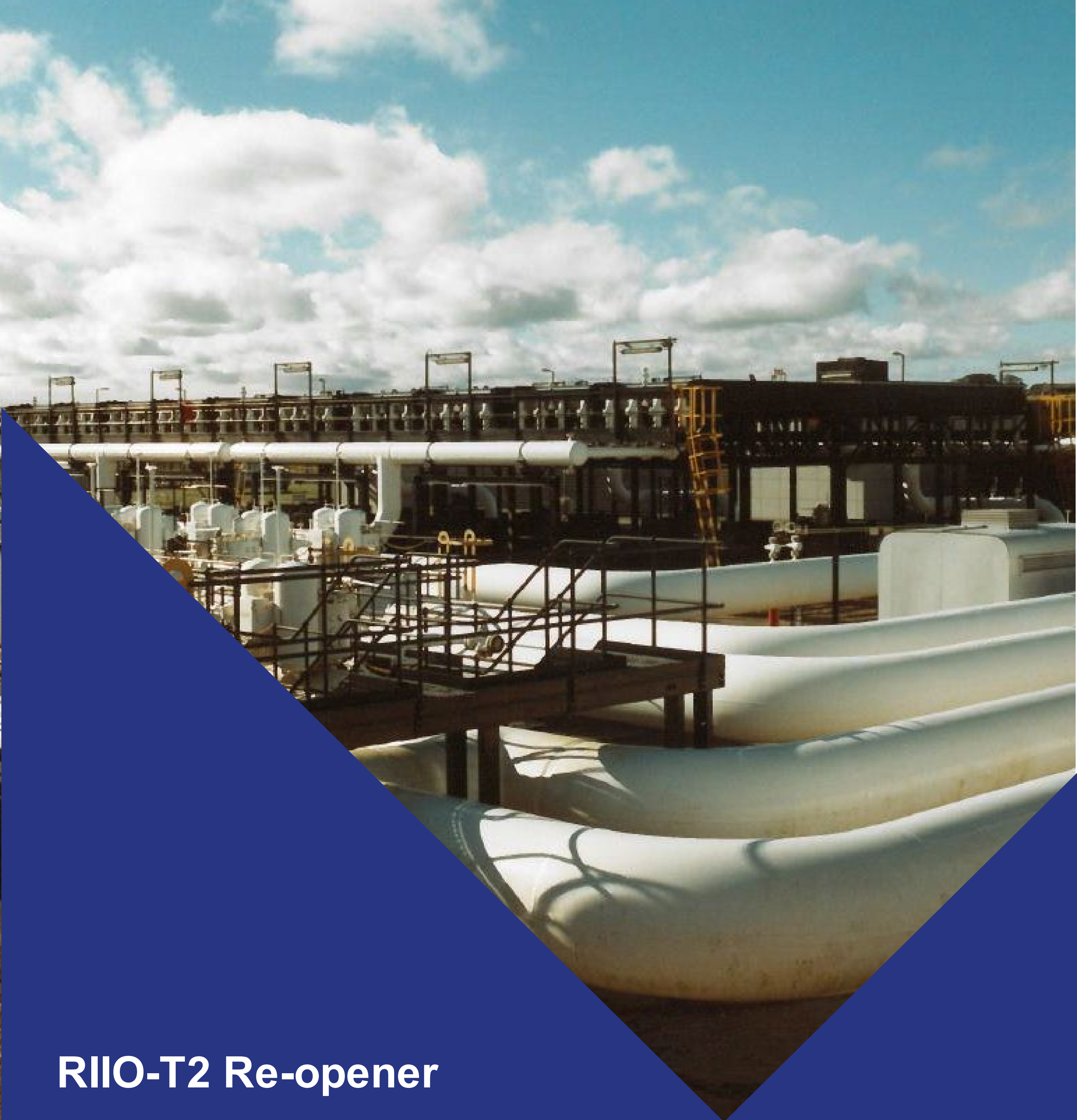

RIIO-T2 Re-opener

St Fergus Terminal Plant 1 Aftercooler

Engineering Justification Paper
Version 5
January 2023

nationalgrid

Contents

1. Executive Summary

1.1. National Grid Gas Transmission, (hereafter referred to as 'NGGT'), are submitting the needs case in accordance with the RIIO-T2 Engineering Justification Paper Guidance v2 document. The purpose of this stage of the process is to justify the project need, set out the different options considered along with the preferred strategic options, and request funding for the preferred option justified within this paper. This EJP details the investment for a number of works associated with the Plant 1 Aftercooler, an air-cooled aftercooler system at St Fergus Terminal. Specifically, replacement of Aftercooler Frame, Fin Tubes and Cooling Blades. This paper also assesses the condition of the structure foundations and concludes no remedial action is required.

1.2. This is part of a suite of documents, shown in Figure 1, and should particularly be read in conjunction with the St Fergus Site Strategy and its appendices. The St Fergus Site Strategy describes the gas terminal's function, its criticality to the network and the proposed investments in line with the site strategy.

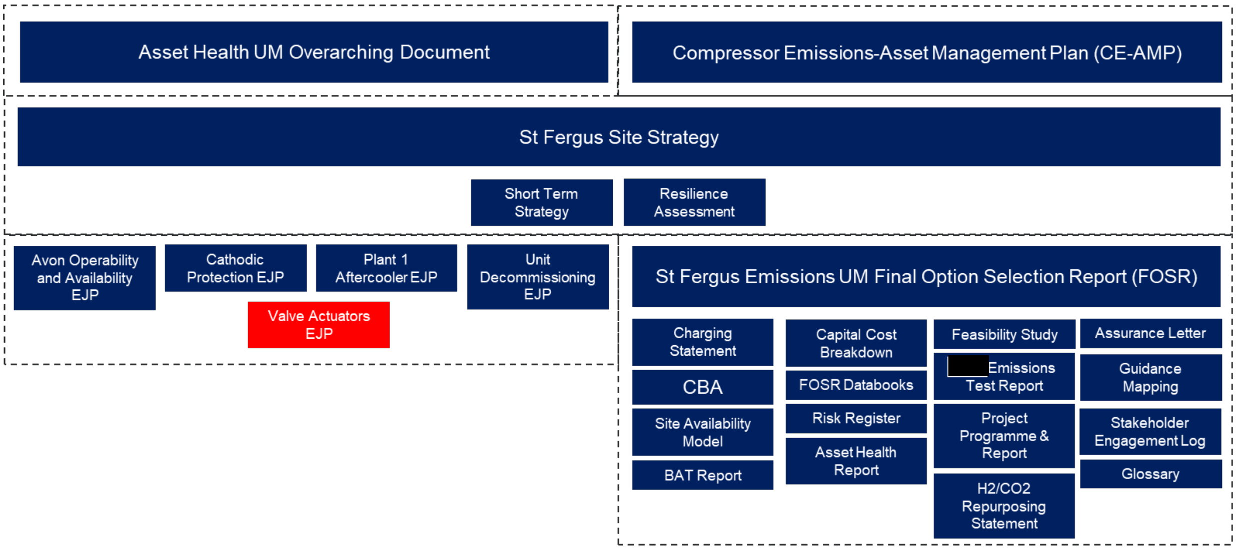

Figure 1: St Fergus Submission Documents Structure

1.3. The current aftercooler assets at the site were installed at the time of terminal construction in 1974, and have since this time been operated, with Plant 2 Aftercoolers, to provide the necessary cooling to prevent downstream asset integrity issues within the St Fergus Terminal buried pipework area and our downstream feeder mains pipelines for over forty-years (with an OEM design life expectancy of twenty-five years). Plant 1 and Plant 2 aftercoolers are used interchangeably, and they can both cool gas from any of the 3 compressor plants (named compressor Plants 1, 2 and 3). Despite the naming convention, Plant 1 aftercooler is not exclusive to Plant 1 compressors, the same is true for Plant 2.

1.4. Our St Fergus Short-Term Strategy[1] provides certainty on the terminal operation requirements, including minimum compression across Plant 1 and 2, for operation out to 2030. This baselines the aftercooling requirements at the site. As St Fergus is a 24/7/365 operation there is a level of redundancy in the aftercooling function required, however the original design did not provide 100% redundancy across Plant 1 and Plant 2 Aftercoolers.

1.5. During 2018 a range of inspections were undertaken on the Plant 1 aftercooler at the site utilising a range of inspection techniques (Near Field Testing (NFT) and Internal Rotary Inspection System (IRIS)). During recommissioning activities, a series of leaks were identified, and further inspections utilising Dye Penetrant testing identified two through wall corrosion defects on the tubes, where these connected to the header box (hence undetectable from the

[1] See Appendix 1

wider NFT and IRIS testing). This resulted in the halting of commissioning and further inspections and interventions progressed. This included detailed assessments of the Aftercooler frame that highlighted significant corrosion had occurred resulting in critical concern for the integrity of the structure. Furthermore, the cooling blade shafts had been identified as reaching the end of life, this was validated through third party assessments.

1.6. The preferred strategic options to remediate the defects were determined in 2020 following extensive surveys and inspections. However, this occurred after our RIIO-T2 business plan submission, and due to the criticality of the aftercooler assets in maintaining continuous supplies from St Fergus, the required interventions could not wait and NGGT initiated a project to address. Additionally, the resolution of defects on Plant 1 Aftercooler and the return to service of this plant were required to facilitate a Plant 2 Aftercooler outage, required to enable the provision of an outage of Plant 6 mixing area and other downstream assets containing 54 CM4 CAT6 defects identified within a previous HSE Intervention and Action legal commitment.

1.7. A range of options were considered and assessed against a wide range of criteria, to manage the corrosion related defects on the tube bundles and aftercooler frame, including repairs to specific tubes, replacement of tubes and localised repairs to the aftercooler frame girders and trusses. Cost assessment identified the option for the replacement tube bundles was comparable to repair options due to the minimum milling cycle whilst eliminating the risk of discovering additional tubes needing repairs through commissioning. Structural assessment of the frame was undertaken with the recommendation from a third party to replace the structure due to the severe through wall corrosion identified, as documented in this report.

1.8. Thermal Calculations were completed based on the preferred option for replacing the Tube Bank Assemblies, replacing the frame and installing new shafts and fan motors. The St Fergus gas compression plant has a design throughput of 75 mcm/d with three compressors in operation with typical discharge temperatures of 65–80°C. If Plant 1 Aftercooler is operating in this scenario it can achieve the necessary cooling to meet the 30-35°C discharge temperature in winter conditions (Air inlet 10°C) but not in summer conditions (Air inlet 20°C).

1.9. In summer conditions, the Plant 1 Aftercoolers are able to cool about 22–30 mcm/d which corresponds to the outlet of only two compressors. The lower throughput is due to the higher ambient temperatures resulting in increased cooling duty required by the aftercooler, with temperature and volume across both sides of the plant equal (as per Charles law, $V1 / T1 = V2 / T2$). In high ambient temperature scenarios both Plant 1 and Plant 2 Aftercoolers will be required to operate in parallel to meet the cooling duty of the compressor outlet gas. Increasing the throughput of the aftercooler would have resulted in modifications to the aftercooler inlet pipework resulting in a project at higher cost and with a longer programme duration.

1.10. Interventions on the asset to remediate the identified defects totals [redacted] (18/19 prices) of which [redacted] is being requested. The current estimated RIIO-T2 cost profile is shown in Table 1.

£m 18/19	FY2022	FY2023	FY2024	FY2025	FY2026	Total
Total Cost	[redacted]					
Baseline						
Not Requested						
Funding Requested						

Table 1: Current estimated RIIO-T2 spend profile

1.11. NGGT are making this funding application for the Aftercooler Programme RIIO-T2 investment costs through the Asset Health Re-opener, in line with Special Condition 3.14, requesting an adjustment to the value of the NARMAHOt term for costs incurred in RIIO-T2. This is summarised, along with other investments, within section 9 of the Asset Health Overarching Document provided as Product 1 of the January 2023 Asset Health Re-opener Submission.

1.12. We will evaluate the condition of Plant 2 aftercooler once Plant 1 aftercooler is back in service. The true overall condition of Plant 2 Aftercooler can only be determined once Plant 1 Aftercooler is returned to service, and we can isolate Plant 2 Aftercooler and conduct intrusive condition assessments. Based on this position we are reviewing the most efficient plan to develop our understanding of the condition and any associated interventions required. A draft of this paper was shared with Ofgem prior to this submission.

2. Summary Table

Name of Scheme/Programme	*T2_2022_St Fergus Plant 1 Aftercooler*
Primary Investment Driver	*Asset Health*
Scheme reference/ mechanism or category	*T2_2022_St Fergus Plant 1 Aftercooler*
Output references/type	*Replacement*
Cost	[redacted] *RIIO-T2 costs*
Delivery Year	*2018 - 2022*
Reporting Table	*6.4 Asset Health Projects*
Outputs included in RIIO T1 Business Plan	*No*

Table 2: Plant 1 Aftercooler Summary Table

3. Introduction and Background

3.1 This paper provides the justification for the replacement intervention on the Plant 1 Aftercooler at the St Fergus Gas Terminal.

3.2 In developing our investment programmes at the St Fergus Gas Terminal since the RIIO-T2 Final Determinations we have adopted a two-phase strategy to ensure clarity between short-term asset health and long-term site operating strategy. Our St Fergus short-term strategy provides certainty on the terminal operation requirements, including minimum compression across Plant 1 and 2, for operation out to 2030. The long-term strategy will deliver the enduring terminal solution, including gas compression, required for operation beyond 2030. The aftercoolers are used in conjunction with both the gas and electric compressors and will be needed for as long as the site continues to compress gas.

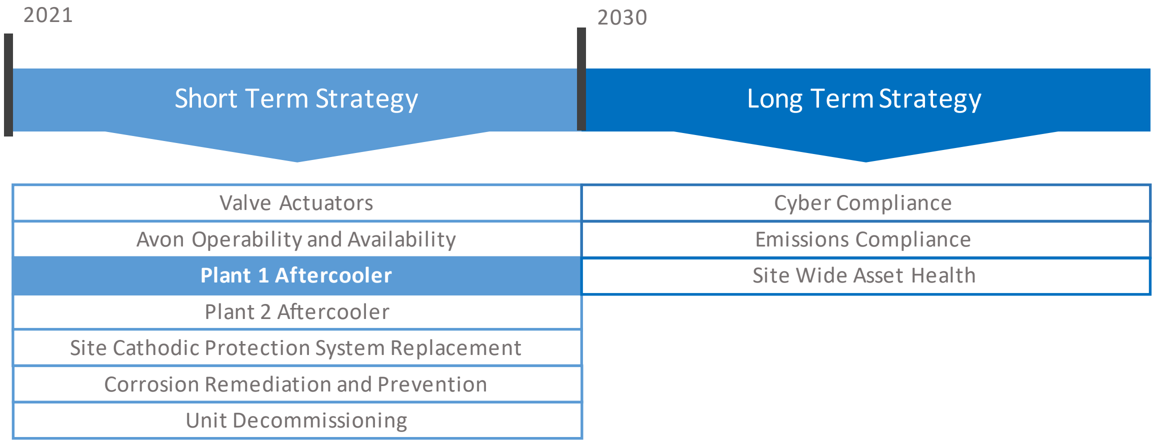

Figure 2: St Fergus Strategies Summary

3.3 The investment outlined in this justification paper concerns the site aftercooler system which is fundamental to the safe and reliable operation of the St Fergus terminal and has been in service since 1973. The condition of the Plant 1 Aftercooler system presents significant operational risks to site operations, with the Plant 1 and Plant 2 aftercoolers being required for 24/7 operation of the terminal.

