the corrosion of the fins on Convertor Transformers. Due to the design of the fins these cannot be recoated or repaired and when this occurs the cooling fins need to be replaced. This problem is expected to be found on other units as they age.

20.11. For other compressor locations, the electric drive units are the compressors of choice for environmental reasons. They do not produce any emissions when running unlike the gas turbine compressors. For this reason, they are an essential part of the overall compressor strategy and not investing in these units would result in a higher level of investment being required in the gas turbine compressor fleet.

20.12. The chart below shows the age profile of the electric drives for compressors by commissioning date.

**Electric Drives Age Profile**

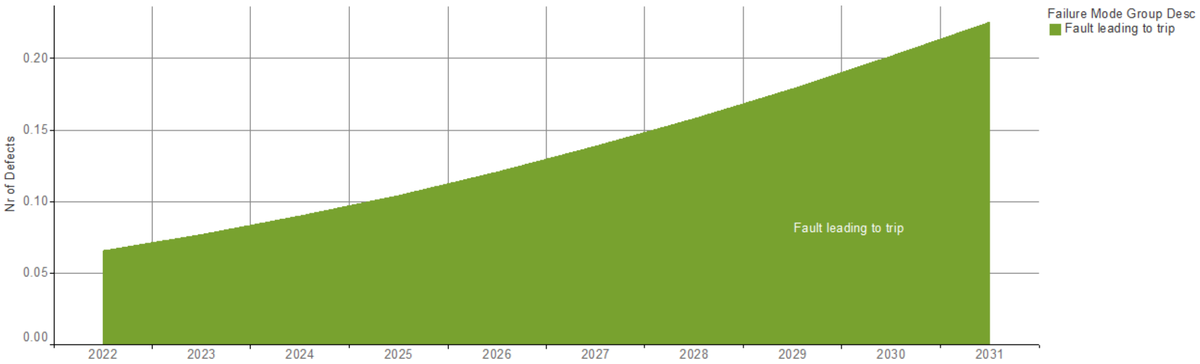



20.13. The proposed investment includes all Electric Variable Speed Drive assets on the NTS, including all their subcomponents except for those within the St Fergus site that are included in the “Engineering Justification Report – Asset Health, St Fergus”.

## 21. Electrical Variable Speed Drives - Probability of Failure

21.1. The probability of failure is modelled using our NOMs methodology. The chart below shows the predicted frequency of failures split by failure mode.

**Predicted VSD Failure Modes**




21.2. For variable speed drives, the chart indicates that the failure modes that contribute most to the probability of failure are:

- Fault leading to trip.

### Probability of Failure Interventions

21.3. The table below shows the drivers for Compressor Train investment that are related to the current and future Probability of Failure (PoF). This includes investments that are driven by future PoF deterioration.

**NARMs Interventions**

| NARMs Asset Intervention Category | Secondary Asset Class |
|---|---|
| **Extension of Expected Asset Life**<br>Includes Minor Refurbishments | Electrical variable speed drive |
| **Asset Replacement (PoF Driven)**<br>Includes Asset Replacements | Electrical variable speed drive |
| **Asset Refurbishment (PoF Driven)**<br>Included Major Refurbishments | Electrical variable speed drive |

21.4. These are defined as PoF driven investments as the risk change delivered through investment is modelled as a direct consequence of replacing or refurbishing the asset. The benefits delivered through these investments will be reported as a Network Asset Risk Metric (NARM) as a reduction in monetised risk, arising from a lower PoF delivered through investment. Investment benefits vary depending on the intervention category and are consistent with the Cost Benefit Analysis (CBA) accompanying this Justification Report.

## VSD Interventions

21.5. The interventions in electrical variable speed drives are shown in the table below:

**VSD Intervention Options by Category**

| Option Name | SAC | Intervention Category |
|---|---|---|
| A22.10.3.10 / Electric Drives - Harmonic Filter - Replacement | Electrical Variable Speed Drive | Replacement |
| A22.10.3.11 / Electric Drives - HV Motor & Exciter - Major Refurb | Electrical Variable Speed Drive | Major Refurbishment |
| A22.10.3.12 / Electric Drives - HV Motor & Exciter - Minor Refurb | Electrical Variable Speed Drive | Minor Refurbishment |
| A22.10.3.14 / Mopico Motor Compressor Replacement | Electrical Variable Speed Drive | Replacement |
| A22.10.3.2 / Electric Drives - Auxiliary Systems - Minor Refurb | Electrical Variable Speed Drive | Minor Refurbishment |
| A22.10.3.3 / Electric Drives - Converter Transformer - Major Refurb | Electrical Variable Speed Drive | Major Refurbishment |
| A22.10.3.4 / Electric Drives - Converter Transformer - Minor Refurb | Electrical Variable Speed Drive | Minor Refurbishment |
| A22.10.3.5 / Electric Drives - Converter Transformer - Replacement | Electrical Variable Speed Drive | Replacement |
| A22.10.3.6 / Electric Drives - Frequency Converter - Major Refurb | Electrical Variable Speed Drive | Major Refurbishment |
| A22.10.3.7 / Electric Drives - Frequency Converter - Minor Refurb | Electrical Variable Speed Drive | Minor Refurbishment |
| A22.10.3.8 / Electric Drives - Frequency Converter - Replacement | Electrical Variable Speed Drive | Replacement |
| A22.10.3.9 / Electric Drives - Harmonic Filter - Minor Refurb | Electrical Variable Speed Drive | Minor Refurbishment |
| A22.22.3.10 / Electric Drives - HV Motor & Exciter - Minor Refurb (St. Fergus) | Electrical Variable Speed Drive | Minor Refurbishment |
| A22.22.3.11 / Electric Drives - HV Motor & Exciter - Major Refurbish (St. Fergus) | Electrical Variable Speed Drive | Major Refurbishment |
| A22.22.3.12 / Electric Drives - Auxillary Systems - Minor Refurb (St. Fergus) | Electrical Variable Speed Drive | Minor Refurbishment |
| A22.22.3.5 / Electric Drives - Converter Transformer Minor Refurb (St. Fergus) | Electrical Variable Speed Drive | Minor Refurbishment |
| A22.22.3.6 / Electric Drives - Converter Transformer - Major Refurbish (St. Fergus) | Electrical Variable Speed Drive | Major Refurbishment |
| A22.22.3.7 / Electric Drives - Frequency Converter - Minor Refurb (St. Fergus) | Electrical Variable Speed Drive | Minor Refurbishment |
| A22.22.3.8 / Electric Drives - Frequency Converter - Major Refurbish (St. Fergus) | Electrical Variable Speed Drive | Major Refurbishment |
| A22.22.3.9 / Electric Drives - Harmonic Filter - Minor Refurb (St. Fergus) | Electrical Variable Speed Drive | Minor Refurbishment |

### Data Assurance

21.6. All PoF and CoF values are taken from the National Grid Gas Transmission 'Methodology for Network Output Measures' (the Methodology). The Methodology was originally submitted for public consultation in April 2018, with three generally favourable responses received in May 2018. On this basis, Ofgem were happy to provisionally not reject the Methodology pending further work to:

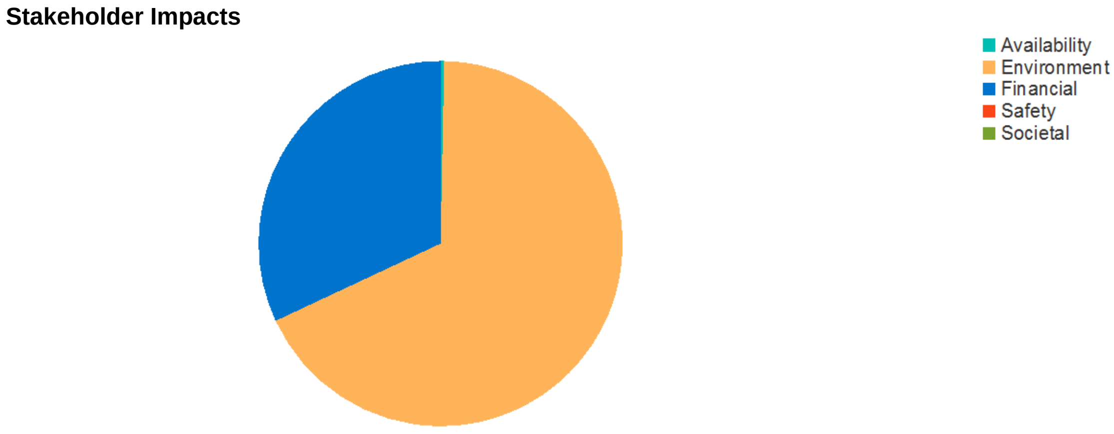
- Produce a detailed Validation Report, confirming the validity of data sources used in the Methodology
- Test a range of supply and demand scenarios and incorporate an appropriate scenario to best represent Availability and Reliability risk

21.7. A review of the Methodology by independent gas transmission experts has been carried out and several improvements identified and incorporated.

