Kings Lynn Bi-directional Area FEED Engineering Justification Study

Kings Lynn Compressor Station (7210)

Technical Report

04	Updated Following National Grid Review. Costs Added.	[redacted]	14/03/22	[redacted]	15/03/22	[redacted]	15/03/22
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Issue	**Description**	**Originator**	**Date**	**Checked**	**Date**	**Approved**	**Date**

Abbreviations

[redacted]	[redacted]
AGI	Above Ground Installation
API	American Petroleum Institute
Barg	Bar Gauge
BAT	Best Available Techniques
BBL	Balgzand to Bacton Line
BS	British Standard
CAD	Computer Aided Design
CBA	Cost Benefit Analysis
CDM	Construction (Design and Management)
CIPS	Close Interval Potential Survey
CIT	Carbon Interface Tool
CO2e	Carbon Dioxide Equivalent
CP	Cathodic Protection
CPEL	Cathodic Protection Engineering Ltd.
DCVG	Direct Current Voltage Gradient
DP	Design Pressure
DSEAR	Dangerous Substances and Explosive Atmospheres Regulations
eDNA	Environmental DNA
EJP	Engineering Justification Paper
ELD	Engineering Line Diagram
ESD	Emergency Shut Down
FE	Finite Element
FEA	Formal Environmental Assessment / Finite Element Analysis
FEED	Front End Engineering Design
FES	Future Energy Scenarios
FPSA	Formal Process Safety Assessment
GA	General Arrangement
GNCC	Gas National Control Centre
HAZCON	Hazards in Construction
HAZID	Hazard Identification
HAZOP	Hazards and Operability Analysis
HSWA	Health and Safety at Work etc Act

IGEM	Institute of Gas Engineers and Managers
IUK	Interconnector UK
MOM	Minutes of Meetings
MOP	Maximum Operating Pressure
MSCMD	Million Standard Cubic Meters per Day
MTO	Material Take Off
NARC	National AGI Renovation Campaign
NB	Nominal Bore
NORM	Naturally Occurring Radioactive Material
NRV	Non-Return Valve
NTS	National Transmission System
OFGEM	Office of Gas and Electricity Markets
PSR	Pipeline Safety Regulations
PSSR	Pressure Systems Safety Regulations
QEHSMS	Quality, Environmental, Health, Safety and Management System
RFI	Request for Information
RIIO-T2	Revenue = Incentives + Innovation + Outputs Transmission 2
SIL	Safety Integrity Level
SOL	Safe Operating Limit
SSSI	Site of Special Scientific Interest
TQ	Technical Query
UK	United Kingdom

Executive Summary

This report, produced by [redacted]. for National Grid, describes the work undertaken by [redacted] Ltd. and [redacted] to assess the asset health condition of the bi-directional pipework area at National Grid's Kings Lynn Compressor Station.

Previous assessments of the area completed under the National AGI Renovation Campaign (NARC) and other projects have been reviewed and further refined to gain a clearer picture of the current condition of the asset. Following this, some high-level design solutions have been developed to resolve a number of the issues identified.

A desktop study of historical records including drawings and photographs have found evidence that all of the six original (circa. 1972) 900NB ball valves are supported on a piled beam foundation. The supporting arrangement of these valves was previously unconfirmed.

Remedial works undertaken since 2016 including relevelling of 50NB pipework, drainage works, and valve maintenance activities have been considered in this study. Details of these remediation works are provided in section 2.2.

Additional data has also been gathered from excavations of buried 900NB pipework at strategic locations and subsequent installation and surveying of fixed monitoring points. Locations of above ground pipework has also been measured by total station and laser scan surveys.

The additional data gathered from the pipework surveys and excavations has been utilised to create a refined model of the current area. This refined model, in conjunction with the additional historical records (particularly the presence of piled foundations supporting the original 900NB valves) has been used by [redacted] to complete a more comprehensive stress analysis study including fatigue analysis for continuous operation to allow the asset to retain its integrity and retain compliance up to the year 2050. The initial results showed a number of potential over-stresses, however all but one of these (on a 900NB equal tee) was resolved by detailed finite element analysis of the identified fittings.

The thorough investigation in to the as built and current condition of the pipework, ground water and drainage has allowed refinement to the pipework stress analysis models and increased confidence in the results and predications of future safe operating life. The perceived extent of subsidence and associated integrity risks have therefore been reduced to manageable levels by this study.

Cathodic protection surveys (CIPS and DCVG) have also been completed on site. These surveys highlighted one or more potential coating failures in the central area of the bi-directional area. This would need investigating and repairing as part of the selected option.

Condition assessments of all the actuators were also completed and recommendations for refurbishment have been provided with associated costs.

The high-level design solutions developed as part of this study are:

- Option 0 – Do Nothing.
- Option 1A – Minor In-Situ Remediation
- Option 1B – Major In-Situ Remediation
- Option 2A – Specification Compliant Re-build In-situ
- Option 2B – Re-build In-Situ (as per current arrangement)

- Option 3 – Re-build in New Location

Engineering Line Diagrams, General Arrangements, Isometric Views, and high-level Material Take Offs for each of these options have been developed. In conjunction with National Grid stakeholders, the options have been assessed from and safety, technical, and environmental perspective.

A Formal Process Safety Assessment including HAZID, HAZOP, layout review, safe working design study, and hazardous area review was completed with National Grid stakeholders to identify the shortcomings and potential hazards associated with the current arrangement and examine inherent safety of each of the proposed solutions. The study concludes that superficially, Option 3, appears to offer more process safety benefits than the other options.

The study was also cognisant of the 'buildability' of the various options and concluded that options 2A and 2B were not credible due to the length of the station outage required to facilitate their construction.

Finally, some potential innovative solutions that could be deployed by National Grid to resolve some of the identified issues have been briefly discussed.

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1 Introduction

1.1 Project Background

In 2017 as part of National Grid's National AGI Renovation Campaign (NARC), National Grid identified a number of asset health issues at Kings Lynn Compressor Station. Many of these issues related to the bi-directional pipework area include valves and actuator issues, corrosion, and evidence of adverse ground settlement. Stress analyses undertaken at the time also reported numerous potential stress exceptions in the area.

The 2017 NARC works were based on a number of assumptions and best information available at the time. Many of these assumptions have been further investigated and refined through this (2021) study. Details of available of information and assumptions at various stages of the project are outlined in Table 1.

To resolve the observed issues and provide some enhanced features, [redacted] developed, as part of the NARC campaign, a conceptual design for a new bi-directional located elsewhere on site (option 3 within this report). A budget allowance option was included in National Grid's OFGEM RIIO-T2 price control period submission for design and build 2022 to 2024.

Given the visible condition of pipework, the measurements taken at the time, the available data, and the fact that Kings Lynn is a strategically important site for UK security of supply, National Grid considered there to be little option other than to pursue further work associated with Kings Lynn since low-probability/high impact events that were hinted at require mitigation by National Grid as a prudent and responsible operator of the network.

In January 2021 OFGEM instructed National Grid to complete an engineering justification study to assess the various potential options for remediation of the subsidence issues in the bi-directional area and to facilitate the submission of a Final Option Selection Report in March 2022.

In May 2021 National Grid engaged [redacted] to complete a FEED Engineering Justification Study for the area to support and inform National Grid's Kings Lynn Subsidence Reopener Submission.

Table 1 – Key Information and Assumptions Over Time

Pre- NARC Information (before mid-2017)	NARC Information (mid-2017 to mid-2018)	Post- NARC Information (mid-2018 to present)
Stress Analysis		
[redacted] Engineering Ltd. report ground settlement and indicate numerous potential stresses exceeding IGE/TD/12 code limits. Pipe depth and soil conditions unknown. 900NB pipework not considered in this study.	In August 2018 [redacted] completed a limited stress analysis of the bi-directional area based on a number of assumptions. No direct investigations were completed to inform this study; therefore, a number of worst-case assumptions were made include:	In 2021 [redacted] were able to refine their stress analyses based on the additional information gathered from record reviews and direct investigations carried out as part of this study. Previous assumptions were amended accordingly: • All 900NB valves were found to be on piled

	• Some 900NB valves are not on piled foundations • Only lower bound soil properties as specified in the earlier [redacted] report were considered. • In the absence of direct investigation of buried pipework, an iterative approach of applying displacement profiles was used to establish a profile that would give some agreement with observed above ground pipework movement (30 to 40mm settlement). The study found >30 stress exceptions considering 30 to 40mm settlement.	foundations according to historic records found on site. • Original as-built profile and current profile of the pipework were determined by combination of as-built / historic records, direct measuring of top of pipe at various locations, trend line analysis, and free span analysis (to resolve a discrepancy in the 2003 AOD survey data) as described in section 5. • Accurate representative ground models were used based on borehole logs. Initially identified IGE/TD/12 stress exceptions were subject to FEA and all were resolved apart from one 900NB equal tee (see 5.4). Additionally, a fatigue assessment and assessments considering removal of pits were completed as described in section 5.
Ground Conditions		
[redacted] specialists report following desktop study and site visit (non-intrusive) that the main cause of the ground settlement and pipe deformation is likely to be weak ground exacerbated by saturated conditions and the susceptibility of the ground to liquefaction.	In August 2018, [redacted] undertook three rotary boreholes on site to a maximum depth of 51m and completed laboratory testing to determine various soil parameters. The ground water table was also measured by installation of monitoring wells and found to be relatively shallow at approximately 1.36mbgl.	No additional specific GI investigations were completed as part of this study; however, trial holes were excavated to top of pipe to install monitoring points. Anecdotal evidence suggests that ground was reasonably firm and stood up well. Additionally, a mains water leak was identified and rectified on site which was suspected to have been

	Based on the proposed new design for the bi-directional area developed by the NARC project, shallow raft / pad foundations were deemed not suitable for proposed load and base size due to the ground conditions found on site, therefore piled foundations were proposed. No assessment was carried out on the existing arrangement.	exacerbating the water saturation issues in the bi-directional area. Anecdotal evidence from site suggests the area has been less waterlogged since installation of a land drain in the area in late 2018 / early 2019.
Foundations		
[redacted] report assumed that 900NB pipework is on piled foundations however notes that this cannot be confirmed for the original (pre- [redacted] pipework). [redacted] produced a known foundation summary which shows piled supports on the additional valves installed by [redacted] in 2003 only. The [redacted] report does not consider buried supports.	Based on the available information at the time, it was not possible for the NARC project team to confirm whether the original 1970s valves were on piled foundations or not. The [redacted] records showed that the additional valves installed for the bi-directional upgrade works were on individual piled foundation. Based on this unknown and the known ground conditions on site, it was deemed plausible that settlement could occur on 900NB pipework, as well as the already identified differential settlement of the small bore (50NB) pipework.	Following review of records on site it was found that the existing 1970s valves were supported on a piled raft foundation in the form of a piled beam across either side of the original six 900NB ball valves as shown in Figure 12 (section 2.3) supported by six 20 tonne capacity piles. This allowed the stress analysis to remove the worst-case assumptions previously used that the 900NB valves were on a combination of piled and non-piled bases.
Laser Scan Surveys		
No laser scan surveys completed in the bi-directional area pre-2017.	Laser scan surveys were completed in June 2017 and July 2018. Comparison of these two points clouds showed movement of the small-bore pipework and perceived movement of a 900NB valve stem (downwards movement of 10mm).	Further laser scans were completed in July and December 2021. Further interrogation of the laser scans and the additional data subsequently obtained concluded that due the compounded tolerances on the accuracy of laser scan equipment, the lack of information of buried

	In light of all the other indications of ground settlement, it was considered at the time that this could have been indicative of settlement of the 900NB pipework.	pipework (any below ground movement being inferred from above ground data) and the human judgement for picking points for comparison, the 10mm 900NB valve stem movement identified in 2018 was not significant enough to infer movement. Monitoring rods were affixed to the crown of the pipe to facilitate more repeatable and direct measurement of 900NB pipe movement.