3.4 St Fergus is an establishment governed under the Control of Major Accident Hazards (COMAH) Regulations 2015 and as such is subject to numerous requirements to demonstrate that safety and environmental risks from and within the facility are understood and being managed to a level to be shown to be '*As Low As Reasonable Practicable (ALARP)*' taking '*All Measures Necessary*' to manage such risks. The Health and Safety Executive (HSE) issued an enforcement notice to the site [Ref: HSE Intervention Action Letter, 07-12-17] requiring NGGT to address numerous severe defects. Over a period of 3.5 years many of these defects have been mitigated through temporary measures and remediated through repairs. The remainder have been risk assessed to allow safe continued operations whilst engineering solutions to eliminate the present corrosion and subsidence risks are developed and implemented.

3.5 During 2018 a range of interventions were undertaken on the Plant 1 aftercooler at the site, to address corrosion related issues. During recommissioning activities in January 2020, a series of leaks were identified through dye penetration tests from the junction of the fin tube bundles and header boxes that resulted in further inspections and interventions. This resulted in the commissioning of the asset being stopped to undertake further investigation.

3.6 Certainty on our proposed intervention was reached mid-2020 however this was after our RIIO-T2 submission. The required interventions on these assets could not wait, and NGGT has had to initiate the work. This decision was required due to the importance of the aftercooler systems to maintaining the 24/7 operation of the site, operational requirements and the lack of redundancy of our aftercooler systems, asset integrity of downstream systems and wider operational and process safety considerations.

3.7 Additionally, the resolution of defects on Plant 1 Aftercooler and the return to service of this plant is required to facilitate a Plant 2 Aftercooler outage which is required to enable the provision of an outage of Plant 6 mixer and other downstream assets containing 54 CM4 CAT6 defects identified within the HSEs Intervention Action Letter. CAT6 being deemed the most severe from a point-coating condition risk assessment perspective.

3.8 This justification paper is now retrospective in nature based on the programme of works undertaken to address the identified issues.

4. Equipment Summary

4.1 Comprehensive background information about the St Fergus Gas Terminal is available in the St Fergus Site Strategy provided with the Emissions Final Option Selection Report (FOSR).

4.2 Supplies from the PX sub terminal arrive at the terminal at 40 barg and are scrubbed, metered, compressed (to 70 barg) and passed through aftercoolers before being mixed with Shell and Ancala gas and then entering the NTS. Supplies to the terminal from the Shell and Ancala sub-terminals enter the Terminal at NTS line-pressure (70 barg), hence not requiring compression.

4.3 The compression process causes the temperature of natural gas to increase to circa 55-60°C. Aftercoolers reduce gas temperature back to a level which poses no integrity risk to down-stream infrastructure and is maintained within temperature limits (circa 30°C) so as not to damage below ground coal-tar pipework wrapping, which provide primary protection against below ground corrosion. Across the NTS, aftercoolers are currently only in use at St Fergus. This is due to the significant pressure change required which, due to the Joule-Thompson effect, results in approximately 0.5°C change in temperature for every 1 bar change in pressure.

4.4 A high-level overview of the site layout is provided in Figure 3.

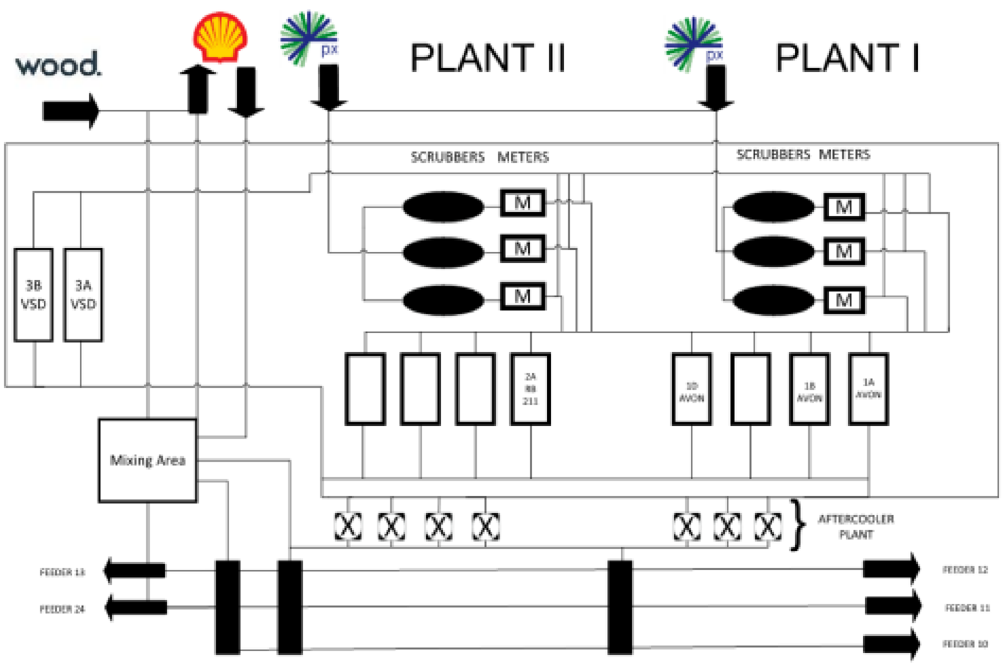

Figure 3: St Fergus Terminal site layout

4.5 There are two banks of air-cooled aftercoolers at St Fergus, known as Plant 1 and Plant 2 Aftercoolers. Both assets were designed and installed in 1973-1974 at the time of the site construction.

4.6 Plant 1 and Plant 2 aftercoolers are used interchangeably, and they can both cool gas from any of the three compressor plants (named compressor plants 1, 2 and 3). Despite the naming convention, Plant 1 aftercooler is not exclusive to Plant 1 compressors, the same is true for Plant 2. The aftercooler systems are more critical if we recirculate gas through the compressors due to the increase in the temperatures.

[redacted]

Figure 4: Aftercoolers Site Diagram

4.7 The pipework immediately downstream of the aftercooler, other buried pipework in the blending manifolds and several the feeders between St Fergus Terminal and Aberdeen Compressor Station are coal tar wrapped which have an upper maximum operating temperature of 38°C. The aftercoolers at the site are used to ensure downstream asset integrity of these assets is managed in addition to assets located within the mixing area of the site

4.8 St Fergus Terminal operates 24/7/365 and is not afforded regular outages from sub-terminals to undertake maintenance. Sections of Plant 1 and Plant 2 serve as redundancy for each other allowing us to undertake statutory inspections and critical testing of our safety critical and emergency shutdown system in addition to any maintenance and defect repairs needed because of regular inspections and testing. However, there is not 100% redundancy and in peak supply scenarios both aftercoolers are required to meet the downstream gas temperatures.

4.9 Although the scrubbers, metering, suction/discharge manifolds and aftercoolers are interchangeable (to enable maintenance of the assets) whilst continuing to provide a robust service to compress and meet daily PX gas nominations), any issue impacting on the operation of both aftercooler banks have the potential to require the reduction or cessation of gas supplies from PX from entering the NTS, resulting in loss of gas supply into the UK.

4.10 The aftercoolers at the site generally consist of:

- A concrete slab foundation with associated piles and concrete fan blocks
- A steel I frame with horizontal and vertical members, anchor bolted to the foundation.
- Main Girders, which run along the length of the structure and directly support the aftercooler units.
- Secondary girders which run across the width of the installations.
- Overhead Manifold Pipework and Header boxes
- Fin Tube assemblies, with circa 400 tubes per assembly

- Cooling Fans (Blades, shafts, motors etc)

4.11 Figure 5 shows a general diagram of an aftercooler bank arrangement with Figure 6, below, showing the Plant 1 aftercoolers at the site. Three inlet pipes enter the Plant 1 Aftercooler system (White pipework in foreground) and enter three individual manifolds. These manifolds connect to the header boxes. From the header box gas travels across the fin tube assemblies where the cooling fans located within the frame are used to reduce the temperature of the gas, before it exits the plant via another manifold on the outlet.

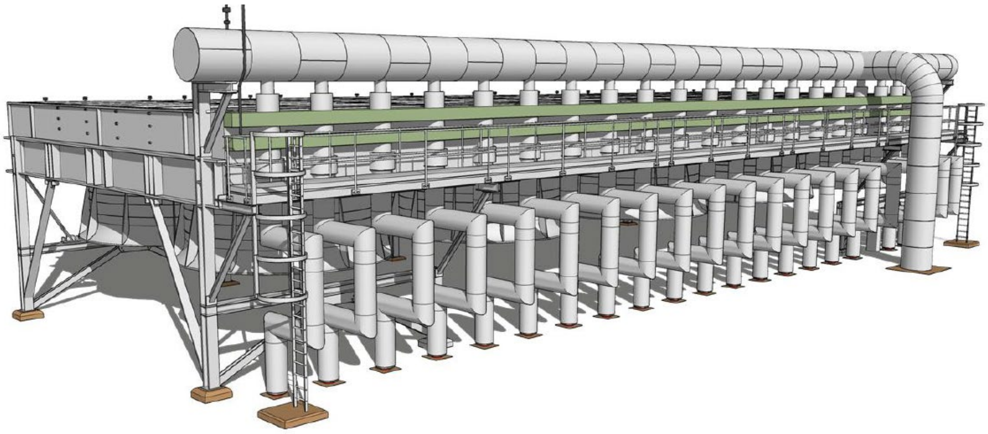

Figure 5: General Aftercooler Diagram

Figure 6: Plant 1 Aftercoolers

4.12 The Plant 1 Aftercooler consists of three banks of fin tubes (Banks A-C) each with four groups of fin tube assemblies (A1, A2, A3, A4, B1 etc). Each bank of fin tubes consists of tubes, header boxes, local support frame and flanged gas pipework connections. These fin tube assemblies are then air-cooled utilising the electrically driven fans (36 no) within the structure. The figure overleaf shows the header and fin tube arrangement as used within the Plant 1 Aftercooler system. This represents a single group of fin tubes.

Figure 7: Fin tube assembly with header connection

4.13 The Plant 2 Aftercooler is slightly larger in construction with four banks of fin tubes (Banks A-D), each with four rows of fin tube assemblies (A1-A4, B1-B4 etc). Plant 1 Aftercooler meets the current cooling requirements for the three compressor plants at the site but has no redundancy as all three banks (A-C) are required to meet the thermal requirements from maximum PX gas flows. Plant 2 Aftercooler being slightly larger (4 banks rather than 3), enables us to isolate a single bank whilst still having the cooling requirements for compression.

4.14 The frame of Plant 1 Aftercooler measures 44.8m (length) x 15.3m (wide) x 4.7m (height). It is of lattice girder grid formation. The main lattice girders run along the length of the structure with the secondary girders running perpendicular to them. There is significant plan bracing to both the top chord (bundle level) and bottom chord (fan deck level) of the frame as shown in the figures below.

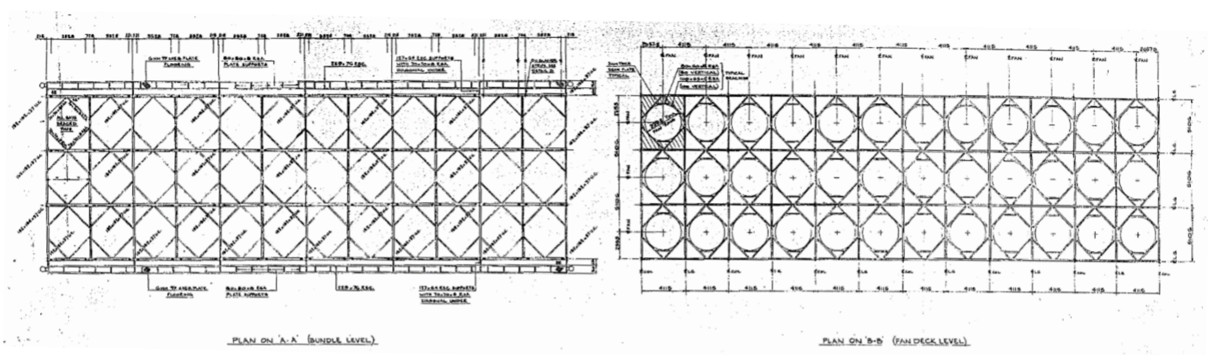

Figure 8: Plant 1 Aftercooler Frame Plan View

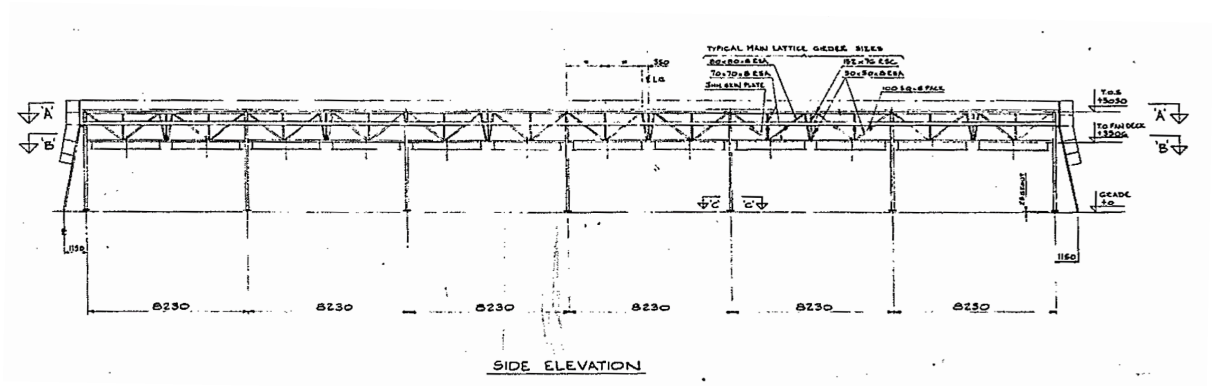

Figure 9: Plant 1 Aftercooler Frame Side View

5. Problem Statement and Needs Case

5.1 Plant 1 and Plant 2 aftercoolers at St Fergus are deeply aged assets, having been installed at the time the site was originally constructed, see Figure 10.

5.2 . Whilst the St Fergus terminal has been operated and maintained for over 40 years with minimal disruption to its upstream and downstream customers, this is a testament to the original design and to the capability of the maintenance and operations teams. Nevertheless, ageing mechanisms of corrosion and fatigue have acted upon the facility's equipment and now the risk from those degraded equipment items and systems is intolerably high.