21.8. At the time of writing, the final Validation Report has been submitted to Ofgem. We understand that once this work is complete Ofgem will formally "not reject" the Methodology and a License change progressed to restate our RIIO-1 targets in terms of monetised risk commenced.

## 22. Electrical Variable Speed Drives - Consequence of Failure

22.1. The chart below shows the expected stakeholder impacts because of failure occurring on the electrical variable speed drive assets. The charts show the relative numbers of consequence events, not relative monetised risk.




22.2. The contribution of individual service risk measures towards the overall risk for the Electric Variable Speed Drive (VSD) can be explained as follows, in order of significance:

- **Environmental risk** is associated with the loss of gas through trips and vents of the unit caused by VSD asset failure. This is an indirect effect and only a small proportion of VSD asset failures will generate a unit trip and associated vent of gas.
- **Financial risk** is mostly associated with the costs of operating and maintaining the asset at the current level of risk, including routine maintenance and repair. Overhauls are considered as Major Refurbishments (proactive interventions) and are not considered in this category

22.3. The risk associated with other service risk measures for the GG Power Train is negligible, based on the assigned failure modes. Safety risk is associated with the ignition of escaping gas in confined spaces and is not a major risk for the GG asset itself.

22.4. Availability risk due to the loss of a unit is quantified but considered small due to the ability of alternative units to be used in the event of an extended outage of a compressor unit.

22.5. As for GG fuel gas, the environmental costs of operating the VSD, from the use of electricity to power the drive, is not considered within the NOMs Methodology as use of the VSD units is largely driven by operational requirements.

## 23. Electrical Variable Speed Drives - Options Considered

### Potential Intervention Options

23.1. We have considered a combination of three intervention categories for the electrical variable speed drives; converter transformer, frequency converter, harmonic filter, HV motor and exciter:

- **Minor Refurbishment** – includes the replacement of consumable parts and individual components
- **Major Refurbishment** – a removal and complete overhaul of the asset together with the replacement of components and re-lifing of other larger items
- **Replacement** – complete replacement of the asset and the associated systems.

### Intervention Unit Costs

23.2. The total RIIO-2 investment for Electrical Variable Speed Drive represents 14% of the Compressor Train investment theme. A large proportion of the unit costs that support the Electrical Variable Speed Drive investment have been developed using quotes obtained from suppliers (61%), with the remainder supported by using other estimation methods (39%) due to the low frequency of these works being completed in the past and therefore having limited supplier quotations and outturn information available.

23.3. The table below provides the unit costs for all the potential Electrical Variable Speed Drive interventions.

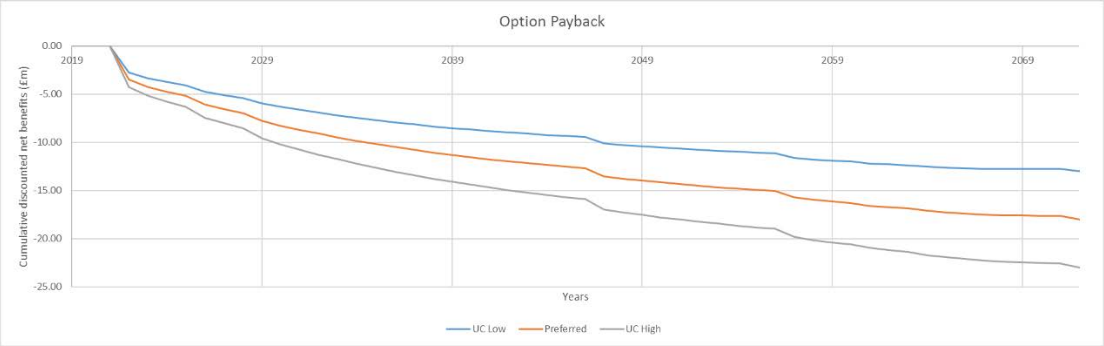
**Intervention Unit costs - Electrical Variable Speed Drive**

| Intervention | Cost (£) | Unit | Evidence | Data Points | Overall value in BP |
|---|---|---|---|---|---|
| **Electrical Variable Speed Drive** | | | | | |
| A22.10.3.2 / Electric Drives - Auxiliary Systems - Minor Refurb | [redacted] | Per asset | Estimated - Other | 0 | £20,611 |
| A22.10.3.4 / Electric Drives - Converter Transformer - Minor Refurb | [redacted] | Per asset | Estimated - Other | 0 | £0 |
| A22.10.3.7 / Electric Drives - Frequency Converter - Minor Refurb | [redacted] | Per asset | Estimated - Other | 0 | £0 |
| A22.10.3.9 / Electric Drives - Harmonic Filter - Minor Refurb | [redacted] | Per asset | Estimated - Other | 0 | £20,611 |
| A22.10.3.12 / Electric Drives - HV Motor & Exciter - Minor Refurb | [redacted] | Per asset | Estimated - Quotation | 1 | £77,292 |
| A22.10.3.3 / Electric Drives - Converter Transformer - Major Refurb | [redacted] | Per asset | Estimated - Quotation | 1 | £371,000 |
| A22.10.3.6 / Electric Drives - Frequency Converter - Major Refurb | [redacted] | Per asset | Estimated - Quotation | 1 | £1,391,250 |
| A22.10.3.11 / Electric Drives - HV Motor & Exciter - Major Refurb | [redacted] | Per asset | Estimated - Quotation | 1 | £1,236,667 |
| A22.10.3.5 / Electric Drives - Converter Transformer - Replacement | [redacted] | Per asset | Estimated - Quotation | 1 | £2,473,334 |
| A22.10.3.8 / Electric Drives - Frequency Converter - Replacement | [redacted] | Per asset | Estimated - Quotation | 1 | £3,091,667 |

| | | | | | |
|---|---|---|---|---|---|
| A22.10.3.10 / Electric Drives - Harmonic Filter - Replacement | [redacted] | Per asset | Estimated - Quotation | 1 | £927,500 |
| A22.10.3.14 / Mopico Motor Compressor Replacement | [redacted] | Per asset | Estimated - Other | 1 | £6,183,334 |
| A22.22.3.10 / Electric Drives - HV Motor & Exciter - Minor Refurb (St. Fergus) | [redacted] | Per asset | Estimated - Other | 0 | £0 |
| A22.22.3.11 / Electric Drives - HV Motor & Exciter - Major Refurbish (St. Fergus) | [redacted] | Per asset | Estimated - Quotation | 1 | £0 |
| A22.22.3.12 / Electric Drives - Auxillary Systems - Minor Refurb (St. Fergus) | [redacted] | Per asset | Estimated - Other | 0 | £0 |
| A22.22.3.5 / Electric Drives - Converter Transformer Minor Refurb (St. Fergus) | [redacted] | Per asset | Estimated - Other | 0 | £0 |
| A22.22.3.6 / Electric Drives - Converter Transformer - Major Refurbish (St. Fergus) | [redacted] | Per asset | Estimated - Quotation | 1 | £0 |
| A22.22.3.7 / Electric Drives - Frequency Converter - Minor Refurb (St. Fergus) | [redacted] | Per asset | Estimated - Quotation | 1 | £0 |
| A22.22.3.8 / Electric Drives - Frequency Converter - Major Refurbish (St. Fergus) | [redacted] | Per asset | Estimated - Quotation | 1 | £0 |
| A22.22.3.9 / Electric Drives - Harmonic Filter - Minor Refurb (St. Fergus) | [redacted] | Per asset | Estimated - Other | 0 | £0 |

23.4. We have used the potential range of unit cost variance to assess the sensitivity of the Cost Benefit Analysis to the upper and lower limits. The graph below shows the results of this compared to the preferred option.