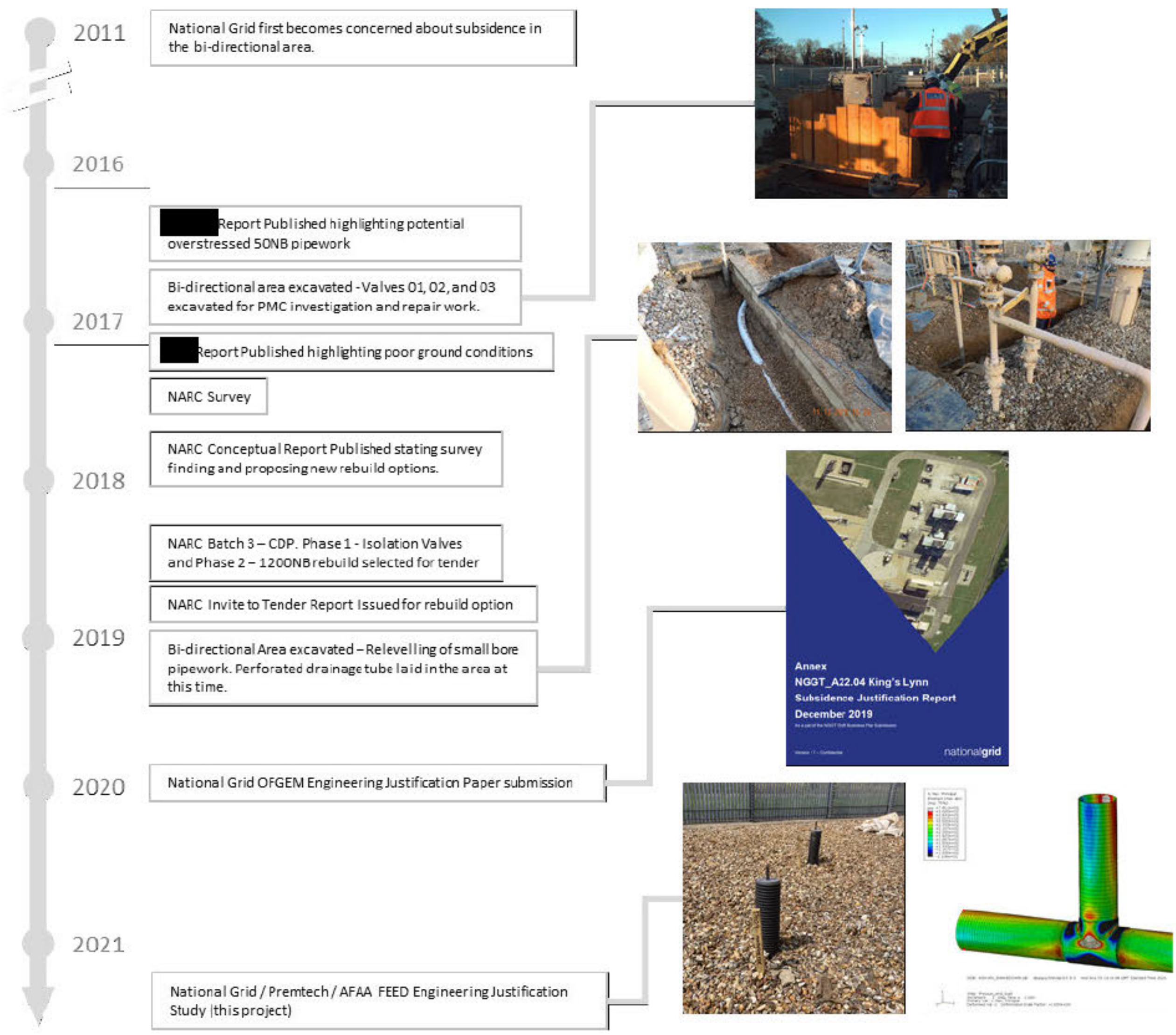

Figure 1 – Timeline of Work Relating to the Bi-directional Area

1.2 Site Location

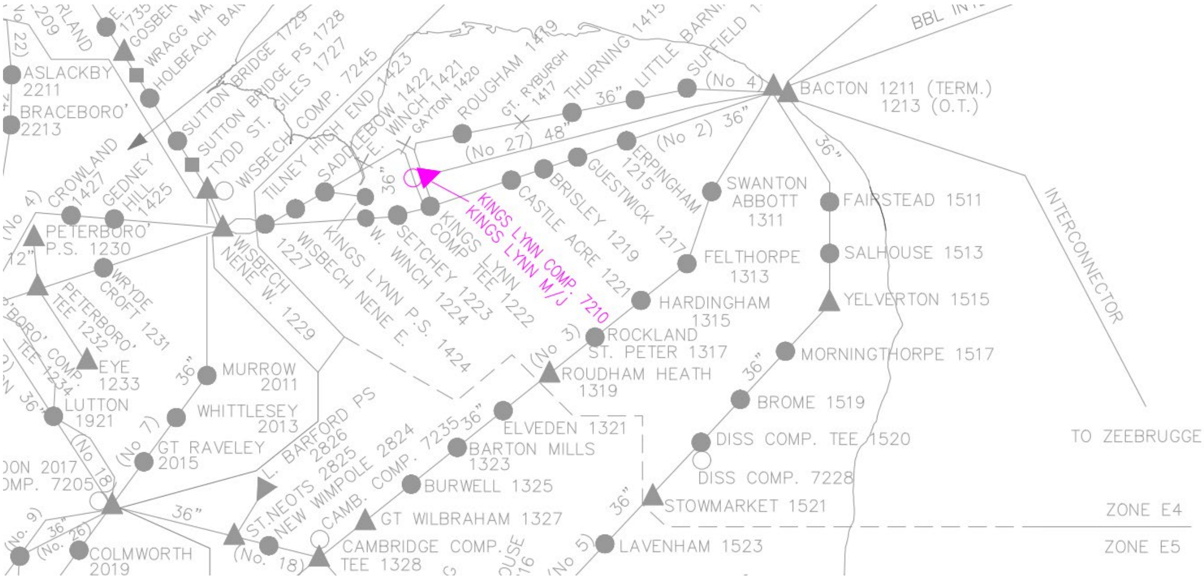

Figure 2 – NTS Map Kings Lynn Location

Figure 3 – A Satellite Image of Kings Lynn Compressor Station

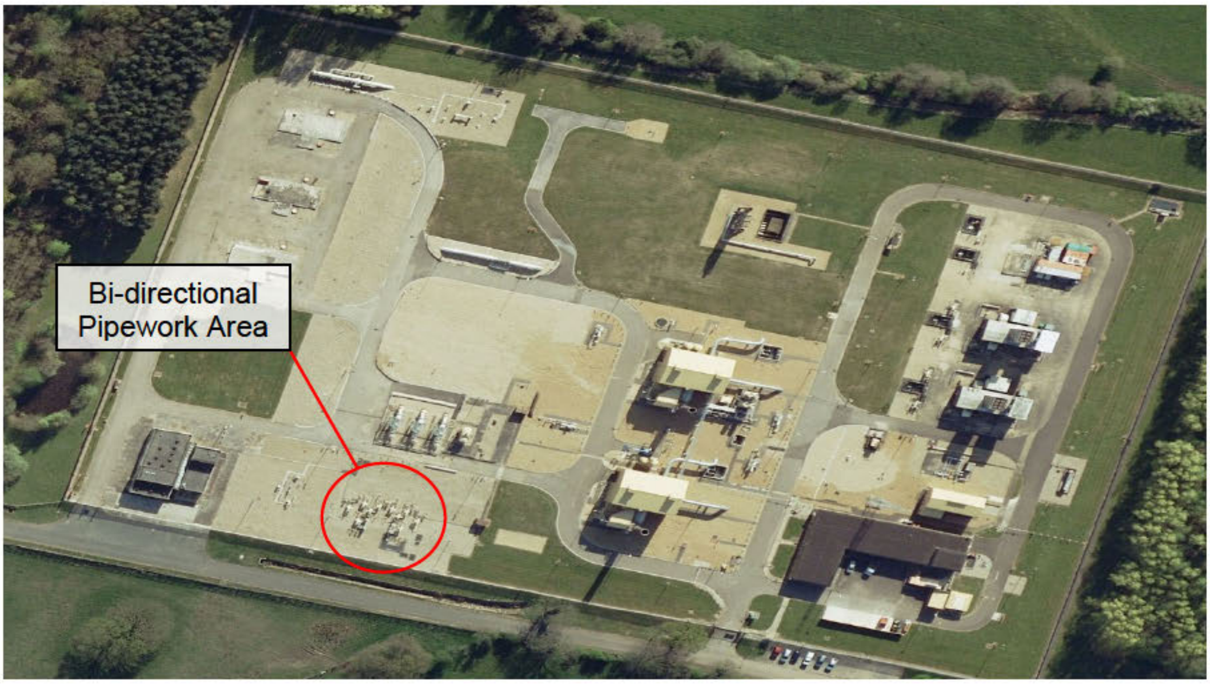

Figure 4 – A Detailed Satellite Image of Kings Lynn Compressor Station

Kings Lynn Compressor Station, originally commissioned circa 1973, is one of 24 gas Compressor Stations around the country that maintains gas pressures and flow during periods of high demand.

Kings Lynn Compressor Station consists of four gas turbines with associated equipment such as filtration, metering, fuel gas pressure reduction and venting, associated pipework, and control systems.

The bi-directional pipework modifications were installed in 1998 to meet the requirement for reverse flow (towards Bacton) of the Interconnector pipeline between Zeebrugge and Bacton.

1.3 Bi-directional Area

1.3.1 Function

The bi-directional area provides the compressor station's connection to the National Transmission system, Feeders 2, 4, and 27. As the name suggests, the bi-directional area allows the compressors to change direction to push gas either east towards Bacton Terminal and the Interconnector, or west inland across the UK as required. This is achieved by manipulation of 10 900NB ball valves with associated rider valves and two equalisation balancing regulator streams.

Figure 5 below shows a simplified diagram of the valve arrangements which facilitate the bi-directional flow. The valves shown can be opened and closed as required to reverse the shown directions of A, B, C and D whilst maintaining the flow directions to the scrubbers and from the compressor. For example, to reverse the shown directions of A and B, valves 13 and 14 would be closed and valves 11, 12 and 15 would be open. Note: balancing regulators are not shown.

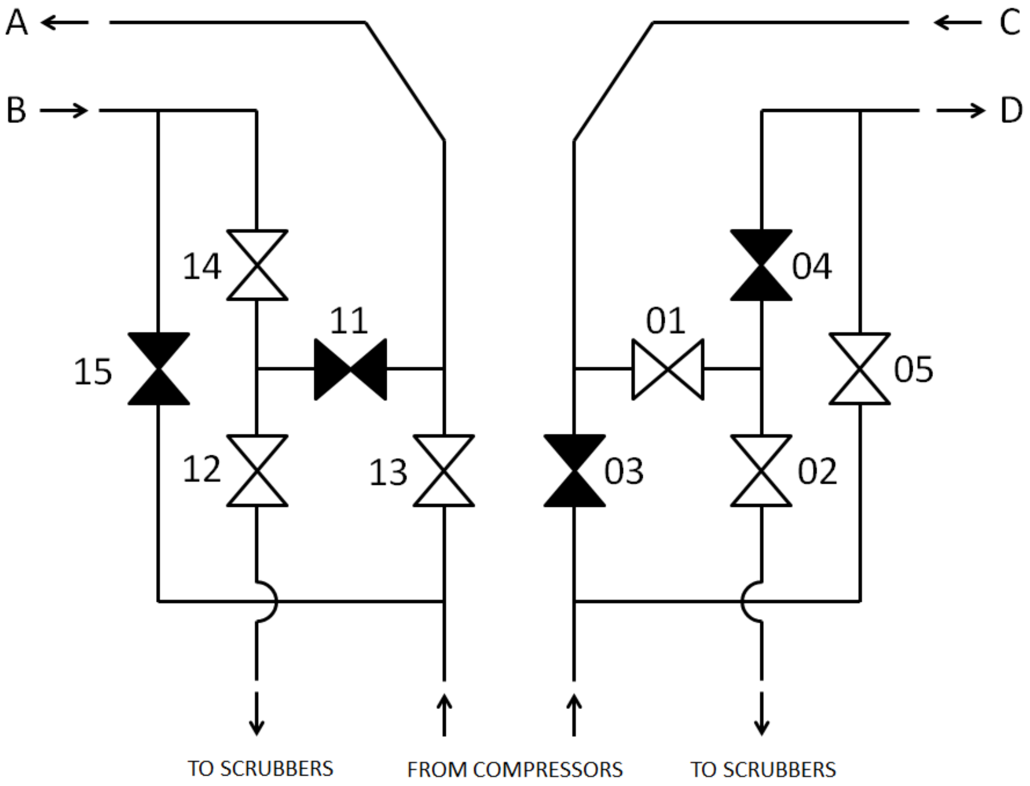

Figure 5 – Simplified Diagram of the Bi-directional Area

The loss of the bi-directional area would result in restriction of Bacton Terminal flows, loss of compression on Feeders 4 and 27, and a significant reduction of flow capacity on Feeder 2.

1.3.2 History

Kings Lynn Compressor Station was originally constructed in two phases between 1970 and 1973. The original layout of the station included a multi-junction where the current bi-directional area is situated providing connection to Feeders 2 and 4 as shown in Figure 6. Feeder 27 was not constructed at this time and the multi-junction did not have bi-directional capabilities.

[redacted]

Figure 6 – 1970s Arrangement of Kings Lynn (pre-bi-directional area)

In 1998, [redacted] upgraded the area as part of the 'Kings Lynn Reversible Flow Project' to allow bi-directional operation of the compressor station. This included installation of the four additional 900NB ball valves and 300NB balancing regulator streams as shown in Figure 7. As part of these works, two of the original 900NB ball valves (Valves 11 and 12) were replaced.

[redacted]

Figure 7 – 1998 [redacted] Modifications to Bi-directional Area

In 2003, Feeder 27 and the Feeder 4 pigging loop were installed as shown in Figure 8. None of the valves within the bi-directional area were replaced however, the connections to Feeder 4 were replaced to tie in the new pigging loop tee. The new 1200NB Feeder 27 was connected on common pipework to Feeder 4 between the new Feeder 4 tee and the bi-directional area. It is noted that the maximum flow capacity of Feeder 27 is significantly greater than the original Feeder 2 and 4 connections and the arrangement connecting

Feeders 4 and 27 to the bi-directional area limits the network's ability to operate these feeders independently of each other.