Figure 10: Construction of Plant 1 Aftercooler (1974)

5.3 The intolerability of the risk is uncovered when the relatively modern principals of, whole life asset management and Reliability, Availability and Maintainability (RAM) optimisation are applied and particularly then considered in light of the requirements under the COMAH regulations. The intervention and continuing scrutiny from the HSE triggered by a significant backlog of potentially serious defects on the Plant 1 Aftercooler, highlights the severity of the situation. The inability of the St Fergus teams to be able to address and mitigate all the original defects first identified and highlighted by the HSE in 2017, is testament to the difficulty in achieving the required isolations to be able to safely inspect those defects in detail, let alone to affect repairs.

5.4 Ongoing risk assessments have taken place alongside continued HSE engagement to provide assurances that risks are being managed and progress is being made to resolve defects. Assessment details and HSE engagement documentation is included alongside this paper.

5.5 The site is in an aggressive coastal location on reclaimed land that is relatively unstable over the long-term with groundwater challenges.

5.6 Maintenance and investment have been unable to keep up with the growing number and severity of defects. This is partly because the range and complexity of the issues being experienced on the asset, and the fact that isolations of the entire plant is required for maintenance purposes.

5.7 A range of interventions have been undertaken on both Plant 1 and Plant 2 Aftercooler banks to continue the operation of these deeply aged assets and extend the life of the current installation.

5.8 Annual aftercooler inspections have occurred throughout the life of the asset, involving visual inspections as per T/PM/MAINT/6 (Maintenance of terminals and compressor installations operating on the NTS) and gas detection testing to investigate leakage from the asset. This requires a visual inspection on an annual basis for equipment Integrity as per T/PR/MAINT/6001/A. In addition, a 6-yearly visual inspection for pipework has been conducted as per T/PR/MAINT/6001/B

5.9 In line with this policy, the old Plant 1 Aftercoolers had a number of washers replaced on the plugs where they enter the side of the header box. Bolts were also replaced that hold the blank flange in place on the top of the header box. The header boxes were also blasted and painted.

5.10 On Plant 1 Aftercooler Composite Wrap repairs have been undertaken, seven in total encompassing eight pipework corrosion defects, to both the 24” inlet and outlet sections of the Plant 1 Aftercoolers along with a cut out repair on the 24” riser of bank B.

5.11 Additionally in 2006/7 a project was completed whereby new fan control equipment and lighting (luminaires) were installed.

5.12 No major interventions were undertaken prior to this project on the assets (Core sub-systems) listed below:

- Fans, Shafts, Motors & Cowlings
- Fin Fan Tube bundles
- Aftercooler Frame
- Fan Plinths and Foundation.

5.13 In 2019 the fin fan cooling tube bundles on Plant 2 Aftercooler and then, following the return the service of this asset, Plant 1 Aftercoolers were inspected by two Non-Destructive Testing (NDT) methods, that of the Near Field Testing (NFT) and Internal Rotary Inspection System (IRIS) inspections to understand the level of corrosion within the tubes. These are two commonly used inspection methodologies for heat exchangers within process industries.

5.14 Due to the number of vanes located on the Fin Fan tubes, it is difficult to assess whether the tubes are suffering from corrosion utilising external inspection methods. In addition, as the tubes are stacked in 4 rows, the middle rows cannot be seen externally to allow their condition to be assessed. The most appropriate method to determine if the tubes are suffering from corrosion and possible wall thinning is to have the tubes inspected utilising internal inspection techniques.

5.15 There are a range of internal inspection techniques for carbon steel finned tubes. However, there are some limitations to these techniques:

Remote Field Testing (RFT) – This is an effective technique for plain tubes, but the fins of a finned tube severely disrupt the RFT signal.
Partial Saturation Eddy Current (PSEC) – This technique is sensitive to internal pitting type defects but is poor for more general wall loss such as inlet end erosion. It is also susceptible to interfering signals from grooved in fins and scale.
Magnetic Flux Leakage (MFL) – MFL is sensitive to internal pitting but not as good for general wall loss. It has very limited depth sizing capability and is also very sensitive to probe speed i.e., the speed of the pull has a strong influence on the results.

5.16 Both IRIS and NFT approaches were utilised, with access to the cooling tubes undertaken via the plugs on the header box as shown in Figure ***11*** below.

Figure 11 Tube Plugs on Header Box

5.17 NFT testing was undertaken on 100% of the tubes within the Plant 1 Aftercooler. This type of testing is specifically suited to the detection of internal corrosion, providing a volumetric material loss of wall thinning. A probe is inserted by removing a plug from the header box and inserting a probe into the tube, Figure 12. Readings are taken of the wall thickness utilising magnetic field emitted from coils on the probe. Current penetration is used to identify corrosion defects impacting on wall thickness.

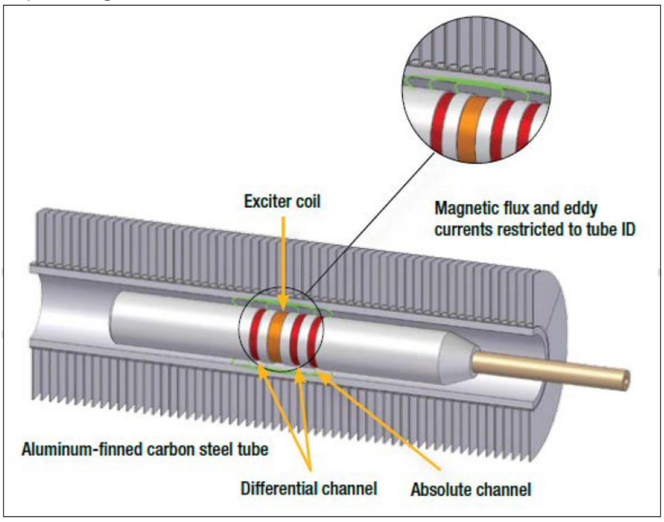

Figure 12 NFT Inspection probe

5.18 Defects identified by this assessed are classified as per the table below:

Defect Class	Categorisation
Class 1	Defect Size <25% material loss volume
Class 2	Defect Size 25%-49% material loss volume
Class 3	Defect Size 50%-74% material loss volume
Class 4	Defect Size 75%-100% material loss volume

Table 3: Defect Classifications

5.19 Results from this inspection did not show any defect like indications greater than Class 1 (Defect Size 25%). A report from the inspection can be found in Appendix 4.

5.20 One limitation of this testing is that no readings are provided for the first 25mm from the tube end, which includes where the tube interfaces within the box header wall. Additionally, external defects are not detectable unless they exceed at least 60% wall loss which is a very rare failure mode in fin-fan tubes apart from where corrosion occurs close to the header box where the tubes are not protected by the aluminium fins.

5.21 IRIS testing was also undertaken and involves an immersion, pulse-echo technique, whereby a transducer is passed through a flooder tube and ultrasonic pulses from the transducer are applied to the inside tube wall (Figure 13). Some of the ultrasonic pulses are reflected from the inside wall and some will pass through the tube wall, with some energy reflected to the transducer upon meeting this interface. The time delay between the echoes of the pulse from the inside wall and the outside wall of the tube is an indication of the tube wall thickness.

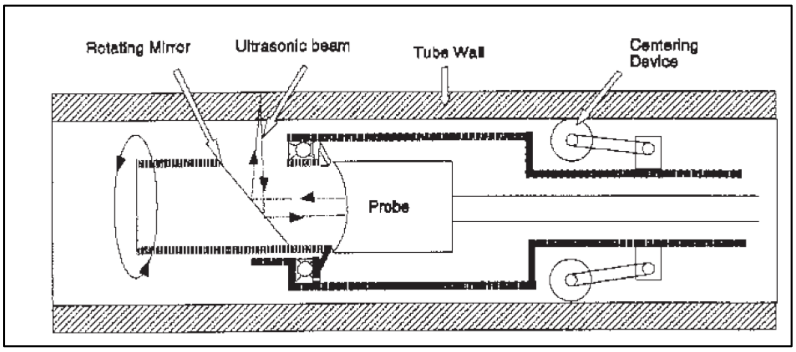

Figure 13 Typical IRIS inspection Test Device

5.22 This is generally considered the most accurate and reliable inspection method for carbon steel fin-fan tubes and in ideal conditions defects smaller than 2.0mm diameter and 0.1mm in depth can be detected utilising the IRIS technique. However, the presence of dirt and scale within the tube seriously impairs detectability, particularly for outer diameter defects. Scale was evident on the tubes of Plant 1 aftercooler due to environmental based corrosion reflective of the age of the asset and the climatic conditions of operation.

5.23 IRIS testing was undertaken on 10% of the tubes of the Plant 1 Aftercooler to support the NFT results. Results from this inspection showed maximum wall loss of 30% resulting in pitting and thinning. A report from the inspection can be found in appendix 4.

5.24 No immediate concerns were raised from the completion of these inspections based on the wall thickness and corrosion detail collected.

5.25 The re-commissioning of all three banks of the Plant 1 Aftercoolers commenced on the 11 January 2020. On 16th January 2020 Plant 1 Aftercooler was being re-pressurised in 10 Bar steps (up to the 50 Bar operating pressure) with snoop leak detection being deployed to the header box plugs along with all disturbed and repaired joints.

5.26 At a pressure of 30 Bar leaks were detected on the uppermost fin fan cooling tubes at the header box inlet located on Bank C. At a pressure of 40 bar leaks were detected on the header box to Bank A. At this point the commissioning was stopped, the Aftercoolers depressurised and made safe. Figure 14 below shows the leak detection fluid identification of a defect on Bank C.

Figure 14 Leak Detection testing

5.27 The corrosion defects detected were initially thought to be that of a “Crack” like defect, a failure type that is not identified through the IRIS. External close visual inspection was undertaken followed by inspection using a “Dye Penetrant”, this proved to be the only practical method for the identification of the corrosion defect(s) due to the limited space and access restrictions at the header box location. The report from the Dye Penetration testing is included in Appendix 5.

5.28 The testing undertaken showed that instead of cracks these were in fact through wall corrosion defects. These being shown in the photos below (Figure 15 and Figure 15).

Figure 15 Tube Bundle Header Connection Through Wall Defects

Figure 16 Tube Bundle Header Connection Through Wall Defects

5.29 At this point commissioning of the system was stopped and investigations commenced to identify options to mitigate these defects. Plant 1 Aftercooler was condemned from operation until the resolution of these defects. A summary of these events is written within a NGGT IMS Investigation Report. This can be found in Appendix 6 of this paper.

Plant 1 Aftercooler

5.30 In general, the condition of the Plant 1 aftercooler system was in a poor state. Severe corrosion has been identified across multiple positions on the frame and through wall corrosion defects have been identified around the junction between the header box and the fin tube bundles.

Fin Tube Bundles

5.31 The Fin Tube Bundles on Plant 1 Aftercooler cross the full width of the structure. Across a number of tubes minor distortion is seen due to corrosion on the fins driven by the harsh environmental conditions and the age of the structure. This is because the cooling performance is directly linked to the surface area of the tubes distortion impacts on the cooling ability of the tubes under operation.

5.32 [redacted], the Original Equipment Manufacturer (OEM) for the fin tube bundles, confirmed that the original design life for these assets was 25 years. The Plant 1 aftercooler has been operational since the terminals commissioning, and therefore we are operating the system well in excess of this design life as these assets are now operating at nearly twice the design life at 49 years old, within harsh environmental climatic conditions.

Figure 17 Plant 1 Fin Tube Bundles

Figure 18 Fin Tube Bundle Header Connection

5.33 The corrosion defects identified on the top layer of the tube bundles at the tube ends where they connect onto the header have resulted in loss of containment. Access to the middle layers of tubes is restricted, as there is little or no effective available room to access them, as shown in the figures above, without the removal of the upper and lower layers of tubes. Therefore we are restricted to internal inspection, rather than external inspections, in order to determine condition assessments.

5.34 During the manufacture of these tubes they are mechanically expanded at the point where they enter the header box to make an effective seal. Under operational temperature conditions this expands and results in an interference fit between the tubes and the header box. Over time due to plastic deformation resulting from ageing and corrosion this interference fit can deteriorate over time.

Aftercooler Frame

5.35 Two surveys have been completed on the Plant 1 Aftercooler Frame, one in October 2020 and another in January 2021, these can be found in Appendix 2 of this report.

5.36 The purpose of the surveys was to obtain a third-party position of the general condition of the frame structure and the completion of appropriate structural calculations to determine where or not there was an issue with the current structure and recommendations on options to manage the risk from corrosion metal loss defects.

5.37 Desktop assessment from the initial study highlighted that "*If no actions are taken then there is potentially an argument to say that the design life has expired on the basis that some structural members have corroded to such an extent where they are currently unable to carry any load*".

5.38 Several locations within the frame were difficult to inspect without the removal of the fin-fan tube bundles and headers. These were removed January 2021 and following this a full structural assessment was undertaken, encompassing the following activities:

- Visual inspection of the lattice girder trusses
- An assessment of the section loss occurred to the top chords of the main girders.
- Visual inspection of a range of the structural members and the top-level plan bracing.

5.39 Condition of the structure was categorised as C5 (Very High) against BS EN ISO 12944-2:2017 Paints and varnishes – Corrosion protection of steel structure by protective paint systems Part 2: Classification of environments

Corrosivity category	Mass loss per unit surface/thickness loss (after first year of exposure)				Examples of typical environments (informative only)	
	Low-carbon steel		Zinc		Exterior	Interior
	Mass loss g/m²	Thickness loss µm	Mass loss g/m²	Thickness loss µm		
C1 very low	≤ 10	≤ 1,3	≤ 0,7	≤ 0,1	—	Heated buildings with clean atmospheres, e.g. offices, shops, schools, hotels
C2 low	> 10 to 200	> 1,3 to 25	> 0,7 to 5	> 0,1 to 0,7	Atmospheres with low level of pollution: mostly rural areas	Unheated buildings where condensation can occur, e.g. depots, sports halls
C3 medium	> 200 to 400	> 25 to 50	> 5 to 15	> 0,7 to 2,1	Urban and industrial atmospheres, moderate sulfur dioxide pollution; coastal areas with low salinity	Production rooms with high humidity and some air pollution, e.g. food-processing plants, laundries, breweries, dairies
C4 high	> 400 to 650	> 50 to 80	> 15 to 30	> 2,1 to 4,2	Industrial areas and coastal areas with moderate salinity	Chemical plants, swimming pools, coastal ship and boatyards
C5 very high	> 650 to 1 500	> 80 to 200	> 30 to 60	> 4,2 to 8,4	Industrial areas with high humidity and aggressive atmosphere and coastal areas with high salinity	Buildings or areas with almost permanent condensation and with high pollution
CX extreme	> 1 500 to 5 500	> 200 to 700	> 60 to 180	> 8,4 to 25	Offshore areas with high salinity and industrial areas with extreme humidity and aggressive atmosphere and subtropical and tropical atmospheres	Industrial areas with extreme humidity and aggressive atmosphere
NOTE The loss values used for the corrosivity categories are identical to those given in ISO 9223.						

Figure 19 Extract from BS EN ISO 12944-2:2017 Paints and varnishes

5.40 On Plant 1 aftercooler there are 24 main lattice girders in total, and surveys conducted by [redacted] identified that they had all suffered from corrosion. Most of the girders (21 out of 24) had suffered severe corrosion in multiple positions. Concerns were raised by the structural engineer within this report about the retention of the existing structure.