**Net Benefits of Upper and Lower Unit Cost Sensitivity**




23.5. Whilst the level of cost benefit changes as the unit costs vary, the investment remains non cost beneficial across the range of unit costs.

## 24. Electrical Variable Speed Drives - Programme Options

24.1. Our aim in developing the investment plan is to deliver value to our consumers and stakeholders.

24.2. As described in the section below 'Electrical Variable Speed Drives - Business Case Outline and Discussion – Investment Decision Approach' these assets are maintained on a proven condition and performance based approach. This approach aligns with industry practice. The predicted levels of investment are based on specifically identified issues, historic analysis and known future requirements. There are therefore no credible programme options to assess that ensure the intended asset performance and safe operation of compressor assets.

24.3. The proposed programme is therefore based on the best information available and represents the lowest whole life programme of investment to deliver the outcomes over RIIO-2 and RIIO-3.

24.4. As a result,we have therefore not considered any further programme options as any of those would be an increase in initial investment and overall whole life cost from this proposed position.

## 25. Electrical Variable Speed Drives Business Case - Outline and Discussion

25.1. In this section, we set out our overall investment plan for electric drives. This section demonstrates why the proposed investment levels for electric drives are the right levels to ensure the health and reliability of these assets for the investment period and beyond.

### Key Business Case Drivers Description

25.2. In developing our risk forecasts and proposed plans we have considered the impact of the following drivers for investment on these assets:

- Asset Deterioration
- Obsolescence
- Legislation
- Environment.

### Business Case Summary

25.3. In appraising asset health investment, we have considered how our assets can impact on several outcomes:

- Reliability risk
- Environmental risk
- Safety risk
- Societal risk

25.4. Failure of electric drives can affect these outcomes.

### Desired Outcomes

25.5. The outcome of this investment is to:

- Ensure we deliver against our stakeholder priority: *"I want to take gas on and off the system when and where I want"*
- Will not be a cause of affecting the availability and performance of the compressors.
- Resolve the specific unreliability and obsolescence issues with the electric drives
- Electric Drive Replacement/Refurbishment – to avoid extended outages and remove the need to run gas turbine compressors

*Stakeholder Support*

25.6. Consumer and stakeholder research and engagement has been integral to the development of our asset health investment plans. Early discussions realised that to engage in meaningful dialogue, our plan outputs should be presented at a programme rather than asset level of detail. This is due to the integrated nature of our Asset Health plan which makes it challenging to disaggregate and engage on individual elements.

For details of our stakeholder engagement approach please refer to 'I want to take gas on and off the system where and when I want' [Chapter 14 of the GT submission].

## Investment Decision Approach

25.7. During the period, we will continue the current approach to investing in the Electric Variable Speed Drives using a condition monitoring system with the requirements for intervention determined through inspections, test and monitoring. The proposed investment during the period comprises:

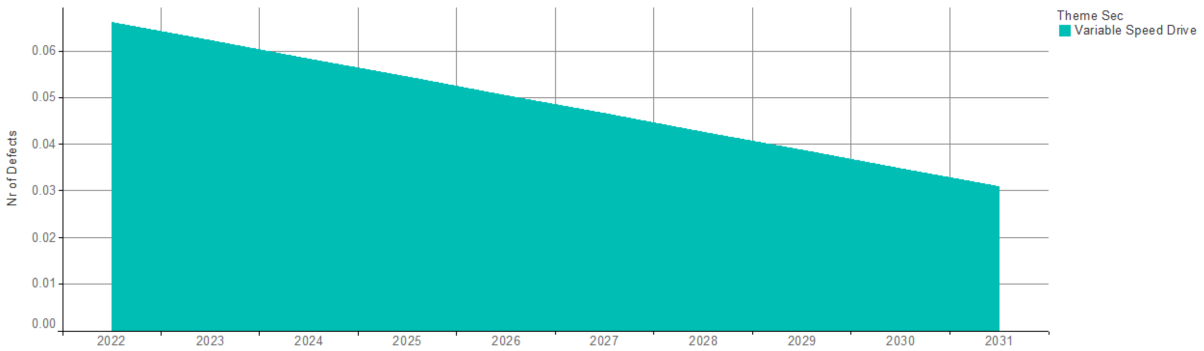
- **Lockerley** – full proactive replacement of both Electric Variable Speed Drives.
- **Siemens Obsolete Control Systems** – replacement of the 4 control systems.
- **Failing HV Motors at Churchover and Wormington** – continued monitoring of the stator winding RTDs on the HV motors. Investment has been forecast to undertake a rewinding of these during the period. This will be subject to a full technical and risk based investigation prior to any work being undertaken.
- **Cooling Fin Corrosion** – allowance has been made in the period for replacement of cooling fins.
- **Other Repairs/Refurbishments** – During the period allowance has been made for several condition-based repairs and / or refurbishments. These will be subject to a full technical and risk based investigation prior to any work being undertaken. These volumes are based on historic data.

## Benefits of the Investment

*Defects*

25.8. The chart below shows the predicted defects with the preferred investment option.

**Predicted Defects with Preferred Option**



## Preferred Option

25.9. To deliver the required outcomes for all our stakeholders we have developed the most effective combination of efficient interventions. These form the programme of work for the electric drives assets in the investment period. [redacted]:

**Intervention Volumes**

[redacted]

## Asset Health Spend Profile

25.10. The profile of investment in the electric drives assets, driven from the derived volumes of work and the efficient unit costs, for the period is shown is the table below:

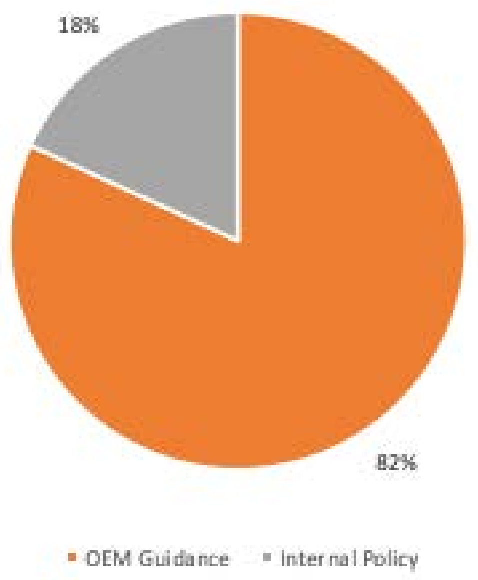
**Spend Profile**

| Investment (£ 000's) | RIIO-2 | | | | | RIIO-3 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 |
| **Electrical Variable Speed Drive** | 12,676 | 1,216 | 0 | 0 | 1,901 | 108 | 0 | 1,840 | 495 | 31 |
| **Total** | 12,676 | 1,216 | 0 | 0 | 1,901 | 108 | 0 | 1,840 | 495 | 31 |
| | **15,793** | | | | | **2,473** | | | | |

## Intervention Drivers

25.11. The following chart shows the breakdown of investment across each of the intervention drivers. This shows that the majority of the investment consists of interventions that are based on OEM Guidance with the remainder based on internal policy.

**RIIO-2 Electrical Variable Speed Drives Intervention Drivers**[5]




## Preferred Programme CBA

25.12. We are targeting an appropriate level of asset health investment in electric drives to mitigate the reliability, safety and environmental risks from the ageing asset base.