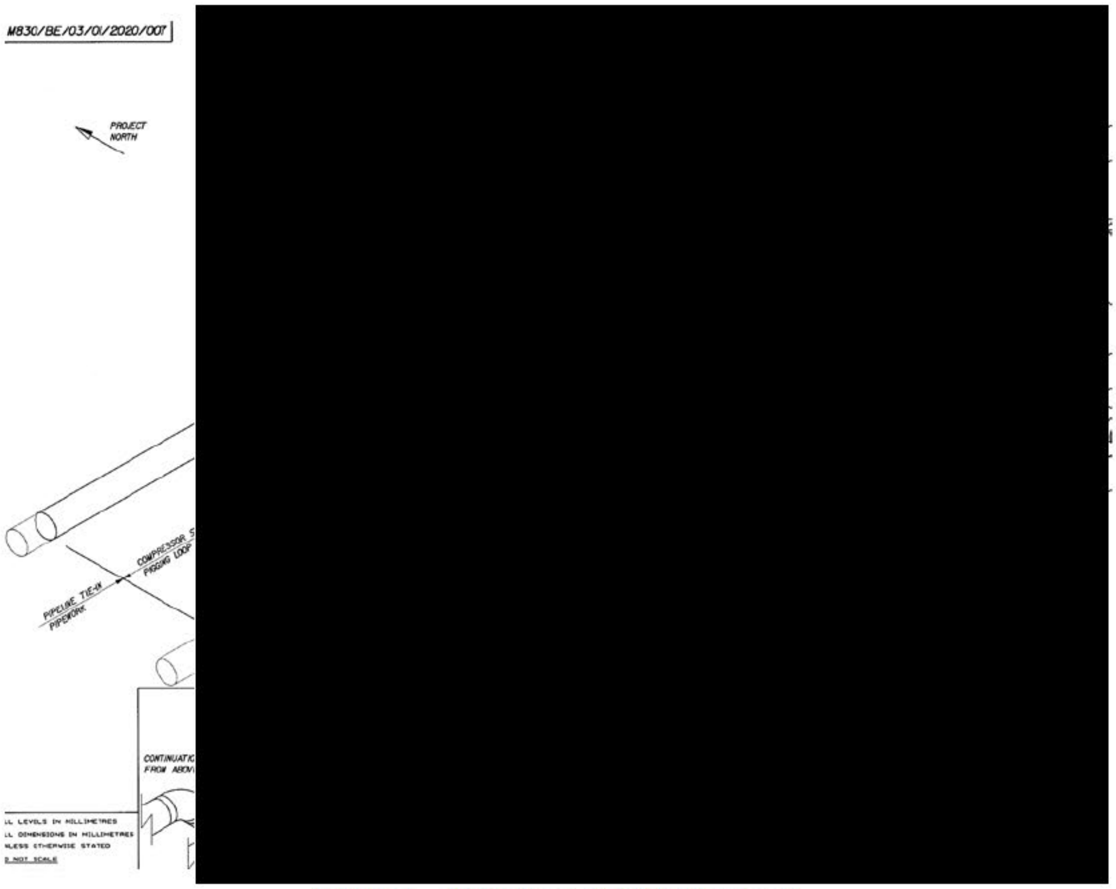

Figure 8 – 2003 Feeder 4 Pigging Loop

In 2019, [redacted] installed two 900NB ball valves between the bi-directional area and the Feeder 2 tee. These valves were installed to provide additional isolation capability between the bi-directional area and Feeder 2 tee.

It is noted that the ground investigations including boreholes undertaken in 2017 resulted in piled foundations being required to adequately support these new valves.

[redacted]

Figure 9 – Feeder 2 Isolation Valves

1.4 Project Scope Summary

1.4.1 OFGEM Requirements

The Reopener Submission for Kings Lynn Subsidence should build upon the RIIO-T2 EJP and CBA, and must:

- Quantify the rate of deterioration and the probability of failure to demonstrate the need for a major investment rather than mere ongoing monitoring.
- Demonstrate a thorough optioneering process to address the risks posed by the current King's Lynn bi-directional pipework, including reference to the probability of failure. All options considered must have a cost estimate built to an equivalent accuracy to allow a fair comparison to be made.
- Use updated FES and Network Capability modelled flows in the CBAs.
- Include consideration of the probability of failure of the King's Lynn bi-directional pipework.
- The CBA must also consider all key drivers of investment including safety and environmental risks.
- Provide an updated breakdown of the capital costs and associated risk, project management, and other such contingencies in line with the RIIO-T2 EJP guidance.

1.4.2 Report Scope

The key scope of this report includes the following:

- Details of monitoring and investigative works undertaken to further understand the extent of any subsidence issues on site.

- Results of additional stress analysis studies undertaking including fatigue analysis.
- Optioneering for a number of identified potential solutions to resolve the subsidence issue including remediation and rebuild options.
- High level design packs for progressed options following the optioneering review.
- Budget cost estimates and programmes for the progressed options.

2 Problem Statement

2.1 Problem Statement

2.1.1 NARC Findings

National Grid have advised the design life of the Kings Lynn Bi-directional area shall be to 2050 to align with the expected life of the compressors.

Kings Lynn Compressor Station was surveyed as part the National AGI Renovation Campaign (NARC) on 28th June 2017. Figure 10 shows evidence of surface level subsidence. The above ground 50NB pipework were not level, were out of plane and had been subject to bending. Pipework and control cabinet supports, and bases were also not level.

The adverse ground settlement issues were known to National Grid at this time with the following two studies having previously been undertaken:

- [redacted] – Initial Site Assessment Kings Lynn Compressor Station – Report Number J17-577-003R Rev 0, dated 30th March 2017
- [redacted] - Assessment of Subsidence Loads on Small Bore Offtakes at Kings Lynn Compressor Station – Report Number 9496 Issue 1, dated 24th October 2016.

The [redacted] assessment concluded many of the 50NB pipework connections were potentially overstressed. In one case over three times the acceptable / allowable limit within IGEM/TD/12 [1]. It is noted that the [redacted] assessment only considered the 50NB pipework connections and did not consider or assess potential over stresses within the main larger diameter pipework.

From the [redacted] report it was noted that a number of the newer large diameter ball valves installed in 1998 are supported from piled foundations and are unlikely to settle. The other large diameter ball valves (1970s) were at the time considered to not be supported on piled foundations as a conservative assumption and may be subject to settlement, this potential differential settlement between the piled and un-piled pipework and valves would cause additional stresses within the pipework, and some of these stresses may be significant. It was not clear where the main pipework has settled or moved.[1]

During the site survey on the 28th June 2017, National Grid Operations confirmed that a number of valve actuators in the bi-directional area have been sized (oversized) to give fast valve closing times. The oversized actuators had caused a valve to break through its stops and complete a full 360-degree movement. Other valves have had the bolts between the valve and valve stem extensions stretched by the inappropriately sized actuators.[2]

There was also a significant amount of corrosion observed in the area particularly on the actuator cabinets.

[1] Subsequent reviews of information discovered during this study (2021) have found evidence that all the original valves are on piled foundations as described in section thus the issue of differential settlement on the main 900NB pipework has become less of a concern.
[2] It was stated during the FPSAs on the 8th and 9th December 2021 that this issue has since been resolved.

Figure 10 – Bi-directional Area – June 2017

2.1.2 Valve Operating & Maintenance Record

In addition to the findings from the NARC study, some operational and maintenance records for valves within and surrounding the bi-directional area were made available by National Grid operations in 2021. An extract from this data is shown in Table 2.

This data forms the basis of the remediation options developed in this study.

Table 2 – 2021 Kings Lynn Valve Operating and Maintenance Register

Valve Number	*Valve Name*	*Time to operate (seconds)*	*Seal rate*	*Date of checks*
MV11114	Scrubber A Suction	N/A	80%	17.11.16
MV11115	Scrubber A Discharge	N/A	100%	17.12.14
MV11214	Scrubber B Suction	N/A	80%	18.11.16
MV11215	Scrubber B Discharge	N/A	100%	17.12.14
MV11314	Scrubber C Suction	N/A	80%	21.11.16
MV11315	Scrubber C Discharge	N/A	100%	17.12.14
MV11205	721002 rider	Instantaneous	100%	03.03.14
MV11229	721005 rider	Instantaneous	100%	07.03.14
MV11236	721003 rider	Instantaneous	100%	07.03.14
MV11136	721013 rider	Instantaneous	100%	07.03.14

MV11129	721015 rider	Instantaneous	100%	07.03.14
MV11105	721012 rider	Instantaneous	100%	06.03.14
MV721002	F4 suction RF/FF	30 open/close	85%	12.01.20
MV721003	F4 discharge RF	28 open/close	80%	12.01.20
MV721004	F4 suction RF	16 open/close	95%	12.01.20
MV721005	F4 discharge FF/RF	20 close 18 open	100%	12.01.20
MV721007	F4 Equalising	N/A	N/A	12.01.20
MV721008	F4	4 open/close	100%	12.01.20
MV721001	F4 suction FF	18 close 15 open	0%	12.01.20
MV721011	F2 suction FF	18 open/close	95%	11.01.20
MV721012	F2 Suction RF/FF	20 open/close	100%	11.01.20
MV721013	F2 discharge RF	17 close 20 open	95%	11.01.20
MV721014	F2 discharge RF	19 close 14 open	100%	11.01.20
MV721015	F2 suction RF/FF	13 open 20 close	95%	11.01.20
MV721017	F2 Equalising	N/A	N/A	11.01.20
MV721018	F2	4 open/close	100%	11.01.20

2.2 Previous Remediation Works

In 2019 remediation work was undertaken on the small bore (50NB) pipework in the area. This included excavation of pipework and removal of concrete blocks attached to the pipework where possible to allow it to return to a level position. The area appears visually much improved in comparison with 2017 survey with the 50NB appearing straight and level in most places.

Also, in early 2019 some shallow land drain pipe was installed in the area, out-falling into an adjacent manhole to help reduce surface level flooding. Anecdotal evidence from site operational staff suggests, the area have been less susceptible to surface level flooding since this drainage was installed, however the pits have still remained flooded.

Figure 11 – Bi-directional Area – August 2021

2.3 Site Records Review

A number of additional drawings have become available since commencement of the FEED Engineering Justification Study which were not previously available. Much of this information was retrieved from archived information on site.

The primary learning from these was that the existing 1970s valves were supported on a piled raft foundation in the form of a piled beam across either side of the original six 900NB ball valves as shown in Figure 12 supported by six 20 tonne capacity piles.

The 1998 [redacted] design to add bi-directional functionality to the area originally proposed to tie-in to this existing raft, however the design was later revised to separate piled individual valve supports to avoid breaking into the existing structure.

The conclusion of this foundation review was that all ten of the existing 900NB ball valves in the bi-directional area are supported on piled foundation. As a result of this, the revised stress analysis undertaken (as described in section 5 of this report) has assumed that there has been no settlement of these valves. The previous 2018 stress analysis study assumed a displacement profile based on surface level observations.

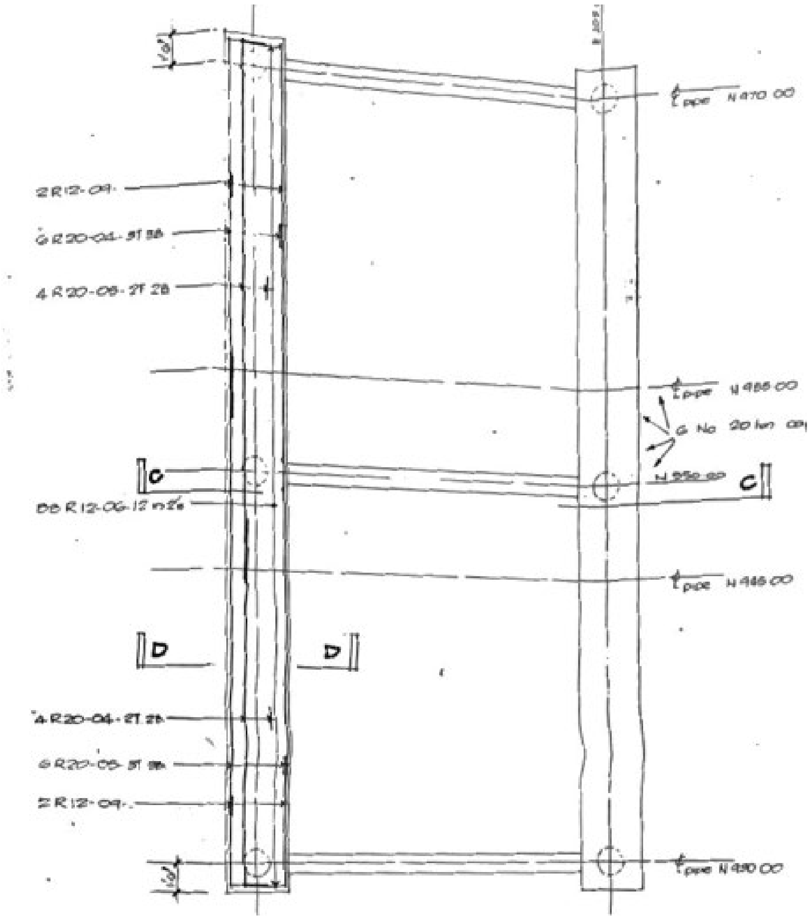

Figure 12 – Gas Council Valve Support Details (*c.*1971)

In addition to the foundation information outlined above, a number of as-built and pre-construction design drawings were obtained. This information, as well as the additional information from site surveys and investigations was utilised to create a comprehensive 3D model of the area.

2.4 Additional Survey Findings, Monitoring & Site Investigations

2.4.1 Laser Scan

A number of laser scan surveys have previously been undertaken in the bi-directional area including June 2017 and July 2018 for NARC. Two additional laser scan surveys were undertaken as part of this FEED study July 2021 and December 2021.

The resulting point clouds from these laser scan surveys provide a useful visual indication of movement of above ground pipework and surface level ground movement. They also provided valuable data to develop a georeferenced 3D model of the area. They were not used as a comparison to quantify pipework movement as a more accurate method was sought for this purpose as outlined below.

Comparison of these point clouds was previously used to quantify movement of pipework, however due the compounded tolerances on the accuracy of laser scan equipment, the lack of information of buried pipework (any below ground movement being inferred from above ground data) and the human judgement for picking points for comparison, a different method was sought to monitor pipework movement more accurately.