5.41 The main defects due to corrosion include:

- Severe pitting of the bottom chords resulting in major section loss on both horizontal and vertical sections.

- Major loss of steel at the bottom node points across the structure; in the most severe cases this involved:
  i. Bottom ends of steep diagonal braces experiencing extreme section loss.
  ii. Bottom ends of vertical RSC suffered severe section loss with holes being a common occurrence.
  iii. Severe section loss of the truss bottom chord.

5.42 Figure 20 and Figure 20 below show examples of this deterioration.

Figure 20 Aftercooler Frame Corrosion

Figure 21 Aftercooler Frame Truss Corrosion

5.43 In addition to the main lattice girders, there are 39 secondary lattice girders. The Condition survey undertaken identified that 33 had visibly suffered from corrosion; 26 of the 33 girders that had noticeably suffered from corrosion, were deemed by [redacted] to have suffered severe corrosion and the other seven had suffered moderate corrosion.

5.44 The major defects due to corrosion include:

- Severe pitting of the bottom chords resulting in major section loss

- Bottom node points at 1/3 point along the girder – Major loss of steel including:
  i. Bottom ends of diagonal brace virtually disappeared.
  ii. Major section loss and holes at bottom end of vertical 70 x 70 x 8 RSA.
  iii. Severe section loss of the truss bottom chord.

5.45 Figure 22 and Figure 20 below show examples of this deterioration.

Figure 22 Secondary Lattice Girder Corrosion

Figure 23 Secondary Lattice Girder Corrosion

5.46 This second survey has established that severe corrosion is evident on the bottom sections of the main and secondary lattice girders in many areas. Feedback from the second survey highlighted that "*In response to the anticipated question 'Can the structure be salvaged?' the author's response is that it can be strengthened so that it is stronger than it was immediately prior to the old Aftercooler Units when it was successfully supporting them; however, this approach wouldn't be recommended due to the following:*

i. It would be a significant challenge to prepare, repair and protect the structure in-situ in an efficient manner; this would likely require a full strip down of the structure to ensure all steelwork faces are inspected, strengthened accordingly and protected.

ii. *Not all parts of the structure will have been remediated to the original condition (typically where relatively minor uniform loss was experienced) and hence it may not be possible to get sign off on a future design life for the structure.*

Based on the above, the author's opinion is that this wouldn't be the correct approach to take as it more than likely to be more expensive and take longer than simply replacing the structure and National Grid may still end up with a structure that doesn't have an assured design life."

5.47 The reports from both surveys, including appendices to the reports can be found in Appendix 2 of this report.

Foundation

5.48 Records held show the Plant 1 Aftercooler foundation was laid in 1973 constructed using “Class A” concrete with a 28-day cube strength of 21 N/mm2 to the concrete design code of CP110, effective from 1972. The photos below show sections of the concrete foundation and concrete fan plinths at Plant 1 aftercooler.

Figure 24 Sections of Concrete Foundation and Fan Plinths at Plant 1 Aftercooler

5.49 A range of tests and survey actions have been carried out on the foundation to understand the residual life of the pre-existing asset.

- An independent residual life assessment was undertaken on this existing Plant 1 Aftercooler piled foundation in September 2021. This included visual inspection of concrete and reinforcing bars (Rebar) within three inspection trial holes.

Figure 25 Foundation Inspection Trial Hole

- Laboratory Tests of the Chloride content of concrete dust samples showed these were well below the 0.4% trigger in The Department of Transport document CS462 Repair and Management of deteriorated concrete highway structure.

5.50 The results of these independent inspections showed there was no physical signs of deterioration of the concrete and no corrosion was evident on the rebar where these had been exposed. Chloride levels falling below the 0.4% trigger showed there is a low risk of chloride driven corrosion within the concrete.
Assessment of the independent report and associated information was completed by NGGT Structural Engineers with the conclusion that there had been no significant deterioration and no immediate drivers for further deterioration. 50 years of remnant life is assessed to be left in the structure which meets the ongoing need from this asset.

Fan Blades, Shafts, Bearings and Motors

5.51 Plant 1 Aftercooler has 36 pulley driven fans to provide cooling to the cooling tubes within the structure. The plan view below shows the location of these fans within the structure. Fan blades are balanced as pairs and installed in matched opposite position

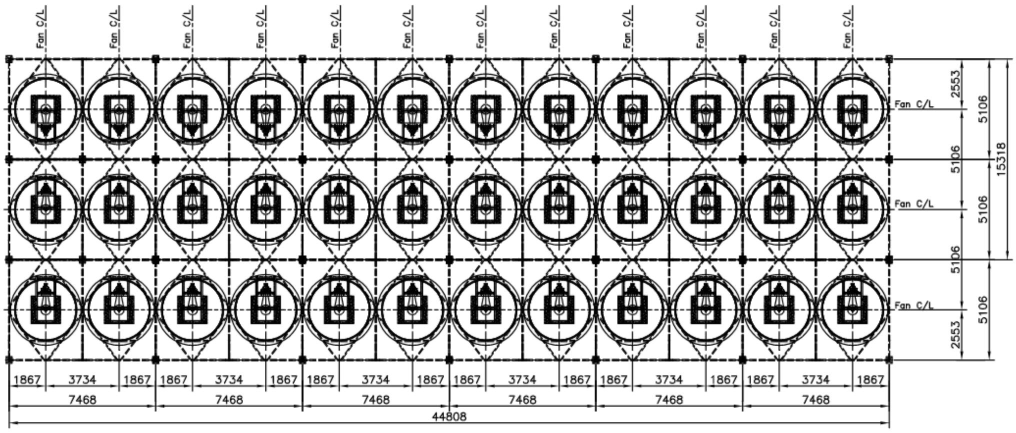

Figure 26 Plant 1 Aftercooler Plan View

5.52 A visual survey of all 36 fans was undertaken covering Motors, Pulleys, Fan Shafts, and bearings was completed in September 2018 (Appendix 7). Through this survey all 36 motor pulleys and fan pulleys were identified to be end of life, with four shafts having found to be snapped. Additionally, for the shaft bearing assemblies all but one of have been assessed as end of life, along with 12 of the 36 motors. Several defects were raised for the drive mechanisms, shown in fan assembly category on the table overleaf.

Defects

5.53 As of November 2021, there were 218 open defects associated with the Plant 1 aftercooler bank at the site. The tables below provide a summary of the defect descriptions and the asset sub-components these are associated with.

	Defect Descriptions									
Aftercooler Asset Components	**Breakage**	**Corrosion**	**External Corrosion**	**Leakage**	**Mechanical damage**	**Other**	**Restricted Movement**	**Structural failure**	**Wear**	**Total**
Aftercooler Equipment	2	7	0	0	0	14	0	0	2	**25**
Fan Assembly	0	61	34	0	0	48	3	0	2	**148**
Heat Exchanger	0	6	0	0	0	0	0	3	0	**9**
Job Effort	0	3	0	0	0	0	0	0	0	**3**
Junction Box	0	15	0	0	0	0	0	0	0	**15**
Local Operated Valve	0	18	0	0	0	0	0	0	0	**18**
Total	**2**	**110**	**34**	**0**	**0**	**62**	**3**	**3**	**4**	**218**

Table 4 St Fergus Plant 1 Aftercooler Open defect (Nov-21)

5.54 As of November 2021, there were 34 Category 3-6 CM4[2] corrosion defects still open associated with the Plant 1 Aftercooler systems at the site. These are shown in the table below by category and by plant.

T/PM/CM/4 Visual Grade	Defect Totals	Plant 1	Plant 2
3	1	0	1
4	37	34	3
5	2	1	1
6	1	0	1
Total	**41**	**34**	**7**

Table 5 St Fergus Plant 1 Aftercooler CM4 Defects

Plant 2 Aftercooler

5.55 In general, the condition of the plant two aftercooler system is only marginally better than Plant 1, all cooling fan support structures have severe corrosion on frame and anchor bolts. Many of the fan foundation blocks are cracked at the corners where the main anchor bolts are embedded in the foundation. Severe corrosion and metal loss affects most seal and vent lines as well as most 2" risers and actuating gas pipe work.

5.56 Currently Bank D of Plant 2 Aftercooler is isolated due to leaks being detected on the header box plugs, leaving Banks A, B and C in operation. Following tests being undertaken on Plant 2 aftercooler, leaks were identified from the header box 13, where the tubes entered the header box.

5.57 The frame of the aftercooler has not had detailed surveys completed on the structure, however vising inspection however as it was installed and commissioned at the same time, it is expected that the condition be comparable to Plant 1. Condition information collected through our maintenance activities highlight a range of issues to the Aftercooler supporting structures. Even if the supporting frame structure is considered to be repairable rather than needing full replacement, it should be noted that Plant 1 redesign work has shown that the structural design to current standards required additional measures against sway, e.g., additional cross-bracing. With more severe weather events being experienced, as a minimum, the structure would need some additional structural enhancement in addition to any structural repairs.

5.58 From visual inspection, there is no evidence of deterioration of the concrete base slab other than general weathering and appears to be in a similar condition to the equivalent slab in Plant 1. It is therefore considered to a reasonable assumption that the base slab and foundations have a similar remnant life to Plant 1.

Fan Plinths

5.59 Fan plinths on Plant 2 Aftercooler are in worse condition than on the Plant 1 Aftercooler asset. Many of these concrete fan plinths are cracked and crumbling at the four corners where the main anchor point plates are connected to the concrete plinth, providing little stability to the fan assembly.

[2] CM4 is National Grid's Corrosion Management policy. Document provided with this submission for reference

Figure 27 Plant 2 Aftercooler Concrete Fan Plinth cracking

Figure 28 Plant 2 Aftercooler Concrete Fan Plinth 36 Severe Concrete Issues

5.60 Corrosion is present across all the fan shafts and the main anchor points are severely corroded. All fans have four main anchor bolts, with most of these fans having one or two of the bolts being completed corroded, as shown in the figures below.

Figure 29 Photos Highlighting Corroded Fan Main Anchor Bolts

Frame

5.61 In relation to the frame, widespread corrosion is seen across the internal and external columns. The photos below show a range of columns from across Plant 2 aftercooler, including general surface corrosion on the columns and around the anchor baseplates.

Figure 30 Plant 2 Column 9 Moderate corrosion to column and baseplate

Figure 31 Plant 2 Column 20 Moderate corrosion of column

5.62 As of November 2021, there were 82 open defects associated with the Plant 2 aftercooler bank at the site. The tables below provide a summary of the defect descriptions and the subcomponents these are associated with.

	Defect Descriptions								
Aftercooler Asset Components	Corrosion	External Corrosion	Leakage	Mechanical damage	Other	Restricted Movement	Structural failure	Wear	Grand Total
Aftercooler Equipment	5	0	0	0	11	0	0	2	**18**
Fan Assembly	0	0	0	0	42	1	0	0	**43**
Job Effort	3	0	0	0	0	0	0	0	**3**
Local Operated Valve	18	0	0	0	0	0	0	0	**18**
Total	**26**	**0**	**0**	**0**	**53**	**1**	**0**	**2**	**82**

Table 6 St Fergus Plant 2 Aftercooler Open defect (Nov-21)

5.63 As of November 2021, there are seven Category 3-6 CM4[3] corrosion defects still open associated with the Plant 2 Aftercooler systems at the site. These are shown in the table below by category and by plant.

T/PM/CM/4 Visual Grade	Defect Totals	Plant 1	Plant 2
3	1	0	1
4	37	34	4
5	2	1	1
6	1	0	1
Total	**41**	**34**	**7**

Table 7 St Fergus Plant 2 Aftercooler CM4 Defects

5.64 Based on the condition of the Plant 2 Aftercooler it is our intention to submit an Engineering Justification Paper within the June Asset Health Re-opener window to request funding for our intervention.

[3] CM4 is National Grid's Corrosion Management policy. Document provided with this submission for reference

Aftercooler Duty Requirements

5.65 Plant 1 and Plant 2 Aftercoolers were designed and constructed as part of the initial terminal design. Each Aftercooler had three banks of cooling tubes. Subsequently Plant 2 aftercooler was extended to include one additional bank of tubes; Plant 2 Aftercoolers Extension (i.e., unit E2302D).

[redacted]

Figure 32 Plant 1 and Plant 2 Aftercoolers

5.66 Plant 1 and Plant 2 aftercoolers are used interchangeably, and they can both cool gas from any of the three compressor plants (named compressor plants 1, 2 and 3). Despite the naming convention, Plant 1 aftercooler is not exclusive to Plant 1 compressors, the same is true for Plant 2. The aftercooler systems are more critical if we recirculate gas through the compressors due to the increase in the temperatures with these potentially reaching 100°C.

5.67 The maximum allowable flow from our customer through the compressors is 72-75 mscmd, limited by the size of the pipework. National Grid forecast long range supply and demand forecasts through its Future Energy Scenarios (FES). The peak day forecast is utilised by NGGT as part of its planning assumption, that assets should be designed to accommodate peak supply demand conditions. FES data shows that peak flows into our compressor plan are forecast to continue at a maximum of 72-75 mcm/d in the short to medium term.

[redacted]

5.68 Outlet temperatures from the aftercooler are required to be in the range of 30-35°C so as not to damage below ground coal-tar pipework wrapping on the feeders connected to the terminal, which provide primary protection against below ground corrosion. Sustained temperature greater than 50°C can result in the breakdown of the coating.

Aftercooler Design Parameters

5.69 Both Aftercooler plant (Plant 1 & Plant 2) are air cooled aftercooler designs. This type of design can achieve variable cooling performance based on several parameters including:

- the air flow across the plant,
- gas flows,
- gas pressure, &
- gas & air temperatures.

5.70 At the time of the original aftercooler design and installation a range of calculations were undertaken to test the suitability of the design against the above parameters. A range of these parameters were utilised to simulate the varying conditions that the aftercooler plant would experience across its operational life.

5.71 The parameters included:

- **Day/Night Characteristics** – Impacting the ambient air conditions. Day ambient air temperatures and Night Ambient Air temperatures differ affecting the performance curve characteristics.
- **Ambient Air Conditions** – A range of ambient air conditions were modelled, Day temperatures from 0°C to 20°C, and Night temperatures from 0°C to 20°C were modelled.
- **Inlet Gas Temperatures** – A range of inlet gas temperatures were modelled to provide performance curves across the range from 40°C to 100°C. 100°C being a rare event but is the potential maximum inlet temperature based on operations of the compressors upstream.

5.72 Performance curves were produced showing the performance of the Plant 1 aftercooler in the various parameters shown above. This showed that Plant 1 Aftercooler was not originally designed to provide 100% redundancy with Plant 2 aftercooler due to Plant 1 aftercooler only being apply to cool ~45 mcm/d to the 30°C outlet temperature against a contractual maximum of 72-75 mscm/d.