25.13. In line with HM Treasury Green Book advice and Ofgem guidance we have appraised whether investment in electric drives is value for money. We have considered costs over a 45-year period in a full cost benefit analysis (CBA).

25.14. The CBA for the electric drives investment over the period is shown below.

**CBA Summary**[6]

| | 10 years | 20 years | 30 years | 45 years |
|---|---|---|---|---|
| **Present Value costs** | £8.90 | £12.42 | £15.66 | £19.98 |
| **Present Value H&S benefits** | £- | £- | £- | £- |
| **Present Value non H&S benefits** | £0.19 | £0.65 | £1.31 | £2.59 |
| **Net Present Value** | £(8.71) | £(11.77) | £(14.34) | £(17.39) |

25.15. The option proposed represents the least non-cost beneficial option even though overall the total NPV is not cost beneficial. This is because our CBA model, which is designed to cover deterioration of condition, does not directly model unit run-hours or carbon emissions resulting from operational use of the electric drive. However, our overarching compressor strategy identifies the need case for our compressor stations and units and considers ongoing asset health costs as part of that CBA process. Moving forwards a robust Network Capability review will reassess these needs on an ongoing basis and our asset health programme for our compressors will continually align to ensure we invest to maintain the reliability of these essential machines.

[5] See Appendix A for intervention driver category definitions
[6] A14.11.3 Electrical Variable Speed Drive CBA

25.16. We have challenged whether this is the right programme of work. In developing our plans and making our decision we have been fully cognisant of the need to develop plans that are value for money, acceptable, affordable and deliverable.

25.17. This level of investment will ensure we successfully manage asset deterioration and obsolescence, whilst meeting our legal obligations. It will ensure we deliver the outcomes that consumers and stakeholder tell us they want us to meet.

25.18. We have assessed the sensitivity of the Cost Benefit Analysis to the full range of unit costs. The results of this analysis are presented in the Unit Cost section above.

25.19. Across our stakeholders there is little support for keeping the costs the same as in RIIO-1, given the unacceptable consequential increase in risk.

## 26. Electrical Variable Speed Drives - Preferred Option Scope and Project Plan

26.1. The section summarises our preferred investment plan required to deliver acceptable and affordable outcomes for our stakeholders.

### Preferred Option

26.2. To deliver the required outcomes for all our stakeholders we have developed the most effective combination of efficient interventions. These form the programme of work for the electric drives assets in the investment period. [redacted]:

**Intervention Volumes**

[redacted]

### Asset Health Spend Profile

26.3. The profile of investment in the electric drives assets, driven from the derived volumes of work and the efficient unit costs, for the period is shown is the table below:

26.4. The profile of investment in the electric drives assets, driven from the derived volumes of work and the efficient unit costs, for the period is shown is the table below:

**Spend Profile**

| Investment (£ 000's) | RIIO-2 | | | | | RIIO-3 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 |
| **Electrical Variable Speed Drive** | 12,676 | 1,216 | 0 | 0 | 1,901 | 108 | 0 | 1,840 | 495 | 31 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Total** | 12,676 | 1,216 | 0 | 0 | 1,901 | 108 | 0 | 1,840 | 495 | 31 |
| | **15,793** | | | | | **2,473** | | | | |

## Delivery Planning

26.5. At this point in time the delivery of our RIIO-2 and RIIO-3 plans are in principle deliverable based on initial assessments of work. We will regularly review the plan to consider any known or changing constraints, customer impacts and bundling opportunities. In the event of churn our plan must be re-optimised to reflect the impact of the change and provide an opportunity to reconsider the efficient timing of delivery.

26.6. We recognise that many of our asset classes are co-located across the NTS pipe network and sites. Much of our investment delivery also requires outages of the associated pipelines or plant and equipment. The availability of outages is extremely limited across most of the NTS due to the radial nature of the network. It is therefore most efficient from both financial and network risk points of view to bundle investment across asset classes within the same outage period. This maximises the work undertaken in any outage whilst ensuring efficient delivery through minimised project overheads. For cabs and compressor train projects it may be possible to take more localised outages bypassing the unit. This depends on network flow conditions and the availability of local/supporting units. Therefore, the availability and reliability of the supporting units are also critical factors. Our deliverability assessment and phasing of the work has accounted for supporting unit availability and the availability of sites which can provide similar compression requirements. By providing options to "re-direct" gas flows, compression availability also influences the likelihood of outages on other parts of the network.

26.7. The bundling approach is particularly effective when applied at a feeder level or for a whole site. In which case the preparatory inspection, investigation, risk assessment, planning and procurement activities can be completed as far as possible before the outage. This allows the maximum amount of intervention and risk reduction to be bundled into a single 'campaign' across the length of the feeder. During RIIO-1 this has proved to be an extremely efficient and effective approach to delivery of our programmes of work. Additionally, where work is necessary on both compressor trains and cabs these projects can be easily/locally bundled where larger scale outages are not available and this could be an option where individual or groups of assets that present a risk to our performance that do not 'fit' into the planned 'campaign' approach. We will ensure that these risks are remediated as efficiently as possible through individual or small groups of targeted interventions.

26.8. Where asset interventions do not require outages then the campaign approach will still be applied to maximise the opportunity for delivery of the same type of work across many locations. This enables efficient procurement through significant volumes of common works.

# Vent Systems (£1.4m)

## 27. Vent Systems - Equipment Summary

27.1. Vent systems are present on Compressor Stations and Gas Terminals. Their purpose is to allow a controlled safe and environmentally effective release of contained high pressure gas to atmosphere from transmission plant (not including pipelines). They allow localised de-pressurisation to prevent integrity issues, damage to machinery and to allow maintenance.

27.2. 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.

27.3. Vent systems form a fundamental part of a facility's Safety Shut Down System and must be available and fully functional at all times when there is gas pressure in the compression system.

27.4. Vent systems comprise several elements:

- Fixed vent stacks and their supporting structures and civils
- Vent silencers where applicable
- Molecular seals where applicable
- Nitrogen snuffing systems
- Vent isolation valves
- Volume flow control regulators
- Remote and locally actuated valves.

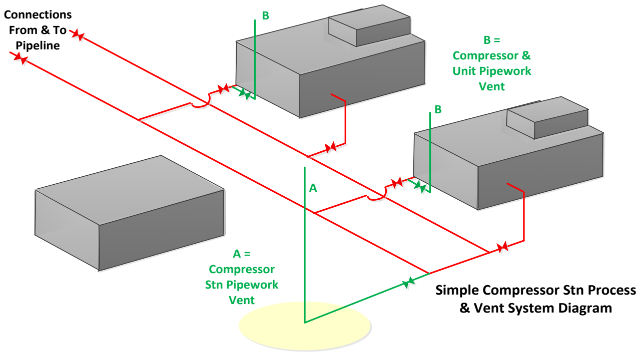
### Location and Volume

27.5. There are 72 vent systems located across 25 sites (23 compressors and 2 terminals).

### Redundancy

27.6. There is typically one vent stack system for each individual compressor unit and one for the site as a whole. A typical layout is shown in the diagram below:

## Simple Vent System Diagram



## 28. Vent Systems - Problem Statement

28.1. The vent systems were installed at the time that the site and associated compressor unit were constructed and therefore many of these systems are approaching or beyond their design life. Many of these vent systems are suffering from corrosion of both the vent pipework and the and also the structural steelwork.

28.2. The vent valve also deteriorates due to age and duty and some of them are leaking leading to a continual discharge of gas to atmosphere.

### Drivers for Investment

28.3. The key drivers for investment in the vent system assets are:

- Asset Deterioration

*Asset Deterioration*

28.4. The vent pipework and the associated structural steel work are subject to corrosion.

28.5. The vent valve is subject to operational wear and tear.

### Impact of No Investment

28.6. The vent systems form a fundamental part of a facility's safety shut down system and must be available and fully functional at all times when the compression system is in operation. Should all or part of the vent system not be in a functional or fit for purpose state, then without any other supplementary option, the facility or its affected element must be declared non-operational on process safety grounds. This will lead to compressor unit or site unavailability.