The solution implemented was to install monitoring rods at key points on the 900NB buried pipework.

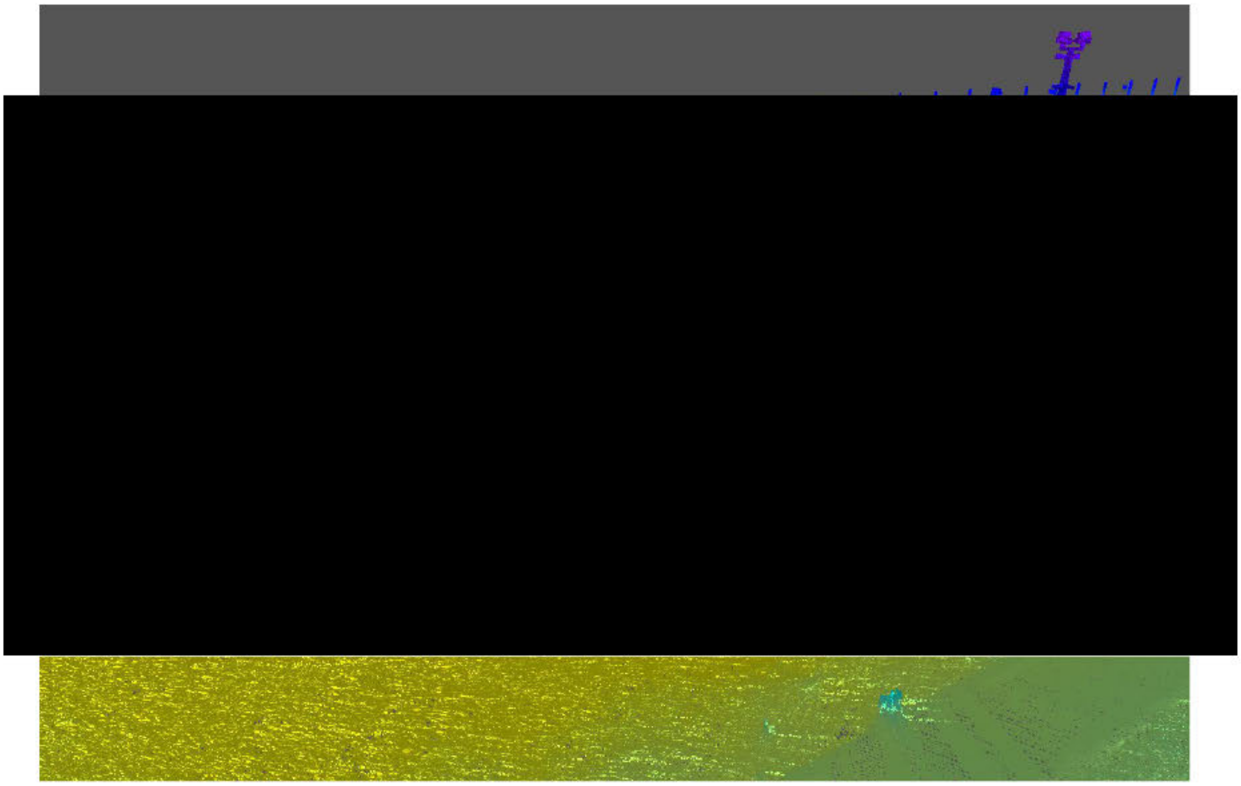

Figure 13 – Laser Scan Survey Point Cloud

2.4.2 Monitoring Points

A number of monitoring points have been installed at strategic locations on the buried 900NB pipework in the vicinity of the bi-directional pipework area. These are metal rods affixed by a plate to the coating on the crown of the pipe using a suitable adhesive. They provide an above ground threaded end connection to facilitate the attachment of surveying prism to allow accurate measurement of the position of the pipe. These points can also be used to measure any subsequent pipe movement.

In addition to the monitoring rods, some above ground pipework was surveyed by placing survey prisms on top of above ground pipework equipment e.g., actuators, bridle pipework, and vent point. These points were not affixed to the pipework therefore will not be utilised for repeat measurements to determine movement but were used to support the laser scan data of above ground pipework positioning.

The positions of the monitoring rods were determined by stress analysis consultants to ensure the most value can be extracted from them to inform the stress analysis model. Typically, these were where existing as-built level information existed as baseline for comparison or where information was critical for the accuracy to the stress analysis model.

Whilst the rods were being installed and the excavations were open the tops of pipe were also measured to provide a sense check for the surveyed prism data.

The monitoring rod positions were first surveyed 29th July 2021. The data obtained from this survey was utilised alongside point cloud data from a laser scan undertaken on the same date to improve the accuracy of the 3D pipework model and generate a new stress analysis model.

The monitoring rods are to stay in situ to allow continued monitoring of the area for as long as deemed necessary by National Grid. A second survey was completed in December 2021, to provide a comparison set of data and check for any movement. Negligible movement (≤ 2mm) was found in the change in height of these points.

Based on recent visual indications from valve stems suggesting valves are not level, it is also recommended that National Grid consider installing additional monitoring points on the Feeder No. 4 pigging loop. The valves in this area are not on piled foundations according to as-built drawings, so may benefit from ongoing monitoring to ensure there is not settlement in this area.

See Figure 14 (right) for a photograph of two of the monitoring points installed prior to attachment of survey prisms.

2.4.3 Mains Water Leak

Kings Lynn Compressor Station and the bi-directional area in particular has a history of flooding and waterlogging. Anecdotal information from site operations suggests that the pits in the bi-directional area have been flooded even after long periods without rainfall.

In July 2021 reeds were noted to growing alongside the site road adjacent to the area where the old control building was situated, see Figure 14 (right). After some excavations in the area, a water main leak was identified and rectified.

It is hypothesised that water from this leak has been flowing into the bi-directional area causing or worsening the localised flooding and adverse ground conditions.

It is recommended that the water levels in the bidirectional area are continued to be monitored to assess the effectiveness of the new drainage system in addition to the resolution of the water main leak.

Figure 14 – Left: Evidence of Water Main Leak. Right: Monitoring Points

2.4.4 Cathodic Protection Survey

In order to evaluate the likelihood of corrosion having occurred on the buried pipework in the bi-directional area and the effectiveness of the current site cathodic protection system, a close interval potential survey (CIPS) and a direct current voltage gradient (DCVG) survey were completed in the area 15th October 2021.

The results of the CIPS show marginal CP levels within the central section of the bi-directional area which may indicate the presence of a potential coating fault (e.g., delamination). All other buried pipework in the area was found to have effective CP levels present.

The results of the DCVG showed a single large DCVG indication within the bi-directional area near valves 721001 and 721011. It is possible that there are other coating defects in the same area, however signals from smaller defects are likely to be shielded.

Full methodology and results can be found in CPEL report, CPEL-1934-D01 in Appendix B.

2.4.5 Actuator Condition Assessments

[redacted] were engaged to complete a detailed condition assessment of the existing actuators and controls in the bi-directional area 12th October 2021.

This included an inspection of all actuators, cabinets, and controls. Individual condition reports were produced for each actuator with recommendations and costs for refurbishments.

Typical issues identified included:

- General corrosion, including cabinet corrosion allowing water ingress into the cabinet.
- Leaking hydraulic reservoirs.
- Insecure vent stacks due for corrosion of fixings.
- Water build up inside actuator housing potentially causing corrosion damage to internals.
- Poor condition travel stops on pneumatic and hydraulic cylinders.

Typical recommendations for refurbishment include:

- Replacement of existing cabinets with new stainless-steel enclosures.
- Replacement of soft seals, unserviceable hard components, control tubing, and vent stacks
- Further assessment of actuator internals to assess damage caused by water ingress.
- Recoating of actuator.
- Gas dehydrator filter replacements.
- Replacement of switchboxes.

Full [redacted] actuator survey reports and proposal to complete the recommended works can be found in Appendix B of this report.

Figure 15 below shows the actuator, cabinet, and controls for Valve 721001.

It is recommended that the issues found are logged as plant status issues for the site.

Figure 15 – Valve 01 Actuator Condition (from Power Mechanical Report SR-6485-01)

2.5 Related Projects

In addition to the NARC project described in section 2.1.1, a number of other project learnings have been utilised to inform this study. These include:

- Geopolymer Injection for Ground Stabilisation National Grid Innovation Project
- Valve Care Kit Innovation Project

Details of these projects and their relevance to this project are outlined in section 12 of this report.

2.6 Project Challenges

Key challenges for consideration within this study include the following:

- Knowledge of existing assets
- Drainage
- Poor ground conditions
- Outage window availability
- Provision of Isolations
- Control System Implications
- Future operational and capacity requirements

Many key risks that have been identified in this study will need to be carried forward into the detailed design. For a complete record of identified technical risks, refer to Technical Risk Register, [redacted]585-REG-7210-0100, included in Appendix B.

2.7 Consequences of Non-Intervention

2.7.1 Total Failure

The Kings Lynn Compressor Station Bi-directional Area is a critical asset for National Grid. As mentioned in section 1.3 of this report, the bi-directional area facilitates the compression requirements for entry and exit connections at Bacton Terminal including the interconnector, therefore total failure of the asset would have significant impact. Bacton Terminal would be restricted to just one of three feeders if King's Lynn compression was lost.

Inability to operate the bi-directional would inhibit National Grid's ability to reverse flow from Kings Lynn could potentially prevent National Grid from fulfilling their interconnection requirements (ability to export gas to Europe when required).

Loss of operability of the bi-directional area will also impede the ability of GNCC to use Kings Lynn Compressor Station on the very rare occasions where Bacton supplier terminals experience supply disturbances resulting in release of condensate.

Various configurations are to be confirmed by GNCC to fully assess the impact of loss of bi-directional function.

Currently all incoming feeders to Kings Lynn flow through the bi-directional pipework, therefore it is not possible to bypass the station e.g., flowing from 27 and 4 to 2 or vice versa is not possible.

A long outage would be required to rectify the issue.

Failure resulting in loss of containment could result in, inventory loss, an environmental and / or hazardous event escalation.

2.7.2 Partial Failure

Partial failure of the asset could result in reduced functionality of the bi-direction. For example, if one or more valves fail to operate, the bi-directional may not be able to be configured in a number of operational modes until the issue is rectified. This may limit National Grid's flexibility to operate the network as required.

Partial failure may escalate to impacts listed under total failure.

2.7.3 Unplanned Maintenance Requirements / Continued Deterioration

If the issues identified during this study and previous studies is not rectified, unplanned maintenance events may be required, or planned maintenance frequency may need to be increased. Assets may continue to deteriorate and the likelihood of partial or total failure as listed above may be increased.

3 Design Management

This study, including site surveys were managed and delivered in accordance with the Premtech Quality Environmental Heath Safety Management Systems (QEHSMS).

3.1 Design Review, Progress and Coordination Meetings

During this design study, [redacted] has held monthly design review, progress and coordination meetings to review the developing designs with project stakeholders. Due to COVID-19 restrictions these meetings have been hosted via videoconference (Microsoft Teams) and all appropriate project stakeholders have been invited to attend these meetings. All design meetings have been fully minuted and actioned where appropriate.

A list of meeting dates and meeting minute document numbers is provided in Table 3. The meeting minutes can be found in Appendix B.

Table 3 – Meeting Minutes – Design Coordination Meetings

Meeting No.	Meeting Date	Minutes Document Number
1	20th May 2021	[redacted]585-MOM-7210-0001
2	17th June 2021	[redacted]585-MOM-7210-0002
3	15th July 2021	[redacted]585-MOM-7210-0003
4	12th August 2021	[redacted]585-MOM-7210-0004
5	9th September 2021	[redacted]585-MOM-7210-0005
6	14th October 2021	[redacted]585-MOM-7210-0006
7	25th November 2021	[redacted]585-MOM-7210-0007

During the design review, progress and coordination meetings, drawings, risk registers and other design documentation are shared and reviewed by the meeting attendees, as appropriate.

3.2 Optioneering Study

An optioneering study was also held on 25th August 2021. This included numerous project stakeholders from National Grid including subject matter experts for stress analysis and civil design, Kings Lynn Compressor operational staff, and network operations representatives.

The study outlined the proposed design solutions, identified additional risks to be considered in designs, and confirmed options to be progressed in the engineering justification study.

The meeting minutes can be found in Appendix B.

3.3 Requests for Information, Technical Queries and Deviations

Throughout the project, a number of Technical Queries (TQ's) and Requests for Information (RFI's) have been submitted by Premtech to National Grid relating to design and construction works, these are listed within the project RFI, TQ and Deviation Register [redacted]585-REG-7210-9000 and summarised in Table 4.

Table 4 – RFIs and TQs Submitted

Document No.	TQ, RFI, Deviation	Title	Response Received
[redacted]585-RFI-7210-0001	RFI	Bi-directional Area Valve Foundations	04/06/21
[redacted]585-RFI-7210-0002	RFI	Small Bore Pipework Stress Relieving Works	27/05/21
[redacted]585-RFI-7210-0003	RFI	Drainage Mitigation Works	16/01/22
[redacted]585-RFI-7210-0004	RFI	Feeder No. 2 Isolation Valve As-builts	03/06/21
[redacted]585-RFI-7210-0005	RFI	Bi-directional Area Valve Maintenance / Plant Status Issues	07/07/21
[redacted]585-RFI-7210-0006	RFI	Bi-directional Area Valve Functionality Requirements	11/08/21
[redacted]585-RFI-7210-0007	RFI	Bi-directional Area Operational Data	10/08/21
[redacted]585-TQ-7210-0001	TQ	Fatigue Cycles	01/10/21
[redacted]585-TQ-7210-0002	TQ (DEV)	Valve 721001 Replacement - Pup Lengths and Weld Separations	15/02/22[1]
[redacted]585-TQ-7210-0003	TQ	Buried Flanges	13/02/22[1]

[1] Items transferred to Technical Risk Register [redacted]585-REG-7210-0100 as per TQ responses.