Summary

5.73 In summary, the condition of the aftercooler systems at St Fergus presents a range of significant risks that must be mitigated. This has been duly recognised by the HSE and as such NGGT embarked on a major programme of works recognising the spend at risk (and associated RIIO-T2 “Plant & Equipment” Asset Health Uncertainty Mechanism) to ensure both the safe operation of the terminal and the security of supply it delivers.

5.74 Plant 1 aftercooler was prevented from being returned to service following the through wall corrosion defects identified resulting in leaks being experienced from the tube bundles. This has left Plant 2 Aftercooler in operation providing a single point of failure. As shown through the evidence above, Plant 2 aftercooler was installed at the same time as Plant 1 aftercooler during terminal construction, and has a range of frame corrosion and concrete related defects and CM/4 defects, resulting in a high-risk position.

5.75 The inability of the Plant 2 aftercoolers to be isolated, due to the site aftercooling requirements and the investment in Plant 1 Aftercooler has resulted in the inability to isolate Plant 6 Mixing area and other downstream assets and resolve 54 CM4 CAT 6 defects contained within the HSE Improvement plan.

5.76 The duty required from the Aftercooler is to cool compressor outlet gas from a temperature of 100°C to 30-35°C so as not to damage below ground coal-tar pipework. FES data shows that peak flows into our compressor plan are forecast to continue at a maximum of 72 mcm/d in the short to medium term, and therefore our aftercoolers should also meet this need for which both Plant 1 & Plant 2 aftercooler are required to be operational.

6. Probability of Failure

5.1 The severity and prevalence of aftercooler defects, CM4 defects coupled with third party condition assessments shows that asset failure has occurred. A programme of works was commenced to ensure the safe operation of assets required for 24/7 terminal compression operations.

5.2 Given the detailed survey and defect information made available to the HSE and their associated intervention notices due to the condition risk, assessing the condition status further to support understanding the probability of failure is not required as the Plant 1 Aftercooler cooling tube bundles and frame can be considered at end of life.

5.3 The existing Plant 1 aftercooler has 218 open defects and 36 CM/4 defects recorded against it and has been operating well in excess of its 25-year design life, having been commissioned in 1974.

5.4 Multiple cooling tubes have already experienced failure due to pinhole leaks resulting from corrosion to the asset. Therefore, the scale of the defects and the observed failures under commissioning at less than operational pressure evidence a high probability of failure under live scenarios. Whilst Plant 2 Aftercooler is in better condition and having been assessed in 2018 using the same inspection approaches (IRIS and NFT) aged based deterioration as evidenced through the inspections is prevalent across the frame and fan plinths.

7. Consequence of Failure

6.1 There are multiple realistic failure modes for which this investment seeks to eliminate. These failure modes could result in the isolation of the aftercooler. Whilst the Plant 1 and Plant 2 Aftercoolers provide a level of redundancy for each other, Plant 1 Aftercooler itself cannot meet the full operating duty, this being capped at 45 mcm/d against a maximum of 72 mcm/d.

6.2 There is also a need to intervene on Plant 1 to mitigate a single point of failure for the Plant 2 Aftercooler. As evidenced in section 4 above there are numerous asset risks associated with the operation of this plant. The resulting loss of this asset would be catastrophic from a financial, safety and reputational perspective.

6.3 Compensation costs to Shippers would run into millions per day, upstream oil production would likely cease leading to significant venting/flaring, UK gas security of supply would be compromised, Scottish distribution pressures could become unmanageable under most demand scenarios and the reputational impact could result in significant limitations for our ability to operate, notwithstanding the risk to site personnel. Quantifying these high impact and compounding risks is not straightforward but it can be safely assumed that any failure as described below would result in costs far outweighing any of the investment options outlined in this paper.

6.4 Focusing on the constraint costs at the terminal, the Uniform Network Code (UNC) Section I liabilities for failure of the aftercoolers at the site can be calculated using relatively simple principles to demonstrate a daily cost consequence of failure. This approach aligns with the approved methodology utilised by the System Operator to forecast constraint risk and for St Fergus the cost assumption is [redacted].

6.5 Average PX Terminal supplies entering the St Fergus Terminal per day for the 2-year period from October 2019 to October 2021 is shown in the chart below, along with the average daily supply from this period.

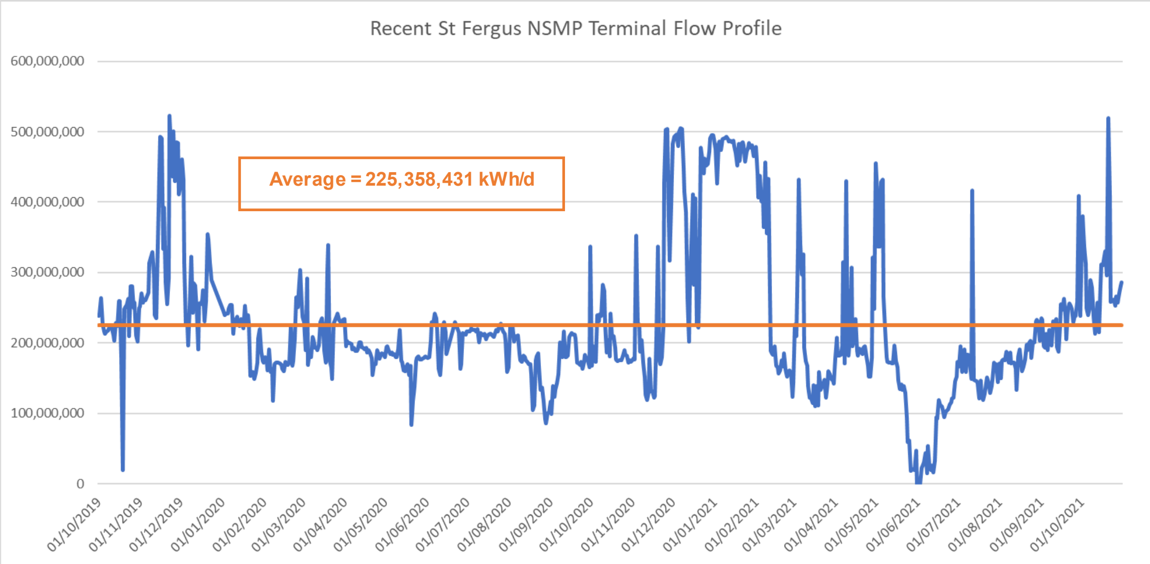

Figure 34 St Fergus Terminal flow profile

6.6 The average daily supply from St Fergus NSMP terminal over the last 2 gas years is 225,358,431 KWh/d. Utilising the constraint cost assumption of [redacted] equates to an average daily constraint cost of [redacted] This is lower than the consequence of failure of other site systems due to the consequence of loss of both aftercoolers only impacting on supplies through the NSMP sub terminal.

6.7 Through wall defects on the header boxes or the interface between the fin tubes and the header boxes would result in the shutting down of the entire aftercooler bank or the entire aftercooler plant.

6.8 Return to service for a failure of this kind is not quick to resolve, tubes need to be manufactured through milling processes. Although there is redundancy provided by Plant 2 Aftercooler in respect of failure this results in a single point of failure. Should Plant 2 Aftercooler also require an outage then no PX flows could be accommodated at the terminal resulting in the expected daily cost of constraint of [redacted].

7. Options Considered

7.1 The Aftercooler Project for Plant 1 Aftercooler has passed through several stages, aligned to our internal project governance within our network development process (ND500). Through this process a range of options to manage the risk associated with the condition of the asset have been considered. This section of the report shall explain the options discounted, before explaining the range of options considered.

Options were immediately discounted due to compliance, operational flexibility, and cost reasonings. Further options are then expanded upon based on sub options of the component parts.

Options Discounted (1)

7.2 Option 1: Do Nothing

Continue to operate without resolving aftercooler defect risk. This would result in the site operating with just Plant 2 aftercoolers since Plant 1 aftercoolers cannot be re-commissioned without the defects identified remediated.

- **This option is not viable due to requirements to operate safe plant in compliance with PSSR, COMAH and other safety regulations**
- **With no resilience Plant 2 Aftercoolers cannot be isolated, resulting in limited access to Isolation 5, Plant 6 Mixing area.**
- **Our Written Scheme of Examination (WSoE) states a full outage at least every 10 years. This couldn't be facilitated on Plant 2 aftercooler without an operational Plant 1 aftercooler.**
- There is no redundancy to provide cooling to the PX gas flows in the event of an outage being required on Plant 2 Aftercooler. Cooling is required to avoid damage to the mixing area pipework, downstream feeders and compressor stations. If a Plant 2 Aftercooler outage is required, with the inability to bring Plant 1 back into operation, the daily cost of constraint of [redacted] would be incurred.

Option Progressed for Further Assessment (2)

7.3 Option 2 Replacement of defective tubes

This option involves the replacement of the existing Plant 1 Aftercooler and the decommissioning of the old system, providing a like for like replacement of the cooling ability of the system.

7.4 The existing Plant 1 aftercooler has three banks which meets the compression requirements at the site. There is no ability to remove a bank from service and still meet the compression requirements. The Short-Term Strategy, Appendix 1, highlights the ongoing requirement for four operational gas driven compressors until 2030 and therefore based on this a like for like replacement is considered required to enable 100% redundancy between Plant 1 and Plant 2 aftercoolers to facilitate the isolation of either plant with no constraint impact to upstream and downstream customers.

7.5 There are a range of sub options associated with the Plant 1 Aftercooler Replacement:

1. A range of interventions to resolve the tube defects (Plugging, Lining, Replacement)
2. A range of interventions to mitigate the corrosion evident on the frame of the structure
3. A range of interventions to ensure ongoing operation of the fans and motors
4. A range of interventions to ensure the structural integrity of the foundation (considering replacement or retention of the concrete foundation plinth).

These sub options are explored in detail though the below sections.

Fin Tubes

7.6 Through engagement with the OEM, [redacted] we explored a range of options to mitigate the corrosion wall loss defects and through wall corrosion detailed in section 4. Options identified included lining or plugging the tubes experiencing loss of containment, or replacement of the tube bundles.

The table below provides a summary of these options and the considerations in optioneering.

Option	Option Description	Considerations
Tube Repair (Plugging)	Partial repair of tubes with the replacement of 20 tubes from the top 2 rows. Other tubes would be plugged. Plugging the tube would result in permanently taking tubes out of commission. This reduces the capacity of the aftercooler, however through investigations it was determined 10% of tubes could be plugged before the aftercooler performance is adversely affected	• Reduction in aftercooler efficiency • If the damaged tubes are located on the top layer then the OEM confirmed these tubes could be easily replaced, however accessing the lower level of tubes would require the complete removal of the upper layers, increasing costs and outage periods. • Defective Tubes identified following commissioning of plant, potential for further tubes to present leakage at higher 10 barg stage commissioning steps. • If repairing, plugging or renewing only 1 or 2 rows of tubes in each cooler there is a probability that the remaining tubes have experienced wall thinning resulting in potential future leakage, intervention and outage within the short to medium term. • Due to the milling process to manufacture the tubes, they can only be purchased in significant quantities as a tube set, (164 tubes). Thus, the material cost delta between repair and replace is not significant • Over time the existing header box plates and nozzles can thin through corrosion and be less than the minimum required thickness for design pressure and temperature resulting in potential future leakage, interventions and outages. • The inside diameters and grooves of existing header box tube holes can corrode and loose shape (plastic deformation) resulting in leaks between the gas side and air side resulting in potential future leakage, interventions and outages, even when fitting new tubes into the system • Delays amount to approximately [redacted] per week are occurring due to the fact our main works contractor is unable to access the Plant 6 mixing area which is unavailable for isolation until Plant 1 Aftercoolers is returned to service. Repair duration is uncertain due to no knowing the full number of tubes to be repaired.
Tube Repair (Lining)	Lining the damaged tubes involves the insertion of a sleeve into the existing tube. This maintains the capacity of the system.	• Removal of all damaged tubes would be required in order to line them resulting in high costs and lengthy outages to remove, remediate and reinstall the assets. • Defective Tubes identified following commissioning of plant, potential for further tubes to present leakage at higher 10 barg stage commissioning steps requiring lining extending outage on plant • Over time the existing header box plates and nozzles can thin through corrosion and be less than the minimum required thickness for design pressure and temperature resulting in potential future leakage, interventions and outages. • This results in a longer return to service and increase in cost to the tube plugging option. • Delays amount to approximately [redacted] per week are occurring due to the fact our main works contractor is unable to access the Plant 6 mixing area which is unavailable for isolation until Plant 1 Aftercoolers is returned to service. Repair duration is uncertain due to no knowing the full number of tubes to be repaired
Replacement	Like for Like replacement of tube bundles across all banks of the Plant 1 Aftercooler.	• All the new tubes are of a quality that should last in the region of 25-40 years. • The header boxes and tubes are designed to the latest 2019 ASME Design Codes and Pressure Equipment Directive 2014/68/EU. • Ensures that the header box plates and nozzles are the correct thickness for design pressures and temperatures • Integrity of the aftercoolers to contain the system inventory is guaranteed. • Least risk to Return to Service Time: eliminating the risk of identifying leakage during re-pressurisation and re-commissioning

Table 8 Aftercooler Tube Intervention Options

7.7 We engaged with the Aftercooler tube OEM in around the viability of the repairability of the tubes within the existing installation.

7.8 Their comments were as follows:

- *If you were to repair, plug or renew only 1 or 2 rows of tubes in each cooler there is a good chance that the remaining tubes would also thin in time causing leaks, would need to be plugged and would reduce the efficiency of the unit.*
- *To replace these tubes you would also need to cut out the newer tubes recently replaced. Over time the inside diameters and grooves of tubeholes can corrode and loose shape resulting in leaks between the gas side and air side.*
  Even if all the tubes were renewed, the existing tubeholes could be out of shape and / or expansion grooves rounding meaning the new tube may not expand properly and again cause future leaks in service.

7.9 Due to the milling process required for the manufacturing of the tubes a minimum tube volume (164 tubes) needs to be purchased. Due to this the cost of the tubes between the repair and replacement option was comparable due to the volume efficiencies of manufacturing.

7.10 The table below shows the costs of each of these options based on quotes from [redacted].

Tube Options	£ (18/19 Prices)
Tube Repair	[redacted]
Tube Replacement	

Table 9 Aftercooler Tube Intervention Costs

7.11 As identified in the options table above the repair options are also subject to a range of risks, including plastic deformation at the deformation between the header boxes and tube resulting in leaks being identified at higher pressures and/or leaks being identified on additional tubes when reaching higher pressure stages during the commissioning.

7.12 These risks could result in further interventions being required to be undertaken, resulting in a longer return to service period. Therefore, due to the minimal cost delta between the two options, the shorter return to service time for the replacement option and the risk reduction against future leaks this is preferred.

Aftercooler Frame

7.13 At the time of the option development, we had identified the preferred option was for the aftercooler tube banks to be replaced. At this time we had identified some corrosion risks on the frame but not the full extent of this, and in trying to reduce costs for consumers procured new banks for the plant, so that it was ensured the new banks would fit into the frame.

7.14 Upon removing the banks, and having grit blasted the frame we uncovered the full extent of the corrosion. We undertook, with [redacted], a structural assessment of the frame with the outcome recommending replacement of it.