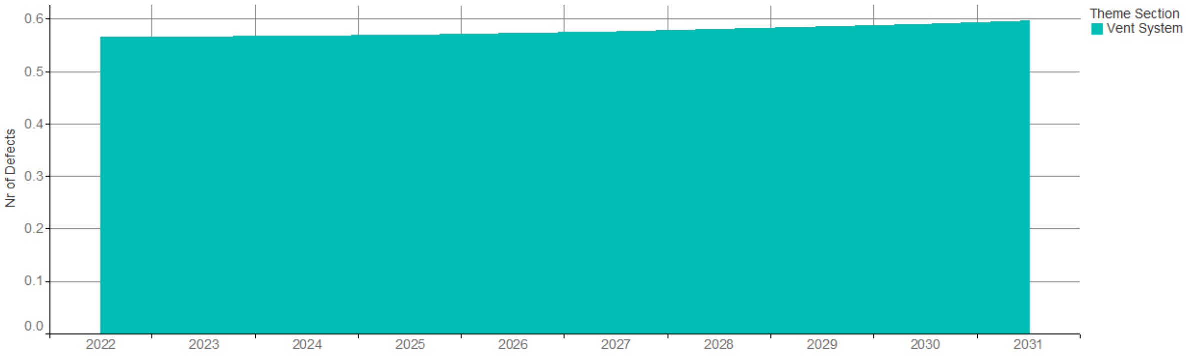
28.7. Similarly, should a system abnormality not allow effective inventory evacuation any aligned maintenance intervention activity cannot be allowed on safety grounds. This impacts the ability to undertake normal or emergency works on other assets further increasing the impact of any failures or extending outage times.

28.8. Lack of investment in the structural elements of the vent stack leads to increased safety risk of structural failure.

28.9. Vent system leakage due to lack of investment in the vent valve can lead to continuous significant volumes of natural gas being discharged to atmosphere with significant environmental impacts as methane is a greenhouse gas.

28.10. The chart below shows the defects predicted for the compressor vent system assets based on defects data recorded in Ellipse and applying our NOMS methodology deterioration models. The deterioration assumes no investment in the vent systems assets.

**Predicted Vent defects without Investment**

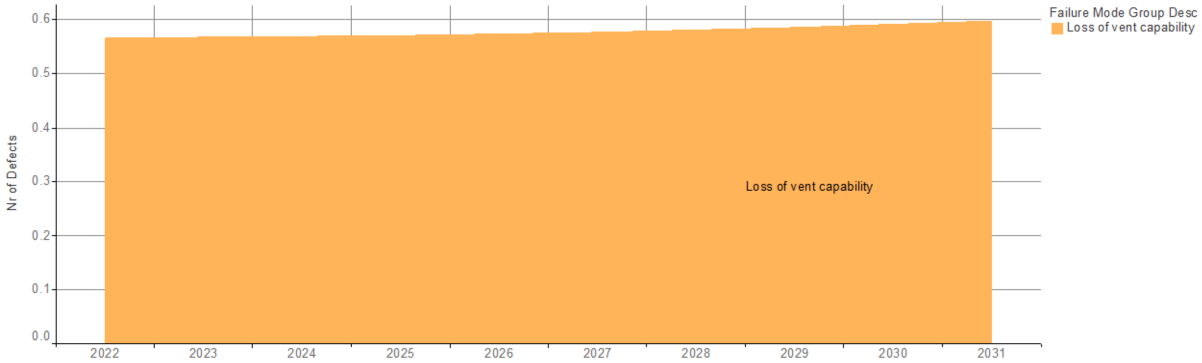



28.11. The proposed investment includes all vent systems assets on the NTS, including all of their subcomponents.

## 29. Vent Systems - Probability of Failure

29.1. The probability of failure is modelled using our NOMs methodology. The chart below shows the predicted frequency of failures split by failure mode.

**Predicted Vent Defects by Failure mode**




29.2. The chart shows that the failure modes that contribute most to the failure of these assets are:

- Loss of vent capability.

### Consequential Interventions

29.3. Several Compressor Train assets are defined as only delivering Consequential Interventions based upon the following definitions:

*"Any intervention on a network asset, or other infrastructure asset, that modifies the probability of failure, or consequence of failure of* ***another network asset****. A consequential asset can include, for example:*

- *installation or removal of physical infrastructure designed to prevent damage to adjacent assets in the event of an asset failure (e.g. installation of a blast wall),*
- *addition or disposal that increases or decreases the resilience of a local or regional network and hence modifies the consequence of failure of other asset(s) in the locality or region."*

29.4. The SACs that are considered to deliver Consequential Interventions are listed in the table below:

**NARMs Interventions**

| NARMs Asset Intervention Category | Secondary Asset Class |
|---|---|
| **Consequential Interventions (Non-risk tradeable)** | Vent System |

### Vent Systems Interventions

29.5. The interventions in vent systems are shown in the table below:

**Vent System Intervention Options by Type**

| Intervention | SAC | Intervention Category |
|---|---|---|
| A22.10.4.3 / Modulating Vent Valve Overhaul | Vent System | Major Refurbishment |
| A22.10.4.4 / N2 Snuffing & Molecular Seal Major Refurb | Vent System | Major Refurbishment |
| A22.10.4.6 / Vent System Pipework Corrosion / P11 Major Refurb | Vent System | Major Refurbishment |
| A22.10.4.7 / Vent System Pipework Minor Refurb | Vent System | Minor Refurbishment |
| A22.22.3.21 / Modulating Vent Valve Overhaul (St. Fergus) | Vent System | Major Refurbishment |
| A22.22.3.24 / Minor remediation works (St. Fergus) | Vent System | Minor Refurbishment |

### Data Assurance

29.6. All PoF and CoF values are taken from the National Grid Gas Transmission 'Methodology for Network Output Measures' (the Methodology). The Methodology was originally submitted for public consultation in April 2018, with three generally favourable responses received in May 2018. On this basis, Ofgem were happy to provisionally not reject the Methodology pending further work to:

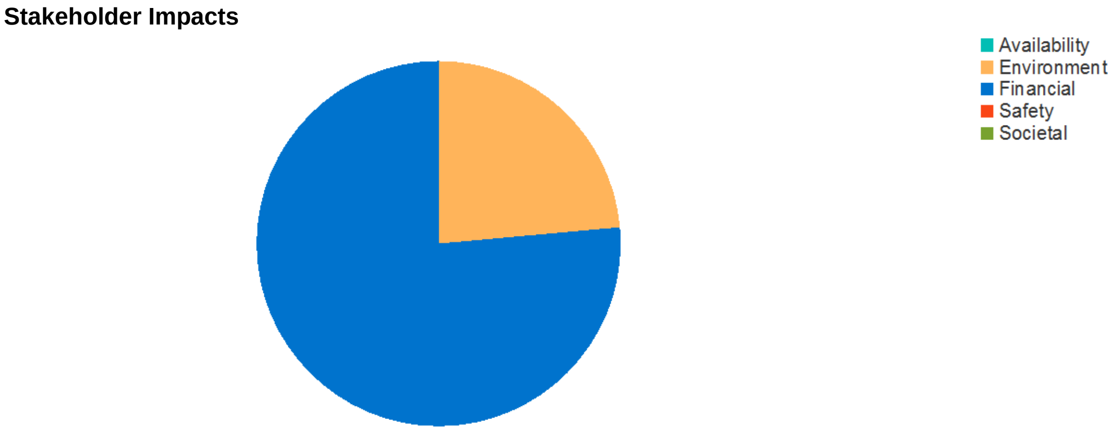
- Produce a detailed Validation Report, confirming the validity of data sources used in the Methodology
- Test a range of supply and demand scenarios and incorporate an appropriate scenario to best represent Availability and Reliability risk.

29.7. A review of the Methodology by independent gas transmission experts has been carried out and several improvements identified and incorporated.

29.8. At the time of writing, the final Validation Report has been submitted to Ofgem. We understand that once this work is complete Ofgem will formally "not reject" the Methodology and a License change progressed to restate our RIIO-1 targets in terms of monetised risk commenced.