4 Design Requirements

4.1 Legislation

For the works detailed, consideration has and will be given to the following and other relevant legislation where applicable.

- Construction, Design and Management (CDM) Regulations 2015 [2];
- Health and Safety at Work etc Act 1974 (HSWA) [3];
- Pressure Systems Safety Regulations (PSSR) 2000 [4];
- Pipeline Safety Regulations (PSR) 1996 [5];
- Gas Act 1986 (amended 1995) [6];
- Dangerous Substances and Explosive Atmospheres Regulations (DSEAR) 2002 [7].

4.2 Specifications

All relevant National Grid and Institution of Gas Engineers and Managers (IGEM) specifications, standards and codes of practice applicable to this type of system shall apply and, unless otherwise specified, the latest edition of these documents including all addenda and revisions shall apply. This includes but not limited to the following specifications and standards.

- IGEM/TD/1 Edition 5 [8] – Steel Pipelines and Associated Installations for High Pressure Gas Transmission
- IGEM/TD/13 Edition 2 [9] - Pressure Regulating Installations for Transmission and Distribution
- T/PM/HAZ/9 [10] – Management Procedure for the Application of Formal Process Safety Assessments
- T/PM/COMP/20 [11] – Management Procedure for Compressor Installations for the National Transmission System
- T/SP/PW/11 [12] – Pipework Systems Operating at Pressures Exceeding 7 bar
- T/SP/TR/18 [13] – Engineering of Pipelines and Installations Operating at Above 7 barg

A full list of all standards and specifications referenced in this study is included at the end of this report.

4.3 Design Parameters

The design parameters used for the purposes of this study are as stated below:

Table 5 – Design Parameters

Design Data		
Parameter	**Value**	**Remarks**
Design Pressure	79.5 barg	Design Pressure equal SOL
Maximum Operating Pressure (MOP)	75 barg	As stated in the NTS Pipeline Data Book – Jan 2017
Safe Operating Limit (SOL)	79.5 barg	6% above MOP as per T/PM/PS/3 [14] section 8.1
Maximum Design Temperature	50˚C	As stated on Pressure System Diagram M7210x17x1

5 Stress Analysis

[redacted] have completed a number of stress analysis activities for this study.

[redacted] completed a previous limited study in 2018 applying various displacement profiles based on above ground pipework movement. No direct investigations or excavations were completed as part of this previous analysis. Over 30 potential over-stresses were identified.

Informed by the additional information discovered from the site archived drawings (historical records) and the measurements from monitoring point installation (pipe depth measurements) taken from site as part of this study, a new stress analysis has been undertaken with a refined pipework model.

The refined model included the piled beam foundation supporting the original 900NB valves as discussed in 2.3 of this report.

5.1 IGE/TD/12 Ed 2 Assessment

Stage 1 of the stress analysis comprised of the following activities:

- Establish the piping elevations at the current time.
- Predict the piping elevations at the time of construction.
- Predict the deformed profile due to the implied movement.
- Confirm that the stress levels are acceptable in accordance with the sustained and shakedown design stress requirements of IGE/TD/12 [1].

A trend line analysis using construction as-built records and site measurements was carried out to estimate piping elevations. Some significant settlements over short spans were predicted that were thought to be implausible and likely derived from erroneous as-built record from the 2003 works. To confirm the plausibility of these results and ensure that the stress analysis results were not skewed by erroneous data, a limit on settlement was set as the lesser of the prediction of a free span assessment and the trend line analysis. See [redacted] report [redacted]-R0706-21-03 for further details.

The initial stress analysis results showed a single fitting exceeding the IGE/TD/12 [1] sustained criterion for the as-built configuration. The current configuration showed 28 fittings exceeding the abnormal sustained criterion and 12 fittings exceeding the shakedown criterion. Details and locations of these exceptions are provided in [redacted] report [redacted]-R0706-21-03 in Appendix B.

All of the stress exceptions identified by this initial analysis were then further analysed by undertaking in finite element analysis to better understand the level and distribution of stress in the fittings. This work was completed in Stage 2 of the stress analysis as described in section 5.4 of this report.

[redacted]

Figure 16 – Stress Exception Locations

5.2 Removal of Pits

In addition to the stress analysis of the existing configuration of the bi-directional area, National Grid requested that analysis was undertaken to determine the impact of removal of three pits on the Feeder 2 side of the bi-directional area. These three pits are shown in Figure 17.

[redacted]

Figure 17 – Location of Pits

It is noted that Pit 1 as identified on Figure 17, was originally installed by [redacted] in 2003 for stress relieving purposes. The driver for removal of this pit is the failure of the pit wall transition seals. This allowing water / fine material to flow into the pit around the pipes passing through it, therefore creating a potential source of corrosion that cannot be easily inspected.

The IGE/TD/12 [1] analysis found the proposed modification (removal and backfill of all pits) exacerbated code stress exceeding the sustained criterion at three locations and the shakedown criterion at six locations.

Removal of pits 2 and 3 only were shown to not increase the existing stress levels. The removal of Pit 1 was found to have an adverse effect on pre-existing stress levels.

Details and locations of the exceptions identified are provided in [redacted] report [redacted]-R0713-21-1 in Appendix B.

All of the stress exceptions identified by this initial analysis were then further analysed by undertaking in finite element analysis to better understand the level and distribution of stress in the fittings. This work was completed in Stage 2 of the stress analysis as described in section 5.4 of this report.

5.3 Fatigue Analysis

In addition to the studies described in the sections above, a fatigue analysis study was also undertaken by [redacted] to establish whether any of the fittings in the bi-directional area are at risk of failing by fatigue before the proposed design life of 2050.

The steps undertaken to achieve this were as follows:

- Perform a rain flow-counting analysis to determine the number of discrete pressure and temperature cycles between 2015 and 2021, for forward and reverse flow operation.
- Create piping models to consider the significant piping arrangement changes between 1971 and 2003.
- Perform a fatigue assessment of the site to the requirements of IGE/TD/12 [1] taking into account past and future operation to 2050.
- Identify which fittings, if any, would be at risk of failing by fatigue.

The pressure cycling data used for this analysis was agreed with National Grid in a response to Technical Query, [redacted]585-TQ-7210-0001. This included application of factor of 10 safety margin for cycles between 2015 and 2021 (cycles extracted from historical data).

The initial analysis showed a total of 8 fatigue code stress exceptions located at five 900mm x 50mm weldolets and two 900mm x 200mm sweepolets.

All of the exceptions identified by this initial analysis were then further analysed by undertaking a finite element analysis to remove the conservatism from the stress concentration factors. This work was completed in Stage 2 of the stress analysis as described in section 5.4 of this report.

When considering the removal of the three pits, as discussed in section 5.2, the fatigue analysis found that the same exceptions remained, however the maximum fatigue usage was reduced at one sweepolet and increased at a further two sweepolets.

Full details and locations of the fatigue exceptions identified are provided in [redacted] report [redacted]-R0711-21-1 in Appendix B.

5.4 Finite Element Analysis

A more detailed analysis was completed to assess the fittings identified in the initial assessments as having code stress exceptions. These exceptions were grouped into fitting types and the greatest exception of each fitting was taken forward for further analysis.

Three-dimensional finite element (FE) models were created for each of the fitting types and finite element analysis (FEA) was undertaken for each case.

The results of the FEA resolved all stress exceptions identified in Stage 1 on all fittings except one. For the 900NB equal tee in the centre of the bidirectional area (left of valve 721011 as viewed on the existing general arrangement drawings) the FEA did not satisfy the IGE/TD/12 [1] local plastic collapse or shakedown assessment criterion. All fatigue exceptions were resolved.

It is noted that in the absence of specific data for the 900NB equal tee in question, conservative assumptions regarding the fittings material grade and geometry have been made. Therefore, it may be possible to resolve the stress exception still. A tee inspection drawing, [redacted]585-MIS-7210-9500, was developed by [redacted] to inform National Grid of the inspections that can be carried out on the tee to provide this information; however, it is noted that this would require at least partial excavation of the tee.

In summary, the stress analysis with FEA concluded that the pipework has a fatigue life up to the required year, 2050, and resolved all bar one of the identified potential IGE/TD/12 stress exceptions.

Full details and methodology of the FEA carried out is provided in [redacted] report [redacted]-R0724-21 in Appendix B.

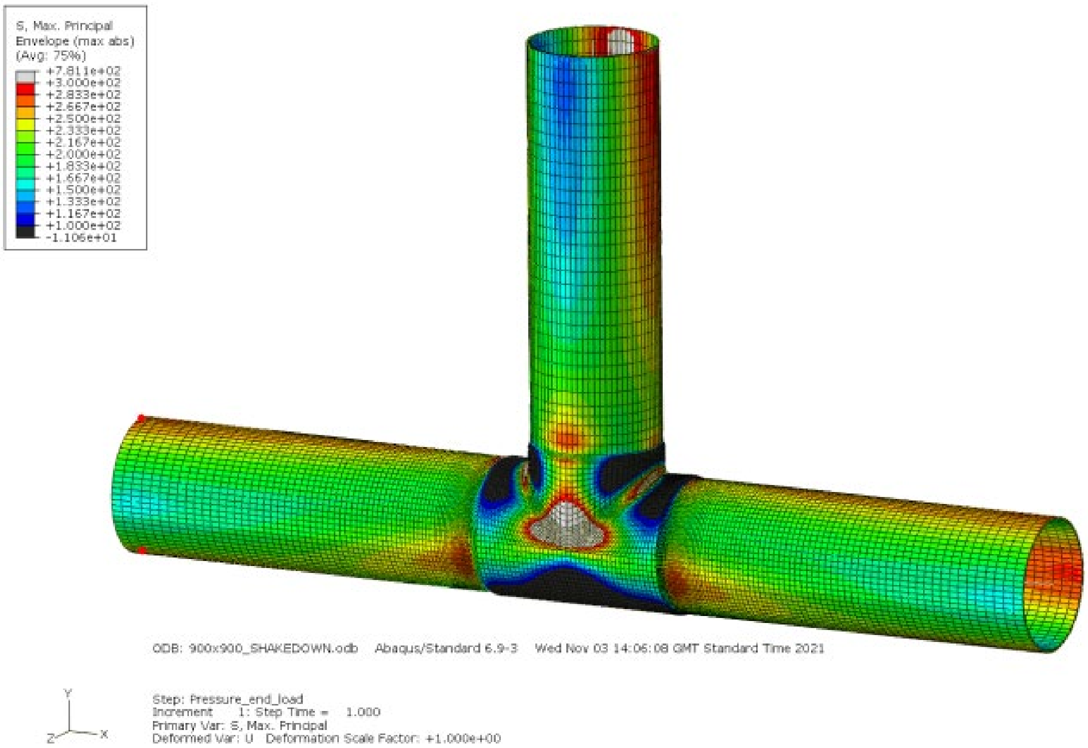

Figure 18 – 900NB Equal Tee Abaqus FE Model

6 Options Considered

6.1 Option 0 – Do Nothing

6.1.1 Mechanical

Option 0 involves no replacement or refurbishment of any of the equipment / assets within the bi-directional area. This is the existing arrangement with no modifications or remediations. Typical ongoing condition monitoring and planned maintenance would continue under this option. There is a greater potential for unplanned maintenance activities with this option.

This option has primarily been included in this report as a benchmark case for the alternative developed options.

In the best case, this option is likely to be a deferral of intervention due to age of the asset.

The stress analysis results described in section 5 of this report shows that the pipework has a fatigue life up to the required 2050, however a potential code overstress still remains on a single 900NB equal tee in the absence of further site investigations.

[redacted]

Figure 19 – Option 0 Isometric

6.1.2 Civil

Following the desktop review of the supporting arrangement of the valves in the bi-directional area, there is compelling evidence to suggest that the valves are supported on piled foundation therefore should not be subject to settlement despite evident surface level settlement. The condition of the concrete foundations however has not been assessed and would not be determined under Option 0.

The three pits identified to have problematic / failed pit wall transitions would not be replaced under this option.

6.1.3 Electrical, Control, & Instrumentation

The existing control system and all electrical and instrumentation assets would remain under this option.

6.1.4 Cathodic Protection

The potential coating defects identified in the cathodic protection surveys as described in section 2.4.4 would not be resolved by this option. This may lead to further deterioration of the coating and potentially ultimately corrosion of the buried pipe in the area.

6.1.5 Key Technical Risks & Opportunities

The primary technical risk of this option is the continued deterioration of aging pipework and equipment. This may limit the bi-directional areas capability to facilitate certain flow configurations or escalate to a more severe failure such as outlined in section 2.7.

The potentially overstressed tee and potential coating failure would not be investigated or resolved under this option.

6.2 Option 1A – In-Situ Minor Remediation

6.2.1 Mechanical

Option 1A replaces 721001 valve and actuator and maintains or refurbishes other 900NB valves in situ. All existing actuators are to be overhauled and actuator cabinets replaced with a suitable less corrosive alternative such as stainless-steel cabinets. The scope of the actuator refurbishment and cabinet replacement is covered in more detail in section 2.4.5.

The valve operating and maintenance check in 2020 (see section 2.1.2) found valve 721001 to have 0% 'seal rate'. A number of other valves (shown in magenta) did not have 100% seal rates (all 80-95%). Maintenance of these valves is recommended with potential utilisation of 'Valve Care' innovation project tools to rectify any corrosion / water in stem tube issues.