7.15 It would have not been cost effective to progress a differing design route at this stage as the tube banks were procured and onsite, so the project continued to be progressed.

7.16 In early optioneering three options were considered for the management of the condition issues and associated risks on the Plant 1 Aftercooler frame as identified in section 4:
Repair – Repair elements of the frame structure, replacing the worst affected full sections of truss or individual trusses
Full Replacement – A full replacement of the frame structure from existing foundation level upwards, including vertical and horizontal members and support braces, with new high-level

walkways along the length of the structure and stairways for access, and new lighting to support aftercooler access.
Partial Replacement - A replacement of the frame structure retaining the existing vertical I beam columns.

7.17 Further details of each option are presented below.

Option		Option Description	Considerations
1	**Repair Frame**	Repair elements of the structure, replacing the worst affected full sections of truss or individual trusses. Retain existing access structures, walkways and lighting systems	o Intrusive surveys undertaken in October 2020 by [redacted] showed considerable section loss and through wall corrosion on main and secondary members. o A repair option is available however it would be a significant challenge to prepare, repair and protect the structure in situ in an efficient manner, requiring a full strip down of the structure. o Extensive onsite fabrication requirements to cut out and insert new sections, and preparation works to facilitate this. Thereby there is little time saving between repair and replace options. o Minor uniform loss would still be present on a number of members that over time could deteriorate into full section loss requiring replacement, necessitating additional plant outages to rectify in the future, and the potential removal of tube banks to facilitate. Requiring extended outages to facilitate.
2	**Full Replacement**	Full replacement of steelwork structure based on new design in accordance with the latest codes of practice. The segregation of fan bays shall match the existing layout and include fan casings and protection gratings similar to the existing design. Walkways shall be installed along each long side of the structure to facilitate maintenance and inspection of the aftercooler units with associated lighting.	o Full Replacement option addresses all corrosion and through wall corrosion defects identified on the frame. Frit blasting undertaken in October 2020 identified significant areas of through wall corrosion. o [redacted] structural Engineer's recommendation, from this 2020 Condition Assessment, Appendix 2, was for the replacement of the asset, given the considerable through wall corrosion. o Full Replacement option aligns the expected asset life between the frame and the tubes, therefore mitigating any future intervention requiring plant outages to undertake repair interventions on the frame. o Base programme length longer to demolish and install a new frame to the footprint of the existing frame compared to repair option, however repair option may be delayed if further members are identified through the repair process.
3	**Partial Replacement**	Replacement of the horizontal members based on new design in accordance with the latest codes of practice, with the retention of vertical members. Existing vertical members retained.	o Minor uniform loss would still be present on a number of members that over time could deteriorate into full section loss requiring replacement. Future interventions would require plant outages and the potential removal of tube banks to facilitate. Requiring extended outages to facilitate. o Partial replacement option does not reduce the duration of the programme and therefore duration of plant outage. o This option does not align the structural advice from a third-party survey.

Table 10 Aftercooler Frame Intervention Options

7.18 A decision matrix exercise was undertaken on the above frame options to select an option considering 32 individual requirements, which were split into five main categories:

- Meeting Terminal/Operational Strategy
- Project Delivery Complexity
- Design Complexity
- Design Time Cost, Quality and Safety
- Construction Build Complexity

	Plant 1 Aftercooler Frame Decision Matrix	Option #1: Repair	Option #2: Replacement Full	Option #2a: Replacement Partial	Importance	Weighting	Option #1: Repair Repair elements of the structure – This will involve replacing the worst affected elements; this could be either full sections of truss or individual and with not come with any design liability elements.		Option #2: Replacement Full A full replacement of the structure from existing foundation level upwards; this may involve re-threading the holding down bolts to a smaller size if they are corroded		Option #2a: Replacement Partial A full replacement of the structure however retaining the existing vertical I-beams (columns)	
	Section & Requirements						Requirement	Total	Requirement	Total	Requirement	Total
1.0	**Terminal/Operational Strategy**							**13**		**26**		**20**
1.1	Does the option align to the Terminal strategy? Both aftercooler banks are required to provide appropriate cooling for the retained compressors over the full machine operating envelopes. The retained plant compressors are 1 (4 units) & 3 (2 units). Aftercooler original design parameters for duty/standby capacity (N+1) is to be retained.	No design life - terminal exposed/no strategy	Can provide a design life linked to terminal strategy	Can provide a design life linked to terminal strategy	Required	3	0	0	3	9	2	6
1.2	Will the time allowance adversely impact Terminal Operations?	Full programme not established as further investigation required	Longer install - will impact scheme programme and extend down time	Longer install - will impact scheme programme and extend down time	Required	3	1	3	1	3	1	3
1.3	Will the Option result in additional HSE intervention visits?	Medium risk	Low risk if full programme of works supports the narrative	Low risk if full programme of works supports the narrative	Required	3	1	3	3	9	2	6
1.4	Can the option be funded within RIIO:GT2?	Uncertainty mechanism	Uncertainty mechanism	Uncertainty mechanism	Required	3	1	3	1	3	1	3
1.5	MTTR vs (De-construction and Fabrication) + Installation - select best optimised solution mindful of terminal downtime and impact on associated programme of wider works	Forecast Aug-21	Forecast Oct-21	Forecast Oct-21	Desired	2	2	4	1	2	1	2
2.0	**Project Delivery Complexity**							**18**		**21**		**21**
2.1	Does the Option require additional supply chain partners to complete/approve/appraise T/PM/G/35	No additional [redacted] for elec / earthing	No additional [redacted] for elec / earthing	No additional [redacted] for elec / earthing	Required	3	1	3	2	6	2	6
2.2	Will the option adversely affect the Project programme - X5/X7 clause impact?	Yes	Yes	Yes	Required	3	1	3	1	3	1	3
2.3	Contract Strategy aligns as supplementary agreement	Yes	Yes	Yes	Required	3	3	9	3	9	3	9
2.4	Re-planning of P6 programme to account for the time allowance to complete the preferred option	Yes	Yes	Yes	Required	3	1	3	1	3	1	3
3.0	**Design Complexity**							**16**		**20**		**18**
3.1	Does the design require additional design of surrounding assets such as valves, manifold, etc	No	Yes - Manifold temp support	Yes - Manifold temp support	Required	3	3	9	2	6	2	6
3.2	Does the current material and design standards adversely impact on the proposed design	Yes	No	No	Required	3	1	3	2	6	2	6

3.3	Are there additional survey works required to ascertain the base information (Basis of Design Document)?	1. Walkways 2. Foundations 3. Laser scan	1. Walkways (steps+width) 2. Foundations 3. Possible Elec/earthing 4. Fan motors 5. Fan motor plinths 6. laser scan 7. Foundations 8. Manifold	1. Walkways (steps+width) 2. Foundations 3. Possible Elec/earthing 4. Fan motors 5. Fan motor plinths 6. laser scan 7. Foundations 8. Manifold	Desired	2	2	4	2	4	2	4
3.4	Does the design include for the verification of foundation adequacy? Have the NDT requirements been defined such as rebound hammer/Ultrasonic Pulse Velocity	No	No	No	Required	3	0	0	0	0	0	0
3.5	Does the option align to asset life and the strategy requirements for the terminal. Civils foundations have approx. 50year remaining life	Design life will not achieve strategy	Design life will achieve the strategy and aligns to the civils remaining life	Design life will partially achieve the strategy and aligns to the civils remaining life	Desired	2	0	0	2	4	1	2
4.0	**Design Time Cost, Quality, Safety**							**18**		**26**		**26**
4.1	What is the time allowance to achieve a T/PM/G/35 approved/appraised design?	4 weeks design 10 working days approval/appraisal	4 weeks design subject to TQ responses 10 working days approval/appraisal 1 week Part C	4 weeks design subject to TQ responses 10 working days approval/appraisal 1 week Part C	Required	3	1	3	1	3	1	3
4.2	What is the forecast defined cost (Option A) for the design?	[redacted]	[redacted] however section 3.3 requires review	[redacted] however section 3.3 requires review	Desired	2	2	4	2	4	2	4
4.3	Are there significant HSG48: Human factors				Desired	2	1	2	2	4	2	4
4.4	Will the risk of suction/discharge manifold alignment to the replacement fin tube banks be clarified and confirm in the design?	N/A	Yes	Yes	Required	3	2	6	1	3	1	3
4.5	Will fire protection as per T/SP/SFP/1 included in the design?	Partial design to T/SP/SFP/1	Yes design to T/SP/SFP/1	Yes design to T/SP/SFP/1	Required	3	1	3	2	6	2	6
4.6	Will access for operations/maintenance by reviewed and possibly upgrade to meet current working at height regulations	No as repairs to existing structure	Yes design to T/SP/SHR/1	Yes design to T/SP/SHR/1	Required	3	0	0	2	6	2	6
5.0	**Construction Build Complexity**							**10**		**28**		**23**
5.1	Does the build rely on deconstruction of adjacent assets	Risk item depending on the extent of further corrosion being identified	Existing frame to be removed No impact on adjacent assets such as valves, etc	Existing frame to be removed (except main verticals) No impact on adjacent assets such as valves, etc	Required	3	0	0	1	3	1	3
5.2	Does the build require additional supply chain partners involvement	No	Yes managed by JMS	Yes managed by JMS	Required	3	2	6	1	3	1	3
5.3	The option does not introduce extensive temporary works (Standard/Complex)	Complex	Standard	Standard	Desired	2	0	0	2	4	2	4
5.4	The scope of works more than 80% clarified and clear prior to commencing works	Many unknowns and refitting members to fit between existing structure	Yes once section 3.3 surveys provide clarity	Yes once section 3.3 surveys provide clarity	Desired	2	1	2	2	4	2	4
5.5	Are there any specialist tools and equipment required for construction and/or maintenance	Yes - Holding down bolt	No	No	Desired	2	1	2	2	4	2	4

		arrangement to existing frame											
5.6	The option does not introduce additional hazards that are difficult to manage (Hot works/welding in ATEX Zone 2)	Yes - Significant welding on existing frame	No - Off site manufacturer and bolted at site	Yes - Welding required on the retained vertical beams.	Required	3	0	0	2	6	1	3
5.7	Will the risks during construction be mitigated in any way, such as eliminating hot works on site?	No - Welding will have to be undertaken on the existing structure	Yes - Off site manufacture and bolted up on site	Reduced - Off site manufacture, bolted up on site with some welding to existing vertical beams	Desired	2	0	0	2	4	1	2
6.0	**Construction Time Cost, Quality, Safety**							**3**		**15**		**13**
6.1	The option does not impact construction work faces (Clash of resources/equipment/etc)	Impact	Impact	Impact	Required	3	0	0	1	3	1	3
6.2	Is there assurance on forecast ECC defined cost (Option A) for the build adequate	[redacted]	[redacted]	[redacted]	Required	3	1	3	2	6	2	6
6.3	The option does not increase the risk value in Predict - Within parameters (Tolerable risk)	Too many unknowns on levels of corrosion	Risk removed	Risk partially removed	Desired	2	0	0	2	4	1	2
6.4	The option does not require additional specialist resources	Increase welding resource	Mechanical/Structural	Mechanical/Structural	Desired	2	0	0	1	2	1	2
	TOTALS							**78**		**136**		**121**

Table 11 Plant 1 Aftercooler Frame Decision Matrix

7.19 The preferred option identified was Option 2 – Full replacement of the entire structure and this was supported by the assessment by our third-party structural engineers [redacted]

Aftercooler Foundations

7.20 Two options were identified for the foundation of the Plant 1 Aftercooler,

- Do-Nothing, retaining the existing foundation
- Install a new replacement foundation.

Option		Option Description	Considerations
1	**Do Nothing**	Utilisation of the existing reinforced concrete foundation and fan plinths	○ As highlighted in Section 4 of the report visual surveys showed no major deterioration of the foundation surface ○ Trial holes conducted on the foundation showed no corrosion or deterioration of the rebar within the structure. ○ Chloride Content measured was found to be below the thresholds defined within BS1881 Part 124:2015, having 0.3% Chloride content. ○ Low levels of Chloride across the asset life to date, and no changes to operation suggest no immediate driver for acceleration of deterioration of the reinforcing structure. ○ 50 years of remnant life is assessed to be left in the structure, meeting the ensuring need from the Aftercooler assets, in line with the St Fergus Short Term Strategy.
2	**Replacement Foundation**	Full replacement of the reinforced concrete foundation and fan plinths.	○ Deconstruction of the existing foundation and construction of a new foundation ensures it is designed to latest standards. ○ Highest Cost option.

Table 12 Aftercooler Foundation Intervention Options

7.21 The assessment by our senior civil engineer recommended the Do-Nothing option given the level of chloride showed there had been no significant deterioration and no immediate drivers for further deterioration.
50 years of remnant life is assessed to be left in the structure which meets the ongoing need from this asset.

Fan Blades and Shafts

7.22 For the 36 cooling fans and associated shafts a range of investment options were considered to address the issues identified in section 4 of this report.

Fan Shafts

7.23 The table below compares the options considered to intervene on the fan shafts. Following inspection of the shafts, four were identified as snapped with the remaining having pitting and grooves around the impeller and pully/drive ends.

Option		Option Description	Considerations
1	**Replace 4 snapped fan shafts, Refurbish the remaining 32 shafts**	Based on initial conditions information, as shown in Section of the report, 4 shafts were identified as snapped. Option proposed to replacement the 4 snapped fan shafts and refurbish the remaining 32 installation of new bearings and seals.	o Lowest Cost intervention identified o Existing fan shafts have a number of areas of pitting and grooves that show signs of wear. o Third party assessment undertaken [redacted] at the point of deconstruction that showed the existing shafts were not in a suitable condition to assemble even with refurbishment. (Appendix 8) o Therefore, this option was discounted
2	**Replace all 36 Cooling Fan Shafts, bearings and install Accelerometers**	Replacement of all 36 Fan shafts for each of the 36 cooling fans within the structure, along with new bearings and new seals. Installation of 36 accelerometers to each of the shafts in accordance with recommendations from the International Association of Oil and Gas Producers (S-710) for the installation of accelerometers in air cooled heat exchangers.	o [redacted] to replace all fan shafts. o A number of shafts were found have be pitted and have many grooves and marks showing wear on both the impeller and pully/drive ends, discounting the refurbishment option. o Third party assessment undertaken [redacted] at the point of deconstruction that showed the existing shafts are not in a suitable condition to assemble even with refurbishment. o New shafts should ensure the operating life of the of the shafts are aligned to that of the frame and tube banks, resulting in reduced probability of failure.

Table 13 Fan Shafts Intervention Options

7.24 Based on these considerations, noting the cost benefit and recommendations from a third party, option 2, to replace all 36 cooling fan shafts was progressed.

8. Options Analysis and Selection

8.1 Considering the above rationale and options assessment, the following table provides a summary of the options considered for the tubes, frame, foundation and fans and shaft. The table also highlights the recommended options.