## 30. Vent Systems - Consequence of Failure

30.1. The chart below shows the expected stakeholder impacts as a result of failure occurring on the vent system assets. The charts show the relative numbers of consequence events, not relative monetised risk.




30.2. The risk for the Vent System can be explained as follows, in order of significance:

- **Financial risk** is mostly associated with the costs of operating and maintaining the asset at the current level of risk, including routine maintenance and repair.
- **Environmental risk** is associated with the increased loss of gas associated with the failure of the venting system (valve fails open).

30.3. The risk associated with other service risk measures for the is negligible, based on the assigned failure modes. Noise nuisance, which is a Societal risk, is important for vent systems but has a low risk valuation (as compressor assets are not generally near large centres of population).

## 31. Vent Systems - Options Considered

### Potential Intervention Options

31.1. The following intervention options have been considered for the compressor vent and associated assets:

- **Modulating Vent Valve Diagnostic Inspection** – inspection of the vent valve to check sealing and operation and identify any interventions
- **Modulating Vent Valve Overhaul** – overhaul of the vent valve to replace individual elements and maintain operational capability and sealing capability
- **Nitrogen Snuffing & Molecular Seal Refurb** – refurbishment of nitrogen snuffing system & molecular seal
- **Vent Pipework Corrosion Repair** - Repair typically consisting of damage assessment and re-coating on vent system pipework and nitrogen snuffing systems.
- **Vent Pipework Refurbishment** - Damage requiring significant mechanical intervention, for example the replacement of damaged pipework sections.

### Intervention Unit Costs

31.2. The total RIIO-2 investment for Vent Systems represents 1% of the Compressor Train investment theme. The entire investment for Vent Systems have been developed using other estimation methods due to the low frequency of these works being completed in the past and therefore having limited supplier quotations and outturn information available.

31.3. The table below provides the unit costs for all the potential Vent Systems interventions.

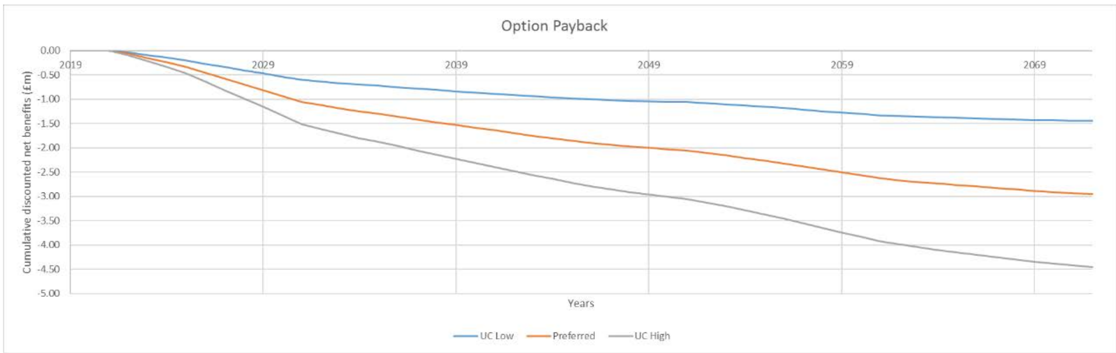
**Intervention Unit Costs – Vent Systems**

| Intervention | Cost (£) | Unit | Evidence | Data Points | Overall value in BP |
|---|---|---|---|---|---|
| **Vent Systems** | | | | | |
| A22.10.4.6 / Vent System Pipework Corrosion / P11 Major Refurb | [redacted] | Per asset | Estimated - Other | 0 | £122,838 |
| A22.10.4.7 / Vent System Pipework Minor Refurb | [redacted] | Per asset | Estimated - Other | 0 | £56,954 |
| A22.10.4.3 / Modulating Vent Valve Overhaul | [redacted] | Per asset | Estimated - Other | 0 | £939,034 |
| A22.10.4.4 / N2 Snuffing & Molecular Seal Major Refurb | [redacted] | Per asset | Estimated - Other | 0 | £218,379 |
| A22.22.3.21 / Modulating Vent Valve Overhaul (St. Fergus) | [redacted] | Per asset | Estimated - Other | 0 | £58,690 |
| A22.22.3.24 / Minor remediation works (St. Fergus) | [redacted] | Per asset | Estimated - Other | 0 | £28,814 |

*Unit Cost Sensitivity*

31.4. We have used the potential range of unit cost variance to assess the sensitivity of the Cost Benefit Analysis to the upper and lower limits. The graph below shows the results of this compared to the preferred option.

**Net Benefits of Upper and Lower Unit Cost Sensitivity**




31.5. Whilst the level of cost benefit changes as the unit costs vary, the investment remains non cost beneficial across the range of unit costs.

## Innovation

31.6. During RIIO-1, we have continued to develop a dynamic portfolio of projects aligned to the Gas Network Innovation Strategy which deliver real value to our customers, stakeholders and the wider industry. We will be continuing to focus on the implementation of innovation into business as usual to drive value throughout everything we do. We will also remain committed to sharing these ideas and best practice across the wider industry to deliver a safe, reliable and efficient network that benefits gas consumers across the UK.

31.7. For the vent systems, we developed and implemented the below project in the RIIO-1 period which will be brought forward into this investment period:

- **Vent Silencer** - Development of a new design vent silencer, which has a smaller foot print than previous designs, saving the need to expand the site, while also reducing visual and noise pollution. The benefits from this will be from future applications.

## 32. Vent Systems - Programme Options

32.1. Our aim in developing the investment plan is to deliver value to our consumers and stakeholders. Hence, we have considered a range of options from the do nothing position through to reductions in risk across all measures. These have been used to explore the credible options for varying the investment and appraising the impact on our legal compliance, risk position and stakeholders.

32.2. In developing our plan, the following options have been considered for investment in the Vent Systems and associated assets. Please note that all programme options include any fixed 'no-regrets' investments associated with the Bacton and St Fergus sites.

*Baseline – Do Nothing*

32.3. The impact of no investment in our Vent System assets increases service risk over a 10-year period, the most significant impact being a doubling in the number of potential outages every year caused by Vent System failures. This would create an inability to evacuate gas safely to atmosphere resulting in unit or site isolations on the NTS. We would likely become a statutory nuisance due to noise, resulting in legal enforcement being taken by our environmental regulators for breaching elements of our environmental permits. Failure to comply would result in significant fines and prohibition notices (unable to operate legally). This option includes the reactive only investment and is the option against which all the other options are compared.

*Programme Option 1 – Vent Valve Inspection*

32.4. This option undertakes the inspection and associated minor remediation works to the Vent valves. No major overhauls of the Nitrogen Snuffing, Vent Valve and Molecular Seals are included. Vent pipework corrosion remediation is included within this option.

*Programme Option 2 – Minimal Vent Valve*

32.5. This option undertakes the inspection and associated minor remediation works to the Vent valves. Only significant major overhauls of the Nitrogen Snuffing, Vent Valve and Molecular Seals are included. Vent pipework corrosion remediation is included within this option.

*Programme Option 3 – Minimal Vent Pipework*

32.6. This option undertakes the inspection and associated minor remediation works to the Vent valves. All predicted major overhauls of the Nitrogen Snuffing, Vent Valve and Molecular Seals are included. Minimal major refurbishment of the Vent pipework due is included within this option. All corrosion remediation on the vent pipework is undertaken via fully reactive minor refurbishments.

*Programme Option 4 – Maintain Risk*

32.7. This option considers the investment required to maintain stable risk. The option undertakes the inspection and associated minor remediation works to the Vent valves. All predicted major overhauls of the Nitrogen Snuffing, Vent Valve and Molecular Seals are included. Major refurbishment of the Vent pipework due is included where appropriate to manage risk at lowest whole life cost. Minor corrosion remediation on the vent pipework is undertaken via reactive minor refurbishments.