It is noted that the existing valve 01 is likely to be welded "fitting to fitting" so there is very limited space between the existing tees to install a new pupped valve. A deviation to T/SP/V/6 [15] and T/SP/P/8 [16] would be required for installation of the new valve as shown on drawing [redacted]585-DET-7210-0220 in Appendix C. A draft deviation has been submitted to National Grid for consider, [redacted]585-TQ-7210-0002 in Appendix B.

6.2.2 Civil

For this option the two small pits on the Feeder 2 side of the bi-directional area are to be removed. The U-shaped pit is to remain under the current high-level review; however, it is recommended that removal of this is considered if this option is progressed to detailed design.

Actuator cabinet bases are replaced as part of this option to renew and relevel following the ground settlement issues.

It is recommended that existing piled supporting arrangement is exposed, and condition assessments are carried out including visual and concrete sampling. Consideration should be given in detailed design for methods of revalidation of existing piles, particular attention should be given to the weight of the new valve.

Backfill shall be fully in accordance with T/SP/CE/2 [17] and shall be adequately compacted prevent settlement of small-bore pipework in the vicinity of the excavation as has been previously observed on site.

[redacted]

Figure 20 – Option 1A Isometric

6.2.3 Electrical, Control, & Instrumentation

The existing control system and all electrical and instrumentation assets would remain under this option.

The new actuator shall be a like for like (or equivalent) to interface with the existing instrumentation and control system.

6.2.4 Cathodic Protection

It is recommended that potential coating defects identified in the cathodic protection surveys as described in section 2.4.4 are identified and resolved during this option. The cathodic protection survey indicated the defects are in the vicinity of valve 01 however this coating remediation may require a more extensive excavation than would be required for the valve replacement alone.

6.2.5 Technical Risks & Opportunities

The valve 01 replacement space constraints as described in section 6.2.1 is a key technical risk with this option. Failed welds or unachievable tie-ins could result in the adjacent 900NB equal tees needing to be replaced resulting in longer outage requirement. It is recommended that specific buildability assessment for this operation is carried out in detailed design if this option is progressed.

This option as currently shown does not replace the tee identified as potentially being overstressed by the stress analysis. It is recommended that an excavation and tee inspection is carried out, as detailed on drawing, [redacted]585-MIS-7210-9500, to provide material grade and dimensional information, such that a more accurate FEA can be carried out on the overstressed tee. If this overstress cannot be resolved by the material grade and dimensional checks, the tee is also considered for replacement in detailed design.

Consideration should be given to ordering new 900NB equal tees as a contingency for the above risks.

Another technical risk is that the 'valve care kit' refurbishment does not adequately resolve the issues causing the valves to pass, this could result in requirement for an excavation to expose top works to be clean. If this still does not resolve the issue, then the valve may need to be replaced. It is recommended that this solution is attempted early in the programme so that additional more intrusive works can be completed if required.

6.3 Option 1B – In-Situ Major Remediation

6.3.1 Mechanical

Option 1B is to replace all the four of the original 1972 vintage 900NB valves in the bi-directional area. All actuator cabinets are to be replaced with a suitable less corrosive alternative such as stainless-steel cabinets. Alternatively, actuators may be replaced with electric actuators or other suitable actuator type that does not require power gas pipework, thus removing all power gas pipework, as shown in red in Figure 21, if these are found to be suitable actuator types by HAZOP study (dependant on ESD functionality).

The scope of the actuator like for like actuator and cabinet replacement is covered in more detail in section 2.4.5

Valves that are not being replaced and did not achieve 100% seal rate in the 2020 valve operating and maintenance check (shown in magenta) are to be maintained and potential utilisation of 'Valve Care' innovation project tools should be considered to rectify any corrosion / water in stem tube issues where possible.

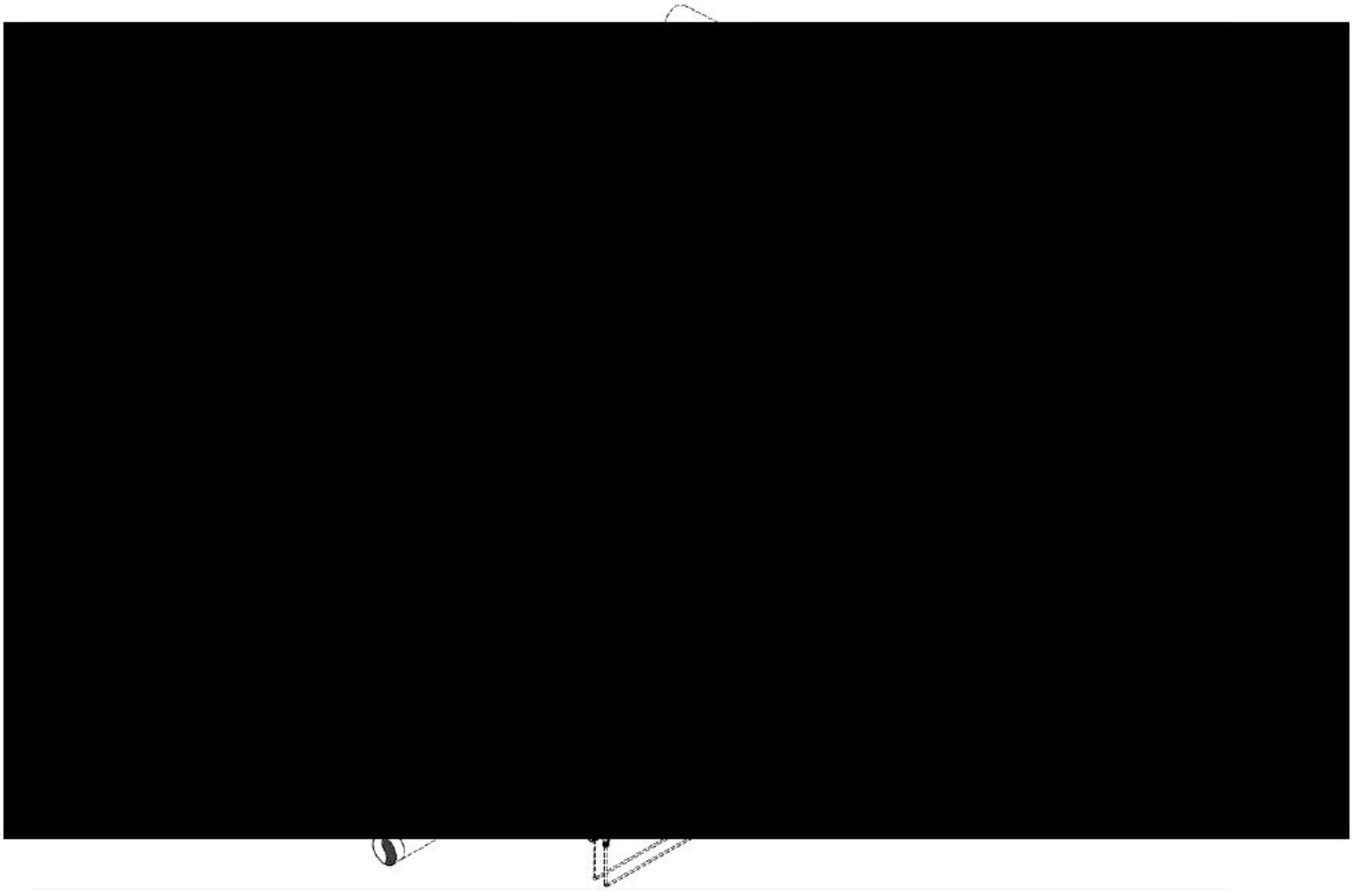

Figure 21 – Option 1B Isometric

6.3.2 Civil

As per option 1A, option 1B removed the two small pits on the Feeder 2 side of the bi-directional area are to be removed. The U-shaped pit is to remain under the current presented option. The stress analysis findings show that removal of the pit would increase current stress levels, however FEA resolved the potential stress exceptions identified with removal of the pit, therefore this should be considered for removal to resolve the potential corrosion issues.

Actuator cabinet bases are replaced as part of this option to renew and relevel following the ground settlement issues.

It is recommended that existing piled supporting arrangement is exposed, and condition assessments are carried out including visual and concrete sampling. Consideration should be given in detailed design for methods of revalidation of existing piles, particular attention should be given to the weight of the new valves.

Backfill shall be fully in accordance with T/SP/CE/2 [17] and shall be adequately compacted prevent settlement of small-bore pipework in the vicinity of the excavation as has been previously observed on site.

6.3.3 Electrical, Control, & Instrumentation

For this option, if electric actuators are chosen for replacement of the existing gas hydraulic type actuators, then significant E, C & I detailed design will be required. ESD functionality and SIL rating of valves must also be considered to assess the suitability of electric actuators.

6.3.4 Cathodic Protection

It is recommended that potential coating defects identified in the cathodic protection surveys as described in section 2.4.4 are identified and resolved during this option.

6.3.5 Technical Risks & Opportunities

Similarly, to option 1a, the valve 01 and valve 11 replacement space constraints as described in section 6.2.1 are a key technical risk with this option. Failed welds or unachievable tie-ins could result in the adjacent 900NB equal tees needing to be replaced resulting in longer outage requirements. It is recommended that specific buildability assessment for this operation is carried out in detailed design if this option is progressed.

This option as currently shown does not currently replace the tee identified as potentially being overstressed by the stress analysis. It is recommended that an excavation and tee inspection is carried out, as detailed on drawing, [redacted]585-MIS-7210-9500, to provide material grade and dimensional information, such that a more accurate FEA can be carried out on the overstressed tee. If this overstress cannot be resolved by the material grade and dimensional checks, the tee is also considered for replacement in detailed design.

Consideration should be given to ordering new 900NB equal tees as a contingency for the above risks.

Another technical risk is that the ‘valve care kit’ refurbishment does not adequately resolve the issues causing the valves to pass, this could result in requirement for an excavation to expose top works to be clean. If this still does not resolve the issue, then the valve may need to be replaced. It is recommended that this solution is attempted early in the programme so that additional more intrusive works can be completed if required. This risk is reduced from option 1a due to the valves being replaced.

6.4 Option 2A – Specification Compliant Re-build In-Situ

6.4.1 Mechanical

Option 2A replaces all the pipework in the bi-directional area. The arrangement is a like for like replacement with no betterment of design, however where existing valve pup length and circumferential weld separations are not compliant with the latest National Grid and industry specifications e.g., T/SP/V/6 [15] and T/SP/P/8 [16] the streams have been spaced out through the addition of bends to allow compliance.

All actuators are to be replaced with like for like new actuators and cabinets. Actuator cabinets are to be replaced with a suitable less corrosive alternative such as stainless-steel cabinets.

[redacted]

Figure 22 – Option 2A Isometric

6.4.2 Civil

Significant challenging civil foundation design would be required for this option. As shown in Figure 23 due to the change in footprint, the existing piled foundations will no longer line up with the new pipework. It is likely that new piled foundations would be required.

Achieving adequate separation to existing piles to avoid adverse interactions would be a key challenge with this design.

Extensive civil works are required for this option to excavate the area, remove existing pipework and foundations, and install new buried pipework supports and above ground cabinet bases following back fill and consolidation.

[redacted]

Figure 23 – Option 2A General Arrangement

6.4.3 Electrical, Control, & Instrumentation

The existing site control system and operating philosophy would be retained for this option.

The new actuators shall be a like for like (or equivalent) to interface with the existing instrumentation and control system.

Electric actuators could be considered for this option as per option 1B subject to E, C & I detailed design to establish ESD functionality and SIL rating of valves to assess the suitability of electric actuators.

6.4.4 Cathodic Protection

The IJs on the feeder 2 side of the bi-directional area are to be replaced with new due to the need to move the existing ones from their current location to make room for the compliant pipework arrangement.

The potential coating defects identified in the cathodic protection surveys as described in section 2.4.4 are resolved by this option due to replacement of all the pipework with new adequately coated and protected pipework.

A detailed CP design would be required for this option due the amount of pipework being replaced. It is noted that the length of pipe being installed is slightly greater than the pipework being removed.

6.4.5 Technical Risks & Opportunities

The primary technical risk for this option is the length of the outage required for its construction. During the FPSAs options 2a and 2b were deemed not credible due to the outage requirements being longer than maximum possible outage.

Additionally, the foundation design as described in section 6.4.2 is a key challenge.

There are opportunities for betterment of design with this option, for example upsizing of the balancing regulators and provision of cross connections between feeder 2 and feeders 4 & 27.

6.5 Option 2B –Re-build In-Situ

6.5.1 Mechanical

Option 2B also replaces all the pipework in the bi-directional area. Similarly, to Option 2a, the arrangement is a like for like replacement with no betterment of design, however unlike option 2a, where existing valve pup length and circumferential weld separations are not compliant with the latest National Grid and industry specifications e.g., T/SP/V/6 [15] and T/SP/P/8 [16] these will remain non-compliant. Deviations will therefore be required.

All actuators are to be replaced with like for like new actuators and cabinets. Actuator cabinets are to be replaced with a suitable less corrosive alternative such as stainless-steel cabinets.

[redacted]

Figure 24 – Option 2B Isometric

6.5.2 Civil

Unlike option 2a, option 2b keeps the footprint of the arrangement the same in order to utilise the existing piled foundations. However civil detailed design will need to assess the existing foundations for suitability for reuse with the new arrangement. It is expected that there will be extensive civil works are required for this option to excavate the area, remove all existing pipework and some foundations, and install new buried pipework supports and above ground cabinet bases following back fill and consolidation.

6.5.3 Electrical, Control, & Instrumentation

As with option 2a, the existing site control system and operating philosophy would be retained for this option.