Solution Considerations	Options Considered									
	Tubes			Frame			Foundation		Fans & Shafts	
	Replacement	Repair (Plugging)	Repair (Lining)	Repair	Full Replacement	Partial Replacement	Do Nothing	New Foundation	Refurbish (Replacing Snapped)	Replace All Fan Shafts
Cost	Low – Cost of new tube bundles is not dissimilar to the repair programme due to minimum milling quantities	Lowest	Medium	Lowest	Medium – New Frame, Walkway & Lighting to be installed	Medium – Replacement of horizontal members only	Lowest	High – Significant cost to decommission, then design & install new plinth	Lowest	Medium
Maintenance – Ongoing Opex	Low	Medium – potential for continuous Opex challenge to maintain	Medium – potential for continuous Opex challenge to maintain	Medium/High – Long Term repair programme may be required in the future to address members with corrosion	Low	Medium – Long Term repair programme may be required in the future to address members with corrosion.	Low	Low	Medium – Potential for future interventions to repair and replace	Low
Maintenance - Risk	Low – A number of CAT3-6 defects are resolved through intervention	Medium – Potential for additional interventions to be required on additional tubes	Medium – Potential for additional interventions to be required on additional tubes	High – 95 defects relating to corrosion are present. Potential for future failure of the structure,	Low – A number of CAT3-6 defects are resolved through intervention	Medium/High	Low	Low	Medium/High – Potential for further interventions from wear based on assessed condition	Low – Replacement shafts should reduce the need for reactive maintenance actions.
Resilience - Facilitating the remediation of Plant 6 mixing Area CAT6 defects	Provides the highest level of resilience to facilitate Plant 2 Aftercooler outage needed to facilitate Plant 6 defect remediation	Medium/High – Potential for further leaks to be identified on additional tubes	Medium/High – Potential for further leaks to be identified on additional tubes	Medium – Potential for future outages being required to mitigate corrosion, necessitating the isolation of Plant 2 Aftercooler	Provides the highest level of resilience to facilitate Plant 2 Aftercooler outage needed to facilitate Plant 6 defect remediation	Medium – Potential for future outages being required to mitigate corrosion, necessitating the isolation of Plant 2 Aftercooler	N/A	N/A	Medium – Potential for future outages being required to mitigate corrosion, necessitating the isolation of Plant 2 Aftercooler	Provides the highest level of resilience to facilitate Plant 2 Aftercooler outage needed to facilitate Plant 6 defect remediation
OEM & Third-Party Feedback	N/A	N/A	N/A	Structural assessment identified not viable due to through wall corrosion.	Recommendation from [redacted] from grit blasting survey (2020).	Structural assessment identified not viable due to through wall corrosion.	Chloride Content measured below the 0.3% Chloride content thresholds defined within	N/A	Not viable, Shafts pitted and has grooves and marks showing wear on both the impeller and pully/drive ends. Extensive Intervention	Recommended Option from [redacted] based on the condition of the shafts.

Solution Considerations	Options Considered									
	Tubes			Frame			Foundation		Fans & Shafts	
	Replacement	Repair (Plugging)	Repair (Lining)	Repair	Full Replacement	Partial Replacement	Do Nothing	New Foundation	Refurbish (Replacing Snapped)	Replace All Fan Shafts
							BS1881 Part 124:2015.			
Operational Resilience (Security of Supply)	Replacement Tubes provides potential for 40+ year operation of the tubes without extended outages, ensuring security of supply. Facilitates the outage of Plant 2 Aftercooler	Potential for leaks to be identified on additional tubes impacting on RTS and outages on Plant 2 Aftercooler.	Potential for leaks to be identified on additional tubes impacting on RTS and outages on Plant 2 Aftercooler	Future interventions would require an outage on the plant, resulting in no redundancy for Plant 2 Aftercooler	Replacement Frame provides potential for 40+ years operation with minimal outage requirements.	Potential for outages to be needed in the future to remediate corrosion on members not replaced through the scheme	No concerns identified resulting in outages to be taken on the plant	New foundation of 50+ year life would minimise outage potential	Refurbishment intervention discounted by OEM on asset integrity grounds	Replacement shafts ensures continued operational resilience of operation, in line with OEM recommendations
Operational Resilience (Point of Failure)	Corrosion related risks removed; Replacement of tubes eliminates the risk of finding further tubes needing intervention)	Additional tubes with corrosion defects could be identified during commissioning prolonging the length of outage	Additional tubes with corrosion defects could be identified during commissioning prolonging the length of outage	Minor uniform loss present on a number of members that over time could deteriorate into full section loss (plant outages to rectify)	Addresses all corrosion and through wall corrosion defects. This mitigates future interventions requiring outages	Addresses corrosion on all girders except for the vertical beams, Corrosion present that could require future outage to remediate	Chloride Content measured below the 0.3% Chloride content thresholds defined within BS1881 Part 124:2015.	New Foundation would require little intervention following installation	Potential for further outages to be required in the future to address operational issues caused by pitting and wear to the components.	Addresses all age-based defects and correlates asset lives with other elements of the installation that are proposed to be replaced.
Overall Viability	Viable	Not Viable	Not Viable	Not Viable	Viable	Not Viable	Viable	Not Viable	Not Viable	Viable

Table 14 Options Analysis Summary

9. Final Option Selection, Cost and Programme

9.1 The assessments outlined in this paper and the associated discounting and costing of options demonstrates there is only one viable, cost effective and logical option to take forward, that being the replacement of the tube bank assemblies, replacement of aftercooler frame, whilst undertaking the repair and replacement of the necessary fans, shafts and motors where these are currently non-operational.

9.2 The Aftercoolers were designed to ASME V11 DIV.1:2019, API 661:2013 and ASME IX Weld Procedures with [redacted] being the notified body. The design also ensured they complied with PED 2014/68/EU Category IV Module G Gas Group. These were the up-to-date standards for this type of equipment at the time of the conceptual and detail design of the project (2020).

9.3 A deviation was required internally within NGGT as T/SP/F/1 (Specification for Steel Forged Components) and T/SP/PV/3 (Specification for Pressure Vessels manufactured to PD550) could not be fully complied with. The deviation was reviewed by the Mechanical Subject Matter Expert and approved by the NGGT Engineering and Policy Manager.

9.4 No material change in design philosophy has occurred. The existing units had been in service for approximately 45 years, which far exceeds the original design life of 25 years, showing that this a proven design.

9.5 The replacement Aftercooler units have the same layout design as the ones that were being removed due to the proven design having operated in excess of its design life, with the same space between the tube bundles, and due to the space available on site.

9.6 The 12 Aftercooler tube bundle banks connect onto 96 branches of pipework that in turn connect into various inlet and outlet headers. Had the layout of the header boxes been changed, such as to give better access to the tubes, then major modifications would have been required on both the inlet and outlet pipework, and possibly cooling fan structures. This would have resulted in a significant increase in cost and program delays.

9.7 Access can be gained from the back of the header box to allow internal inspection of the tubes, or if the tube needs rolling to re-make the joint with the header box. Bird netting has also been applied to the installation which will reduce the amount of residue that builds up along the tubes which can be very aggressive and increase the rate of corrosion.

9.8 Thermal calculations have been completed to evidence the required duty and parameters for these tube bank assemblies. Further information is provided below and in Appendix 9 'Plant 1 Aftercoolers Thermal Performance Review'.

<u>Plant 1 Aftercooler Duty</u>

9.9 The performance of the replacement aftercoolers has been determined by running several operating scenarios using the software Aspen EDR. This performed thermal rating calculations and provided throughput through the Aftercooler. The geometry of the new Plant 1 Aftercoolers has been input into Aspen EDR tool to assess the design of the replacement cooler.

9.10 The table below shows the parameters of the preferred option design that were fed into the Aspen EDR tool.

Description	Value	Unit
Bays per unit	4	/unit
Bundles per bay	1	/bay
Fans per bay	3	/bay
Fan Diameter	3.1	M
Fan Speed (Operating)	165	Rpm
Fan drive efficiency (assumed)	90	%
Number of tubes per bundle	164	/bundle
Tube Outer Diameter / Inner Diameter	31.75 / 27.69	Mm
Tube Length	15.85	M
Number of tube rows	4	
Fin Type	L	
Fin tip dimeter	72	mm
Fin frequency	433	/m
Mean fin thickness	0.45	Mm

Table 15 **Plant 1 Aftercooler Design Parameters**

9.11 The air mass flow for all cases was set such that either the 30°C temperature set point of the process outlet gas (for operating curves) or the maximum face velocity of 3.6 m/s as per API 661 has been reached

Modelling Results

9.12 The table below provides a summary of the maximum achievable flow through Plant 1 Aftercooler to meet 30°C outlet temperature with an inlet air temperature of 20°C and 10°C (reflecting summer and winter operations) and a plant outlet pressure of 69 barg, based on a like for like replacement of the existing aftercooler.

Process Inlet Temperature (°C)	Maximum Achievable Flow (Mscm/d)	
	Air Inlet Temperature 20°C	Air Inlet Temperature 10°C
40	77.9	154.7
50	43.9	78.7
60	32.0	55.5
70	25.9	44.0
80	22.2	37.0
90	19.5	32.3
100	17.6	28.8

Table 16 Maximum Achievable Flow Modelled Results (mcsm/d)

9.13 As explained in Section 4 of this paper, the St Fergus gas compression plant has a design throughput of 75 mcm/d with three compressors in operation with typical discharge temperatures of 65–80°C. If Plant 1 Aftercooler is operating in this scenario it can achieve the necessary cooling to meet the 30-35°C discharge temperature in winter conditions (Air inlet 10°C) but not in summer conditions (Air inlet 20°C).

9.14 In summer conditions, due to the higher ambient temperature, it has been modelled that the Plant 1 Aftercoolers can cool ~22–30 mcm/d flow to a 30-35°C outlet temperature, which corresponds to the outlet of only two compressors. To achieve higher flows excursions above this outlet temperature would be seen. These temperatures are managed by site staff during operation to avoid prolonged periods where this temperature is exceeded. One mitigation is to operate both Plant 1 and Plant 2 Aftercoolers in parallel and this would provide the necessary cooling duty.

9.15 Our revised modelling results has been plotted into operating curves for two scenarios (Summer conditions with an air temperature of 20°C, and Winter conditions with an air temperature of 10°C). Existing curves developed for the original Plant 1 Aftercooler were sourced and plotted with the curves developed through the Aspen modelling completed for this replacement design.

9.16 Good correlation has been seen between the original modelling completed for the original installation and the replacement installation through the Aspen modelling.

9.17 Using the curves and input data on air temperature, inlet gas temperature and flow through the aftercooler the outlet temperature from the aftercooler can be estimated to ensure that the asset operation meets the downstream integrity parameters, in line with the Aspen EDR tool modelling. Figure 35, below, and Figure 36, overleaf shows the Operating Curves for Summer conditions with an Air Temperature of 20°C, and Winter conditions with an Air Temperature of 10°C

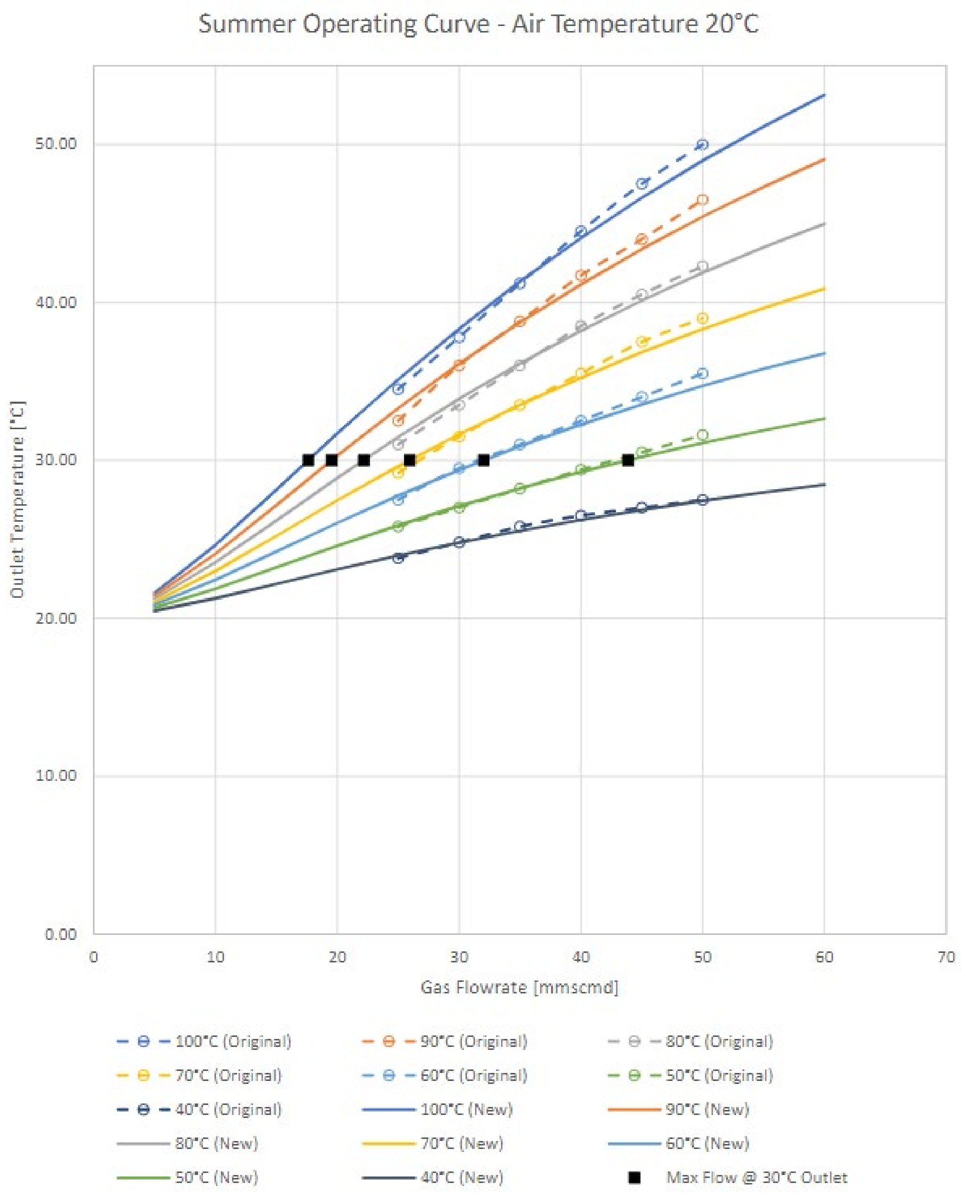

Figure 35 Plant 1 Aftercooler Design Summer Operating Curve - Air Temperature 20°C