## Programme Options Summary

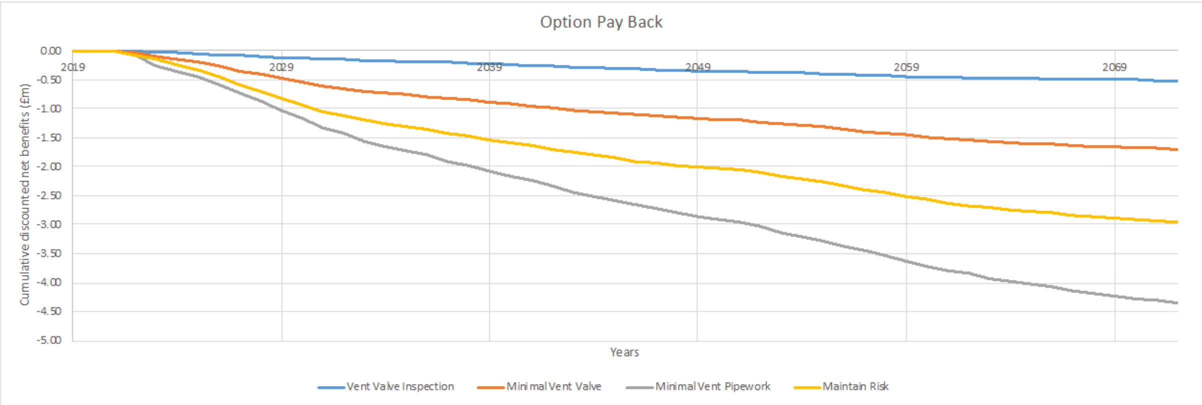
32.8. In considering the CBA for each of the programme options, a summary of all the potential programme options is provided in the table below.

**Potential Programme Options**

| Option | RIIO-2 Invest' £ m. | RIIO-3 Invest' £ m | PV Costs £ m | PV benefits £ m | Net NPV £ m | CB Ratio | Payback Period (years) |
|---|---|---|---|---|---|---|---|
| **1 - Vent Valve Inspection** | £0.21 | £0.25 | £0.70 | £0.22 | £(0.48) | 0.31 | - |
| **2 - Minimal Vent Valve** | £0.85 | £1.03 | £2.16 | £0.54 | £(1.61) | 0.25 | - |
| **3 - Minimal Vent Pipework** | £1.76 | £2.07 | £4.77 | £0.70 | £(4.08) | 0.15 | - |
| **4 - Maintain Risk** | £1.42 | £1.76 | £3.50 | £0.70 | £(2.80) | 0.20 | - |

32.9. The graph shows the cumulative discounted NPV of the net benefit for each of the investment options.

**Option Payback – Net NPV**




## Programme Options Selection

32.10. All the potential options are non-cost beneficial over the 45-year analysis period. The selection of the preferred option has therefore been based on an assessment of the level of risk, maintaining our compliance with legislation and delivering value for consumers and stakeholders. The outcomes associated with each option are provided below:

### *Programme Option 1 – Vent Valve Inspection*

32.11. Whilst undertaking the inspection and associated minor remediation works on the vent systems, the lack of significant overhauls on the major components results in an increased level of risk. The risk of unavailability of compressors due to an underperforming vent system, the inability to vent for works to be undertaken and the potential for loss of gas are all increased.

### *Programme Option 2 – Minimal Vent Valve*

32.12. As with Option 2 the lack of the full investment in significant overhauls on the major components results in an increased level of risk. The risk of unavailability of compressors due to an underperforming vent system, the inability to vent for works to be undertaken and the potential for loss of gas are all increased.

*Programme Option 3 – Minimal Vent Pipework*

32.13. Whilst delivering the required levels of risk on the Nitrogen Snuffing, Vent Valve and Molecular Seals. This option leads to increased minor reactive intervention on the vent pipework. The condition and associated performance of these assets will deteriorate over the period and there will be an increased risk of losing gas, and increases in environmental and safety impacts.

*Programme Option 4 – Maintain Risk*

32.14. This option results in increased minor reactive intervention (i.e. fix on fail) across all valve types. Due to an increase in unplanned interventions, there is a potential increase in feeder outages and the associated vent volumes related would increase environmental impacts.

## Preferred Option

32.15. Our preferred option is Option 4 to maintain the current level of risk. Even though some of the other options require less investment and are more cost beneficial, they do not meet the required outcomes.

32.16. Options 1, 2 and 3 result in unacceptable increases in availability, safety and environmental risk. The whole life cost of Option 3 is also higher than Option 4 to maintain performance through risk based major refurbishments, the benefits are lower and therefore overall it is less cost beneficial than Option 4.

32.17. Maintaining the current level of risk is consistent with the feedback from stakeholders, who want at least the current level of risk maintained. Our chosen option meets the desired outcomes at least whole life cost, across the all vent system assets.

32.18. A complete explanation of the selected option is provided in the next section.

## 33. Vent Systems - Business Case Outline and Discussion

33.1. In this section we set out our overall investment plan for vent systems. This section demonstrates why the proposed investment levels for vent systems are the right levels to ensure the health and reliability of these assets for the investment period and beyond.

### Key Business Case Drivers Description

33.2. In developing our risk forecasts and proposed plans we have considered the impact of the following drivers for investment on these assets:

33.3. The key drivers for investment in the Compressor assets are:

- Asset Deterioration
- Legislation.

### Business Case Summary

33.4. In appraising asset health investment, we have considered how our assets can impact on a number of outcomes:

- Reliability risk
- Environmental risk
- Safety risk
- Societal risk

33.5. Failure of vent systems can affect all of these outcomes.

*Outcomes delivered*

33.6. The outcome of this investment is to:

- Ensure we deliver against our stakeholder priorities:
  - *"I want the gas system to be safe"*
  - *"I want you to care for communities and the environment"*
- Ensure that vent systems do not contribute to the unavailability of compressor units or the ability to undertake planned and emergency works on associated assets and therefore impact the resilience of the NTS.
- Ensure vent systems do not contribute to our environmental impact thorough the unintended release of gas to atmosphere.
- Maintain the integrity of the vent pipe and structural elements to ensure that they do not present an unacceptable safety risk.

*Stakeholder Support*

33.7. Consumer and stakeholder research and engagement has been integral to the development of our asset health investment plans. Early discussions realised that to engage in meaningful dialogue, our plan outputs should be presented at a programme rather than asset level of detail. This is due to the integrated nature of our Asset Health plan which makes it challenging to disaggregate and engage on individual elements. For details of our stakeholder engagement approach please refer to 'I want to take gas on and off the system where and when I want' [Chapter 14 of the GT submission].

## Investment Decision Approach

33.8. In order to deliver the outcomes for the investment period the vent systems assets require a mixture of the defined intervention categories. A risk based approach has been used to develop an asset by asset list of the appropriate category of intervention to be undertaken on the vent systems. This risk based approach included:

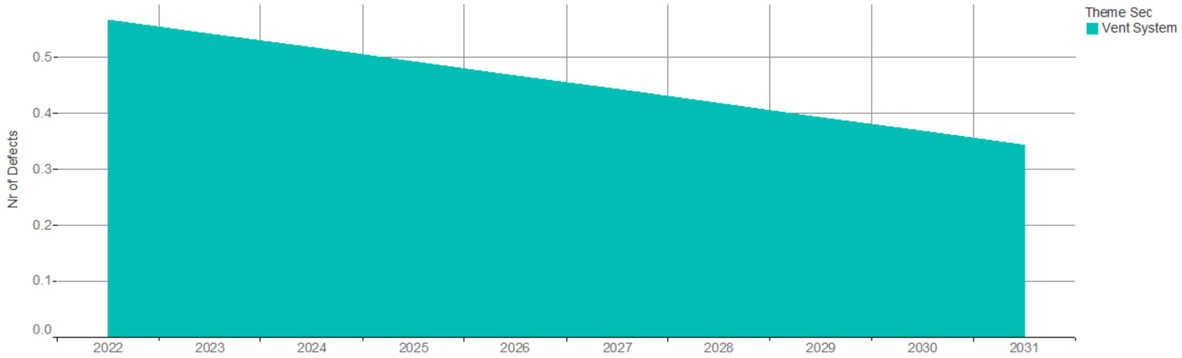
- Issues and defects currently identified and those forecast to arise through the period
- Asset age, condition and probability of failure informed through impacts of deterioration in current investment period.
- Remaining Life of the Compressor Unit
- Forecast Run Hours of the Compressor Unit
- Local Resilience Requirement for the Compressor Unit.