The new actuators shall be a like for like (or equivalent) to interface with the existing instrumentation and control system.

Electric actuators could be considered for this option as per option 1B subject to E, C & I detailed design to establish ESD functionality and SIL rating of valves to assess the suitability of electric actuators.

6.5.4 Cathodic Protection

The potential coating defects identified in the cathodic protection surveys as described in section 2.4.4 are resolved during this option due to replacement of all the pipework with new adequately coated pipework. Feeder 2 IJs are not replaced by this option.

6.5.5 Technical Risks & Opportunities

The same as option 2a, the primary technical risk for this option is the length of the outage required for its construction. During the FPSAs options 2a and 2b were deemed not credible from a buildability perspective due to the outage requirements to facilitate construction (more than 12 months) being longer than maximum possible station outage (circa 6 months).

There are opportunities for betterment of design with this option, however these are limited by the space constraints.

6.6 Option 3 – Re-build In New Location

6.6.1 Mechanical

Option 3 proposes to rebuild the entire bi-directional arrangement on another area of the site with interconnecting pipework to Feeders 2, 4, 27.

The new design provides enhanced functionality compared to the existing bi-directional arrangement with additional benefits and betterment features including:

- Upsized pipework where required to reduce gas velocity / increase flow capacity.
- Upsized balancing regulator streams to reduce time required for equalisation.
- Double block and bleed isolation separation of compressor from pipeline bi-directional area.
- Cross connection of all feeders without flowing through the compressor station.

It is proposed to construct the arrangement shown in four phases to minimise the required Feeder and Station outages. Due to the new bi-directional area being in a separate location it will be possible to construct and test the arrangement without need for an outage. The outage will be required for tie-in connections only.

The current high-level design of option 3 assumes actuator types are to be a combination of remote electric, electro hydraulic, and high-performance manual gearboxes. However, actuator functionality and types for each valve are to be established during detailed design to determine requirements such as ESD and remote functionality. Best Available Techniques (BAT) Assessments and FPSA’s shall be utilised to confirm actuation functionality and types.

[redacted]

Figure 25 – Option 3 Isometric

6.6.2 Civil

Significant civil works would be required for this option including but not limited to the following:

- A number of large above ground and below ground 900NB / 1200NB piled valve supports.
- A 6m x 4m Pipeline Instrumentation Kiosk concrete base foundation (ground bearing slab).
- A new road construction adjacent to the Pipeline Instrumentation Kiosk and the complete removal and disposal of the road and its foundations between the relocated bi-directional area and the pigging loop. All new roads and access ways located within the site boundary shall be designed and constructed from concrete in accordance with National Grid specifications.
- Any proposed drainage or drainage modifications shall be designed and constructed in accordance with National Grid specifications incorporating pollution control devices if required.
- Below ground cable ducting and surface troughs, including access chambers.
- Sand boxes surrounding pipe risers as required in accordance with National Grid specification.
- Instrumentation transmitter stands including concrete bases.
- Lighting columns and foundations.
- All new paths located within the site boundary shall be designed and constructed from concrete with a suitable finish.

6.6.3 Electrical, Control, & Instrumentation

The relocation of the bi-directional pipework would require modifications to the existing station control and protection system to incorporate new valves and instrumentation, and also the separation of the pipeline multi-junction into a separate control system.

As part of the relocation of the bi-directional pipework, the pipeline multi-junction pipework part of the site would be segregated from the station control system and have its own telemetry system communicating with GNCC. Retransmission of all or some of the multi-junction valves and instrumentation to the station control system would be required to enable the same functionality as present to be achieved.

A new instrumentation telemetry kiosk is proposed for the separated multi-junction control system (new 6m x 4m kiosk). The kiosk would be fitted out with electrical distribution and lighting equipment as required.

The detailed designer would be required to produce non-compliance statements of existing control system early within detailed design.

6.6.4 Cathodic Protection

A new CP design would be required for this option due to the large amount of new pipework being installed. This would include all necessary cathodic protection surveys, before, during, and after the works.

6.6.5 Technical Risks & Opportunities

As with option 2, one of the key technical risks identified for this option is outage length. This can be mitigated somewhat by development of a phased construction approach, however there is a signification amount of interconnecting pipework to be installed under a station outage.

Another key technical risk for this option is the control system interface. Since this solution is not a like for like replacement control system modifications will be required. It is noted that cause and effect charts do not appear to be available for the existing station control system, therefore these will need to back engineering from the system on site.

This option does provide plenty of opportunity for betterment in addition to the features already identified. Due to the space available and flexibility of the design, it is possible to account for future flow scenarios, required configurations, and control options within the design.

6.7 Actuation Types

Where options have the potential to include either gas hydraulic of electric actuator types, Best Available Techniques (BAT) Assessments and FPSAs shall be completed in detailed to confirm actuation functionality and types.

As a general guide, some typical advantages and disadvantages of gas and electric actuators have been provided in Table 6 below. Additional actuator types such as electro-hydraulic may also be considered.

Table 6 – Typical Gas vs Electric Actuator Advantages & Disadvantages

Gas hydraulic actuator	Electric actuator
Advantages	
• Gas-powered actuators require no external power supply. Motive power is provided by the pipeline product and is always available for use. • Pipeline pressure can support the use of large actuators in any environment, allowing isolation or fail-safe action through stored hydraulic pressure. • Resistant to shocks making the system less likely to fail, hence require less maintenance. • In corrosive atmospheres, hydraulic fluids offer a higher degree of corrosion protection in the actuator cylinder than air or gas. • No additional electrical power supply is required.	• Electric power is relatively inexpensive, easy to manage and normally available to most industrial sites. The capital cost of electric actuators is typically cheaper than equivalent unit of torque/thrust output. They're also cleaner and safer to operate. • Electric actuators can provide superior positioning accuracy for control or modulating valve functions. • All necessary control functions are integral to electric actuators, reducing capital cost. • Electric actuators significantly reduce control wiring costs by enabling distributed control. They simplify control logic by integrating control commands and feedback into customer SCADA or DCS systems. • As torque and thrust requirements increase, electric actuators weigh less and have smaller footprints compared to pneumatic actuators. • Electric actuators may be combined with external gearboxes to produce extremely high output thrust and torque values. • Facilitates removal of subsided gas pipework which supplies the current gas actuators.
Disadvantages	
• The primary drawback of gas-powered actuators is tied to their main advantage. Using the pipeline product results in a relative waste of the product. • More importantly, every stroke of the valve exhausts pipeline gas into the atmosphere with negative environmental effects. In these cases, an efficient torque mechanism and a smaller cylinder volume per unit of torque are important to reduce the amount of exhaust gas. • High pressure hydraulic fluid is complex to manage, which creates safety and environmental risks. Highly skilled personnel are required to operate high pressure hydraulic systems.	• With the exception of a few specific configurations, electric actuators can't guarantee a fail-safe stroke but will fail in the last position. • Electric actuators have more complex and sensitive components than the mechanical parts used in other types of actuators. Electronic technology also requires periodic refreshing to keep pace with component changes and improvements. • Beyond a certain size/torque range, electric actuators are less cost-effective and generally have limitations in operating speed when compared to pneumatic and hydraulic actuators. • In hazardous areas with potential exposure to explosive process media,

	electric actuators require more specific certifications and construction features to be considered safe for use. • Electrical power supply and cabling installation required to power actuators. • Loss of site power supply results in a loss of motive power to operate the valve

6.8 Options Not Developed

A number of options have not been developed as part of this report. These include:

- A uni-directional arrangement removing the bidirectional functionality from Kings Lynn. It has been confirmed by the HAZOP study that the bi-directional functionality is still required to fulfil IUK and BBL requirements.
- A new greenfield site outside the compressor station. This option was previously briefly considered in the 2017 conceptual design, however, this may require further investigation if a re-build option is progressed.
- Betterment in situ. This was not within the scope of this study as is not directly related to the settlement issue that the study set out to address; however, it is possible to consider betterment of design in some of the in-situ options (primarily option 2a) where space allows. It is deemed likely however that the option 2 solutions are no longer feasible due to outage requirements as stated in sections 6.4.5 and 6.5.5.
- Decommissioning. It has been advised by National Grid Network Strategy that Kings Lynn Compressor Station and the bi-directional flow capabilities are still required for all Future Energy Scenarios (FES). For the purposes of this study, decommissioning would result in the selection of Option 0.
- Underpinning. Since the investigations carried out by this study have found the existing 900NB pipework in the bi-directional area to be supported on piled foundations underpinning has not been considered any further.

7 Options Cost Estimates

7.1 Methodology

Cost estimates for each of the options have been developed by National Grid based on the high-level designs and material take offs (MTOs) developed.

Risk workshops were held on 18[h] November 2021 and 2[nd] December 2021, chaired by [redacted], Estimator at National Grid. During these meeting key risks were identified to inform and refine risk allowances in the cost estimates for each of the design options.

A risk register was also developed and circulated around key National Grid subject matter experts and other project stakeholder for input.

[redacted] provided high level design costs to inform the design allowance for each of the options.

The Option 3 conceptual design was subject to a pricing exercise from a Tier 1 Main Works Contractor in 2017. This was available to cross check with the Options 3 costs estimate developed.

7.2 Summary

The following costs are in 2021 / 2022 base price and are in the preliminary stage of the cost maturation process, included in this report for completeness.

Table 7 – Options Cost Summary Table

Option	Total Cost
1A - Minor In-situ Remediation	£ [redacted]
1B - Major In-situ Remediation	£ [redacted]
2A - Re-build In-situ (Specification Compliant)	£ [redacted]
2B - Re-build In-situ (Non-Specification Compliant)	£ [redacted]
3 - Re-build in New Location	£ [redacted]

8 Flow & Future Requirements

8.1 Gas Velocity Limits

Some high-level gas velocity calculations have been carried out as shown in Table 8 below.

A gas velocity limit of 20m/s (IGEM/TD/13 [9] limit for unfiltered gas) has been selected and maximum flows in million standard cubic meters per day (mscmd) have been calculated. It should be noted that these are based on numerous assumptions and should be used for an indication only.

900NB and 1200NB pipe sizes have been considered as these represent the pipe sized used in all options discussed in this report (all 900NB except Option 3 which is a combination of 900NB and 1200NB).

Table 8 – Maximum Flow Capacities at 20m/s Velocity Limit

	Minimum Pressure	
	50 Barg (inlet)	**60 Barg (outlet)**
900NB	56.37 mscmd	65.88 mscmd
1200NB	102.62 mscmd	116.13 mscmd

Assumptions:

1. Gas composition is as per Mean Bacton Gas.
2. Pipe wall thickness is 19.1mm with 1.5mm over thickness tolerance.
3. Fluid temperature 30ºC for 60 Barg, 15ºC for 50 Barg.

8.2 Current Flow Configurations

Kings Lynn Compressor Station currently has five different configurations available to GNCC (remotely). Each configuration requires the compressor to be 'facing' either towards or away from Bacton. The two main configurations 'to Bacton' and 'from Bacton' are shown in Figure 26 and Figure 27.

The bi-directional area valves are controlled from the compressor station control room to achieve the forward and reverse flow as well as the initiated, de-initiated, equalising, and ESD states. GNCC to not currently have sight or control of the valve positions within the bi-directional area.

All options discussed in this report maintain all the current flow configurations. This was confirmed during the HAZOP on the 8th December 2021. See Combined FPSA report, C410 REP 002 included in Appendix B for details.