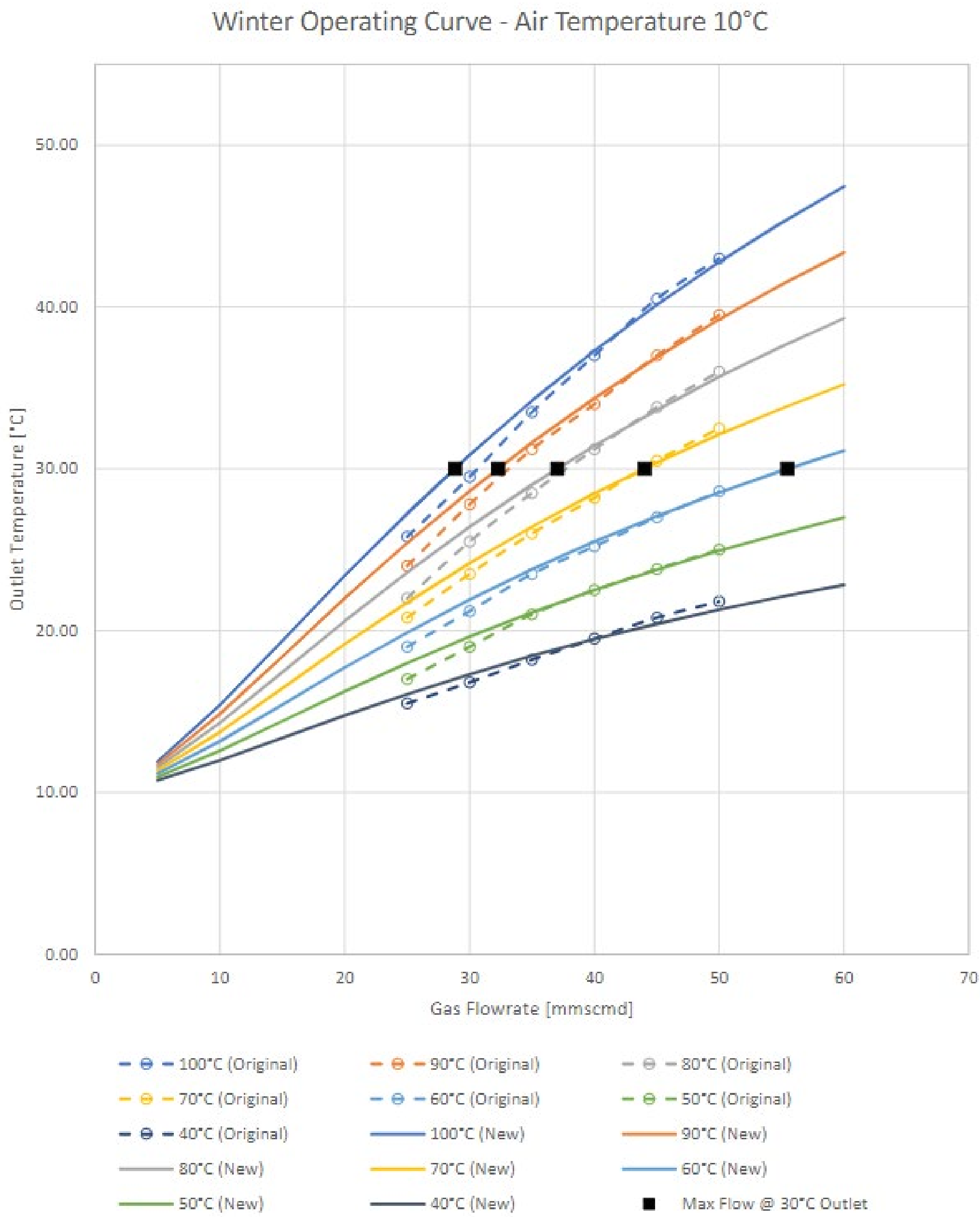

Figure 36 Plant 1 Aftercooler Design Winter Operating Curve - Air Temperature 10°C

9.18 To increase the capability of Plant 1 Aftercooler, and enable complete redundancy between Plant 1 and Plant 2 Aftercoolers would have required significant modifications to the existing inlet pipework that connected the compressor plants to Plant 1 aftercooler. This would have resulted in considerable disruption on site to facilitate this works, extension of the programme and increased cost. Additionally changes in the footprint of the aftercooler would be required resulting in a longer project design period.

9.19 Due to the immediacy of returning the Aftercooler to service to ensure security of supply, modifications to the inlet pipework was not considered, with only a like for like replacement of the tubes and frame, our preferred option. This does not result in any changes to the capacity of upstream pipework resulting in no changes being required to the existing operating parameters of the Plant 1 Aftercooler installation on the site, which were already designed to the capacity of the pipework (45 mscm/d).

9.20 The operational philosophy continues such that both Plant 1 & Plant 2 Aftercooler plants are required in high flow, high ambient temperature scenarios, or scenarios where compressors are operating to recycle the gas prior to its discharge, resulting in higher outlet temperatures. Where temperatures are lower and or flows are lower there is a greater level of redundancy.

9.21 The Plant 1 Aftercoolers Thermal Performance Review report from our FEED consultant, [redacted] can be found in Appendix 9.

Final Cost and Programme

9.22 The table below, Table 17, provides a breakdown of the final costs for the project split by several cost categories. Due to this project being in delivery, and NGGT committing to spend due to the urgency of the project, the risk pot as showing in the table below is much less than would normally be expected. This is because the risks have either materialised, or been retired.

9.23 In addition, some of the costs on this project were incurred during RIIO-T1. These are not being requested in this submission, however, would be predominately indirect design costs.

	Cost Category	Outturn Costs (£m)	Costs (£m) 2018/19 Price Base
	OEM costs	[redacted]	
Direct	EPC Estimate		
Indirect	EPC PM		
	EPC Site Establishment		
Direct	NGGT Direct Company Costs		
Indirect	NGGT Indirect Company Costs		
	Contractor Risk		
Direct	NGGT Project Risk		
	FEED		
	Development / Optioneering		
	Land / Easements		
	Submission		
	Cost incurred not included		
	TOTAL		
	Direct		
	Indirect		

Table 17 Preferred Option Final Cost

9.24 The table below shows the spend profile for our preferred option in 2018/19 pricing. RIIO-T2 costs total [redacted], of which we are requesting [redacted]. We are not seeking to recover costs incurred prior to RIIO-T2.

£m 18/19	Prior Years	FY2022	FY2023	FY2024	FY2025	FY2026	Total
Total Cost	[redacted]						
Baseline							
Not Requested							
Funding Requested							

Table 18 Spend Profile of Preferred Option

[redacted]

[redacted]

Outline tender selection process

9.27 The aftercooler project works were awarded as a call off contract on the existing tendered package including corrosion remediation and cathodic protection upgrade, in accordance with NGGT tender procedures. This decision was made due to interaction between the ongoing site works, and the aftercooler programme, which would mean having two different contractors in the same area would be inefficient and likely to lead to contractual complications in event of issues arising. However, as the wider package of works had been recently tendered, we deemed that the using the same rate provided efficiency and value for money.

9.28 Due to the criticality of completing this work, and the constraints in timescales for delivery, the additional scope included within this investment was delivered via best for task direct allocation i.e. the original OEM was approached to reduce time in redesign, and because it was a proven design. These risks included:

- Reduction in resilience in the event of an issue on plant 2 aftercoolers or associated plant and equipment
- Reduction in ability to take outages elsewhere on site if required, due to having to maintain a gas path across site
- This would impact both the actuator replacement programme and corrosion works, both of which are required to meet HSE commitments
- In the event of a lack of gas path for PX flows, this would lead to significant cost to consumer [redacted]

9.29 A main works contractor was on site with agreed framework rates and a reduced fee, negotiated in the tender from 12.5% to 9.9% for greater efficiency. This enabled quick mobilisation, and no requirement to pay for mobilisation costs, overheads or preliminaries. It also enabled better planning across other scopes of work on site for greater efficiency. There are limited number of contractors available to tender for activities due to the geographical location of the site.

9.30 The process NGGT followed in placing of the original contract (actuators, corrosion, and cathodic protection) was designed to ensure the required works were delivered at the best value for money by leveraging the three scopes of works.

9.31 To manage the issue of cost inflation over multiple years, NGGT split the contract award into two stages; an initial design stage (cost reimbursable contract), followed by a detailed design and build stage under a fixed price contract. This enabled the successful contractor to design all packages of work to a reasonable standard, with the information available, to then give an accurate fixed price, rather than offering an overinflated fixed price due to the inherent risk present before design had been completed.

9.32 It also gave us an "opt-in" break point with the successful contractor, at which point if the final fixed price design was not offering value for money, we would be able to take the design and commence a further tender. This break point included a number of increases in scope following detailed design, which increased the total cost. These scope increases were assessed against the initial stage 2 submission to ensure that NGGT was realising the same value for money as the original competitive tender, whilst also assessing the validity of the additional scope. The price and scope were then negotiated with the main works contractor.

9.33 The contractors on the Minor Gas Framework made it onto the framework through a competitive process which agreed rates for personnel, plant and equipment, fuel etc. at a competitive rate. This base position is used to assess any scope changes to ensure that we are still receiving competitive prices for the works.

RIIO2 volume UIDs

9.34 Costs associated with this project have been assigned against the RIIO-T2 Unique Identifier (UID) [redacted] St Fergus Aftercoolers – Major Refurbishment. The table below provides a summary of the UIDs and associated funding for the scope of works as proposed in this paper.

UID	Baseline volume of Intervention (By PP) (by unit of measure)	Baseline total funding available (18/19)	ECC unit cost (18/19)	Current volume of intervention (by unit of measure)	ECC total funding required (18/19) [redacted]	Output Year	UID funding requested through UM
[redacted] ST FERGUS TERMINAL - After Coolers - Major Refurbishment - ISO_6_Class - 2020	0	0.00	[redacted]				

Table 19 UID Details

Conclusion

9.35 This report has explained the defects NGGT were experiencing on the Plant 1 Aftercooler assets and the implications of these on terminal operations. The intervention was necessary to ensure the ongoing 24/7 365 operation of the terminal facility and to ensure we could remediate several other CAT6 defects included in the HSE Improvement Notice. Interventions on the asset to remediate the identified defects totals [redacted] (18/19 prices) in RIIO-2, of which [redacted] is being requested. NGGT are requesting recover these costs through the Asset Health Re-opener January 2023 submission.

9.36 As highlighted in this report Plant 2 Aftercooler is in significant need of investment. The St Fergus Short-Term Strategy confirms ongoing requirement for Avon and Variable Speed Drive (VSD) compressors at the site until 2030. This position necessitates the requirement for aftercooling at the site, requiring 24/7 365 operation. This highlights the clear need for two operational aftercoolers at the site, in order to ensure the resilience of aftercooling at the site, facilitating outages and maintenance activities without impacting on terminal operation.

9.37 Plant 2 Aftercooler has operated for twice its design life in harsh climatic conditions. There are a range of defects identified on various aspects of the system. Additionally, Bank D of Plant 2 Aftercooler has been isolated following leaks being identified. We have commissioned [redacted] to review the condition, duty, and operation of Plant 2 Aftercooler with a view to reviewing any required investment to be submitted in a later Asset Health Re-opener window.

10 Appendices

10.1 Appendix 1 - St Fergus Short-Term Strategy

Full report provided, filename:
RIIO-T2 St Fergus Short Term Strategy V7.pdf

10.2 Appendix 2 - Plant 1 Aftercooler – Condition Survey/Structural Survey Reports

Files Provided:

1002_000392-MAE-XX-XX-RP-C-0004-P01.pdf
1002_000392-MAE-XX-XX-RP-C-0003-P01.02.pdf
Appendix A.pdf
Appendix B.pdf
Appendix C.pdf
Appendix D.pdf
Appendix E.pdf

10.3 Appendix 3 – Foundation Inspection Report

File Provided:
Appendix 3 Foundation Inspection Report (SFGT-8878-EWP).pdf

10.4 Appendix 4 – IRIS and NFT Inspection Report

File Provided:
APPENDIX 4. NFT_IRIS FINAL REPORT TUTIS ENERGY ST FERGUS

10.5 Appendix 5 - Dye Penetration Report and Photos

Files Provided:

5. Dye Pen Report.pdf
5a. Dye Pen Photo.jpg

10.6 Appendix 6 - National Grid Incident investigation report

File Provided:
IMS 570245 Investigation Report Final 02 01.04.2020.pdf

10.7 Appendix 7 – Plant 1 Aftercooler Visual Survey of Pulleys, Bearings

Bank	fan ID	Motor Pulley Replacement Required	Fan Pulley Replacement Required	Fan Shaft Replacement Required	Bearing Assembly Replacement Required	Motor Overhaul or Replacement Required	Accelerometers for vibration monitoring
1	1A1	YES	YES	YES	YES	NO	Yes
1	1A2	YES	YES	YES	YES	YES	Yes
1	1A3	YES	YES	NO	YES	NO	Yes
1	1B1	YES	YES	NO	YES	YES	Yes
1	1B2	YES	YES	NO	YES	NO	Yes
1	1B3	YES	YES	NO	YES	NO	Yes
1	1C1	YES	YES	NO	YES	YES	Yes
1	1C2	YES	YES	NO	YES	YES	Yes
1	1C3	YES	YES	NO	YES	YES	Yes
2	2A1	YES	YES	NO	YES	NO	Yes
2	2A2	YES	YES	NO	YES	NO	Yes
2	2A3	YES	YES	NO	YES	NO	Yes
2	2B1	YES	YES	NO	YES	NO	Yes
2	2B2	YES	YES	NO	YES	NO	Yes
2	2B3	YES	YES	NO	YES	NO	Yes
2	2C1	YES	YES	NO	YES	NO	Yes
2	2C2	YES	YES	NO	YES	YES	Yes
2	2C3	YES	YES	NO	YES	YES	Yes
3	3A1	YES	YES	NO	YES	NO	Yes
3	3A2	YES	YES	NO	YES	NO	Yes
3	3A3	YES	YES	YES	YES	NO	Yes
3	3B1	YES	YES	NO	YES	NO	Yes
3	3B2	YES	YES	NO	YES	NO	Yes
3	3B3	YES	YES	NO	YES	NO	Yes
3	3C1	YES	YES	NO	NO	YES	Yes
3	3C2	YES	YES	NO	YES	YES	Yes
3	3C3	YES	YES	NO	YES	NO	Yes
4	4A1	YES	YES	YES	YES	YES	Yes
4	4A2	YES	YES	NO	YES	NO	Yes
4	4A3	YES	YES	NO	YES	NO	Yes
4	4B1	YES	YES	NO	YES	NO	Yes
4	4B2	YES	YES	NO	YES	NO	Yes
4	4B3	YES	YES	NO	YES	NO	Yes
4	4C1	YES	YES	NO	YES	YES	Yes
4	4C2	YES	YES	NO	YES	YES	Yes
4	4C3	YES	YES	NO	YES	NO	Yes

	Motor Pulley Replacement Required	Fan Pulley Replacement Required	Fan Shaft Replacement Required	Bearing Assembly Replacement Required	Motor Overhaul or Replacement Required	Accelerometers for vibration monitoring
Yes	36	36	4	35	12	36
No	0	0	32	1	24	0

10.8 Appendix 8 – Shafts Condition Assessment

File Provided:

Appendix 8. H019138 Inspection Report – Shafts

10.9 Appendix 9 - Plant 1 Aftercoolers Thermal Performance Review

File Provided:

Appendix 9. Plant 1 Aftercoolers Thermal Performance Review.pdf