## Benefits of the Investment

*Defects*

33.9. The chart below shows the predicted number of defects following investment.

**Predicted Vent Defects with Preferred Option**



## Preferred Option

33.10. To deliver the required outcomes for all of our stakeholders we have developed the most effective combination of efficient interventions. These form the programme of work for the vent systems assets in the investment period. [redacted]:

**Intervention Volumes**

[redacted]

## Asset Health Spend Profile

33.11. The profile of investment in the vent systems assets, driven from the derived volumes of work and the efficient units costs, for the period is shown is the table below:

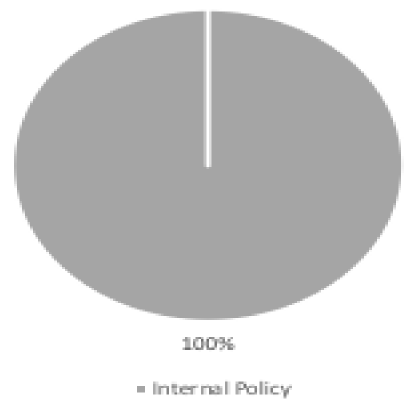
**Spend Profile**

| Investment (£ 000's) | RIIO-2 | | | | | RIIO-3 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 |
| **Vent System** | 236 | 297 | 267 | 268 | 356 | 421 | 334 | 334 | 334 | 334 |
| **Total** | 236 | 297 | 267 | 268 | 356 | 421 | 334 | 334 | 334 | 334 |
| | **1,425** | | | | | **1,755** | | | | |

## Intervention Drivers

33.12. The following chart shows the breakdown of investment across each of the intervention drivers. This shows that all of the investment consists of interventions that are based on internal policy.

**RIIO-2 Vent Systems Intervention Drivers**[7]




[7] See Appendix A for intervention driver category definitions

## Preferred Programme CBA

33.13. We are targeting an appropriate level of asset health investment in vent systems to mitigate the reliability, safety and environmental risks from the ageing asset base.

33.14. In line with HM Treasury Green Book advice and Ofgem guidance we have appraised whether investment in vent systems is value for money. We have considered costs over a 45 year period in a full cost benefit analysis (CBA).

33.15. The CBA for the vent systems investment over the period is shown below.

**CBA Summary**[8]

| | 10 years | 20 years | 30 years | 45 years |
|---|---|---|---|---|
| **Present Value costs (£m)** | £1.13 | £1.89 | £2.48 | £3.50 |
| **Present Value H&S benefits (£m)** | £- | £- | £- | £- |
| **Present Value non H&S benefits (£m)** | £0.07 | £0.25 | £0.43 | £0.70 |
| **Net Present Value (£m)** | £(1.06) | £(1.64) | £(2.06) | £(2.80) |

33.16. The option proposed is non cost beneficial but represents the least whole life cost option to deliver desired outcomes at an acceptable level of risk. This level of investment will ensure we successfully manage asset deterioration, whilst meeting our legal and performance obligations. It will ensure we deliver the outcomes that consumers and stakeholder tell us they want us to meet.

33.17. The outcome of this investment is to ensure:

- vent systems do not contribute to the unavailability of compressor units or the ability to undertake planned and emergency works on associated assets and therefore impact the resilience of the NTS.
- vent systems do not contribute to our environmental impact thorough the unintended release of gas to atmosphere.
- the integrity of the vent pipe and structural elements to ensure that they do not present an unacceptable safety risk.

33.18. We have challenged whether this is the right programme of work. In developing our plans and making our decision we have been fully cognisant of the need to develop plans that are value for money, acceptable, affordable and deliverable.

33.19. We have assessed the sensitivity of the Cost Benefit Analysis to the full range of unit costs. The results of this analysis is presented in the Unit Cost section above.

33.20. Across our stakeholders there is little support for keeping the costs the same as in RIIO-1, given the unacceptable consequential increase in risk.

[8] A14.11.4 Vent System CBA

## 34. Vent Systems - Preferred Option Scope and Project Plan

34.1. The section summarises our preferred investment plan required to deliver acceptable and affordable outcomes for our stakeholders.

### Preferred Option

34.2. In order to deliver the required outcomes for all of our stakeholders we have developed the most effective combination of efficient interventions. These form the programme of work for the vent systems assets in the investment period. [redacted]:

**Intervention Volumes**

[redacted]

### Asset Health Spend Profile

34.3. The profile of investment in the vent systems assets, driven from the derived volumes of work and the efficient units costs, for the period is shown is the table below:

**Spend Profile**

| Investment (£ 000's) | RIIO-2 | | | | | RIIO-3 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 |
| **Vent System** | 236 | 297 | 267 | 268 | 356 | 421 | 334 | 334 | 334 | 334 |
| **Total** | 236 | 297 | 267 | 268 | 356 | 421 | 334 | 334 | 334 | 334 |
| | **1,425** | | | | | **1,755** | | | | |

### Delivery Planning

34.4. At this point in time the delivery of our RIIO-2 and RIIO-3 plans are in principle deliverable based on initial assessments of work. We will regularly review the plan to consider any known or changing constraints, customer impacts and bundling opportunities. In the event of churn our plan must be reoptimised to reflect the impact of the change and provide an opportunity to reconsider the efficient timing of delivery.

34.5. We recognise that many of our asset classes are co-located across the NTS pipe network and sites. Much of our investment delivery also requires outages of the associated pipelines or plant and equipment. The availability of outages is extremely limited across most of the NTS due to the radial nature of the network. It is therefore most efficient from both financial and network risk points of view to bundle investment across asset classes within the same outage period. This maximises the work undertaken in any outage whilst ensuring efficient delivery through minimised project overheads. For cabs and compressor train projects it may be possible to take more localised outages bypassing the unit. This depends on network flow conditions and the availability of local/supporting units. Therefore, the availability and reliability of the supporting units are also critical factors.  Our deliverability assessment and phasing of the work has accounted for supporting unit availability and also the availability of sites which can provide similar compression requirements. By providing options to "re-direct" gas flows, compression availability also influences the likelihood of outages on other parts of the network.

34.6. The bundling approach is particularly effective when applied at a feeder level or for a whole site. In which case the preparatory inspection, investigation, risk assessment, planning and procurement activities can be completed as far as possible before the outage. This allows the maximum amount of intervention and risk reduction to be bundled into a single 'campaign' across the length of the feeder. During RIIO-1 this has proved to be an extremely efficient and effective approach to delivery of our programmes of work. Additionally, where work is necessary on both compressor trains and cabs these projects can be easily/locally bundled where larger scale outages are not available and this could be an option where individual or groups of assets that present a risk to our performance that do not 'fit' into the planned 'campaign' approach. We will ensure that these risks are remediated as efficiently as possible through individual or small groups of targeted interventions.

34.7. Where asset interventions do not require outages then the campaign approach will still be applied to maximise the opportunity for delivery of the same type of work across many locations. This enables efficient procurement through significant volumes of common works.

# Appendices

## Appendix A – Intervention Driver Categories

### Intervention Driver Categories

| | Name | Definition |
|---|---|---|
| A | Legislation & Industry Standards | Intervention required to ensure compliance with relevant safety legislation and/or adopted industry standards. |
| B | OEM Guidance | Intervention recommended by OEM to maintain intended asset performance and safe operation. Any deviation from this guidance shall be specifically risk-assessed to ensure compliance with relevant safety legislation. |
| C | Internal Policy | Internal policy defined intervention required to maintain asset performance, and to align with relevant safety legislative requirements |