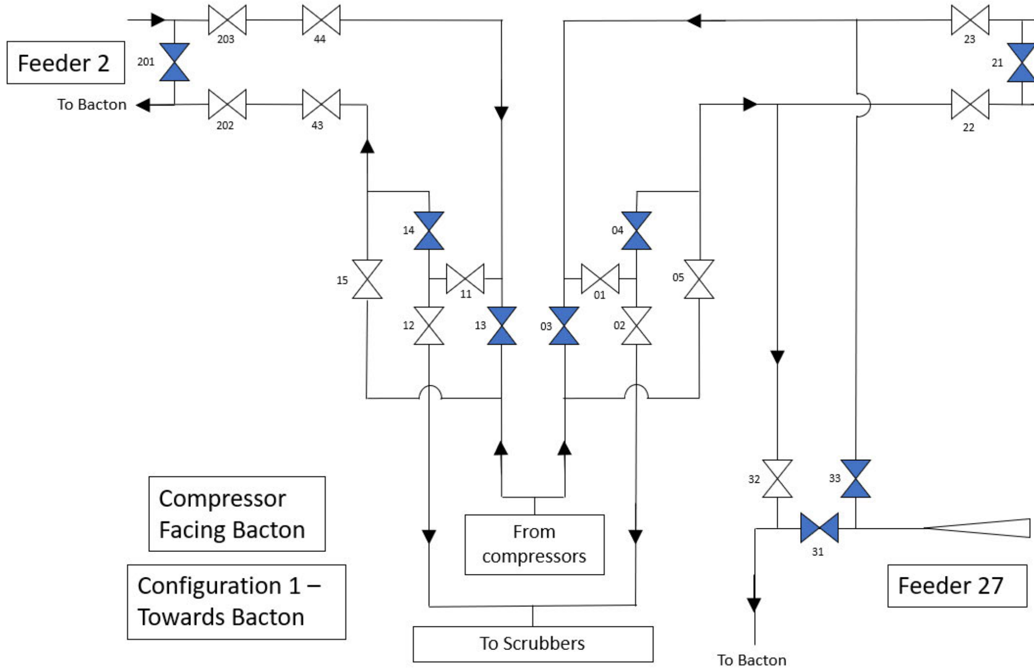

Figure 26 – Flow Configuration Towards Bacton

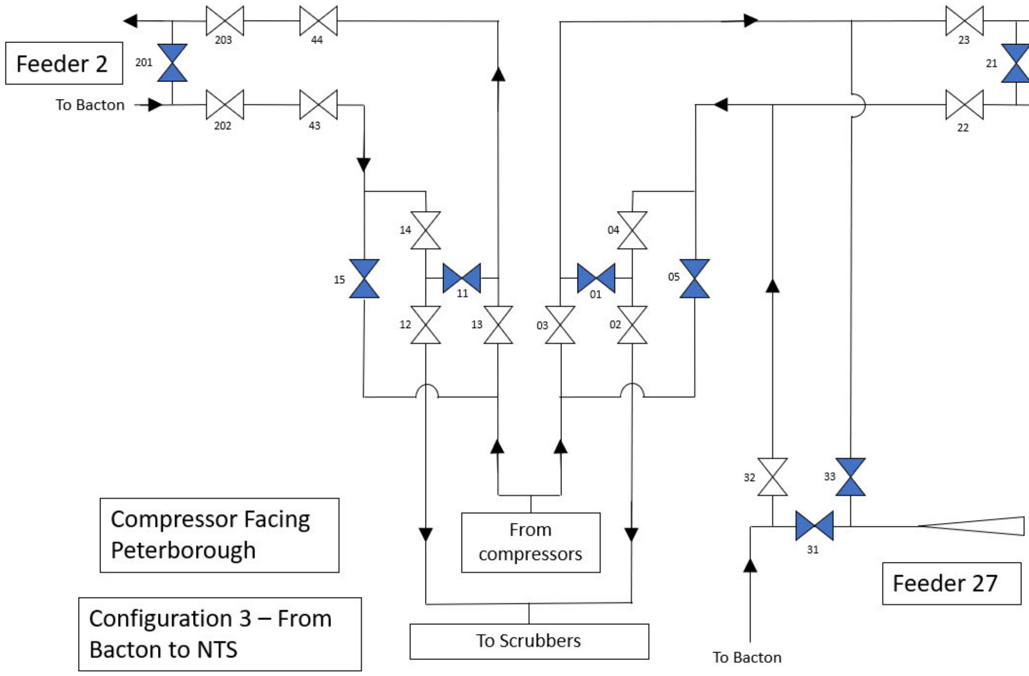

Figure 27 – Flow Configuration from Bacton

8.3 Potential Future Configurations

A number of constraints with the current design in terms of flow configurations were noted in the HAZOP study. These included:

- Long time to balance pressure across equalising bridles, and therefore long time required to change flow direction. This is due to the sizing of the equalising bridle pipework and regulators.
- Inability to cross connect feeders independently of the compressor.
- Inability to isolation bi-directional area without utilising valves within the area.
- Inability to separate feeders 4 and 27.

Option 3 as described in this report resolves all of these issues.

Additionally, some potential future requirements were highlighted during the HAZOP. Including a potential future requirement for the IUK and BBL interconnectors to be operating in different directions, therefore some potential additional configurations may be required.

It is noted that option 3 has the ability to cover the majority of the potential additional configurations theorised by National Grid Senior Network Control Engineer, [redacted]

Details of all potential future configurations shall be considered in detailed design for whichever option is progressed.

9 Control System Considerations

It was confirmed by [redacted] (16th August 2021) that the [redacted] is currently due to be upgraded (on site delivery) in the [redacted] price control period (starting 2026/27). This is likely to be too late for alignment with any bi-directional area upgrade works. Therefore, the options which require modifications to the [redacted] are assumed to require funding through the bi-directional area project budget.

The options that would require modifications to the control system are:

- Option 1B – In-situ Remediation – Major Remediation (with electric actuators)
- Option 3 – Re-build In New Location

Options 2A and 2B may also require [redacted] modification if actuators are not like for like equivalents.

10 Environmental Considerations

10.1 Desktop Environmental surveys

National Grid have completed a Formal Environmental Assessment (FEA) site sensitivity assessment and desktop survey in accordance with T/PM/ENV/20 [18] for the proposed works. A summary of the site sensitivity assessment is produced in Table 9. The full assessment and desktop survey (dated 20/08/2021) is included in included in Appendix B.

Table 9 - Site Sensitivity Assessment Summary

Site Sensitivity Summary	Topic	Sensitivity
	Receptors and complaints	Medium
	Flood Water and Land	Medium
	Air and Noise	Low
	Mining and subsidence	Low
	Planning and permitting	Low

10.1.1 Key points

- Kings Lynn is close (<2km) to two SSSI sites.
- Great Crested Newts are known to be present in the surrounding areas. Surveys completed in the ditch along the site access road were negative on eDNA samples, however adjacent ponds to proposed site establishment areas would also require testing prior to site set up.
- The south east and south west corners of the site are high flood risk areas; however, the bi-directional area, proposed option 3 new area, and proposed site establishments are not within a flood risk area.
- Asbestos is known to be present elsewhere on site. Any contaminated land found during excavations should be separated and tested.

10.2 Further Environmental Assessments

Further environmental assessments, as determined during detailed design, are to be carried out prior to any intrusive works taking place on site.

10.3 Sustainability

Design and construction shall be in accordance with National Grid's environmental management system as per T/PL/ENV/1 and shall be cognisant of National Grid's sustainability and net zero commitments as laid out in the recently published T/SP/ENV/30 [19] – *Specification for Sustainability and Net Zero for Gas Transmission Projects.*

It is noted that National Grid have committed that '*emissions associated with construction will be Net Zero carbon by 2025/26*'.

10.4 Carbon Interface Tool

A high-level carbon assessment of each option was completed using National Grid's Carbon Interface Tool (CIT v5 – November 2021). It is noted that a number of required carbon equivalent values were missing from the database at time of use, therefore actual carbon cost values may appear light, however it serves as an indicative comparison of the likely carbon equivalent impacts of each option.

The results are shown in Figure 28 below. It is recommended that a more thorough assessment is completed for the progressed option in detailed design.

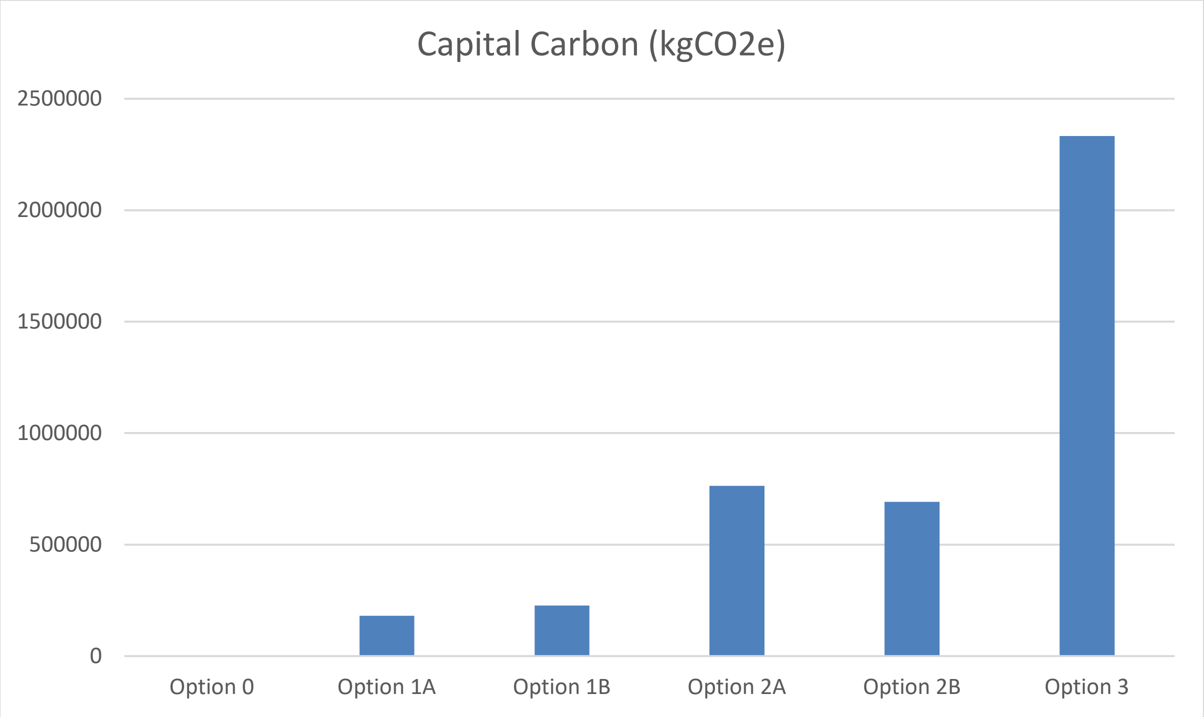

Figure 28 – High Level Carbon Cost Comparison of Each Option

11 Options Summary

Option title	*Project start date (see note 3)*	*Project commissioning date (estimate)*	*Project design life*	*Operating cost*	*Total installed cost*
Do Nothing	*N/A*	*N/A*	*See Note 1.*	*No Change*	*N/A*
Minor In-Situ Remediation	*October 2022*	*September 2023*	*See Note 1.*	*No Change*	£[redacted]
Major In-Situ Remediation	*October 2022*	*September 2023*	*See Note 1.*	*No Change*	£[redacted]
Re build In Situ (Specification Compliant)	*October 2022*	*See Note 4.*	*40 year*	*No Change*	£[redacted]
Re build In Situ (Non-Specification Compliant)	*See Note 4.*	*See Note 4.*	*40 year*	*No Change*	£[redacted]
Re build In New Location	*October 2022*	*October 2025*	*40 year*	*See Note 2.*	£[redacted]

1. Fatigue life up to 2050 as per [redacted] report (see section 5.3). Plant status issues, corrosion and general maintenance issues would be required to be continually addressed.
2. Subject to detailed design including BAT assessments.
3. F2 sanction date as per National Grid '*Plan on a Page*' document.
4. Option found not credible during FPSAs due to outage requirements being longer than possible.

12 Innovation Considerations

12.1 Valve Care Toolbox

Valve Care Toolbox was a Network Innovation Allowance funded project by National Grid which set out to respond to valve asset health issue that typically arise from ingress of water into valve stem assemblies.

The toolbox provides tools to remedy these issues without the need for valve replacements or intrusive works including: a method of detecting water in stem extensions, a pump to drain off water found, inspection tools to inspect down to the base of the valve, and equipment to clean the inside of the buried stem extension and protect it from future damage.

It is recommended that this solution is considered for Options 1A and 1B where valve remediation is required. However, it is noted that this should not be a solution for any locations where long-term corrosion has taken place. In such scenarios, intrusive works are likely to be required.

12.2 Geopolymer Injection

Geopolymer injection for ground stabilisation was another Network Innovation Allowance funded project that considered the use of geopolymer injection to stabilised and in some cases relevel subsided pipework.

The innovation project trialled the technology on some abandoned pipework at Kings Lynn Compressor Station and successfully relevelled a length of redundant buried pipework.

Figure 29 shows the geopolymer injection taking place and Figure 30 shows the results of the relevelling.

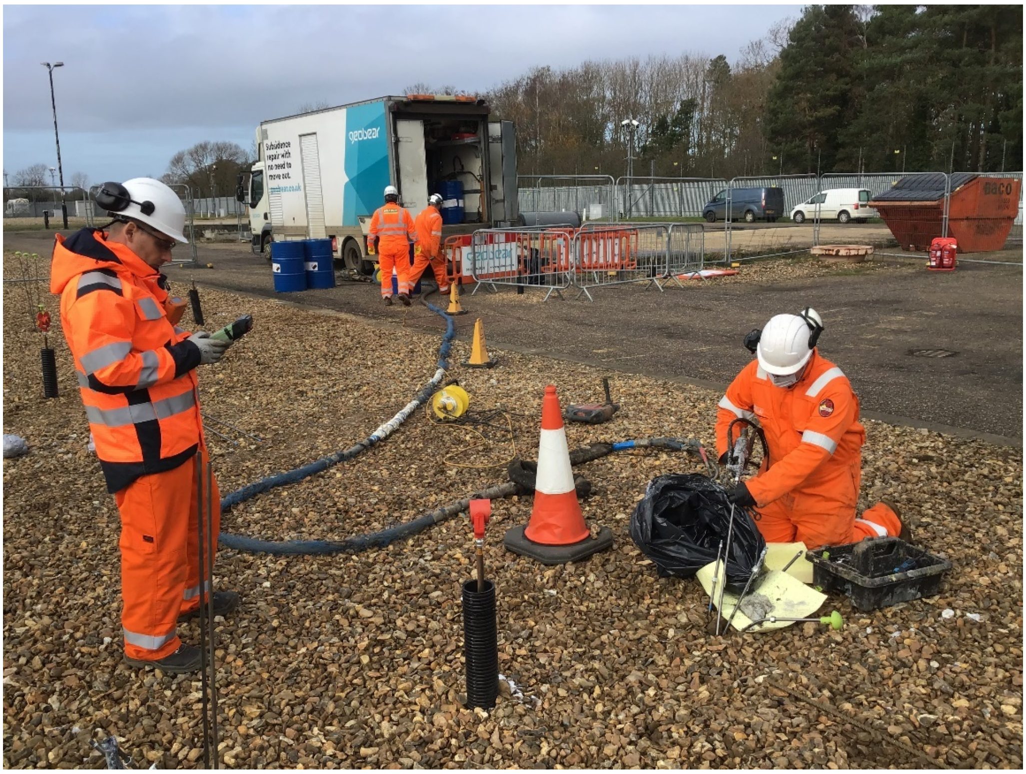

Figure 29 – Trial Geopolymer Injection

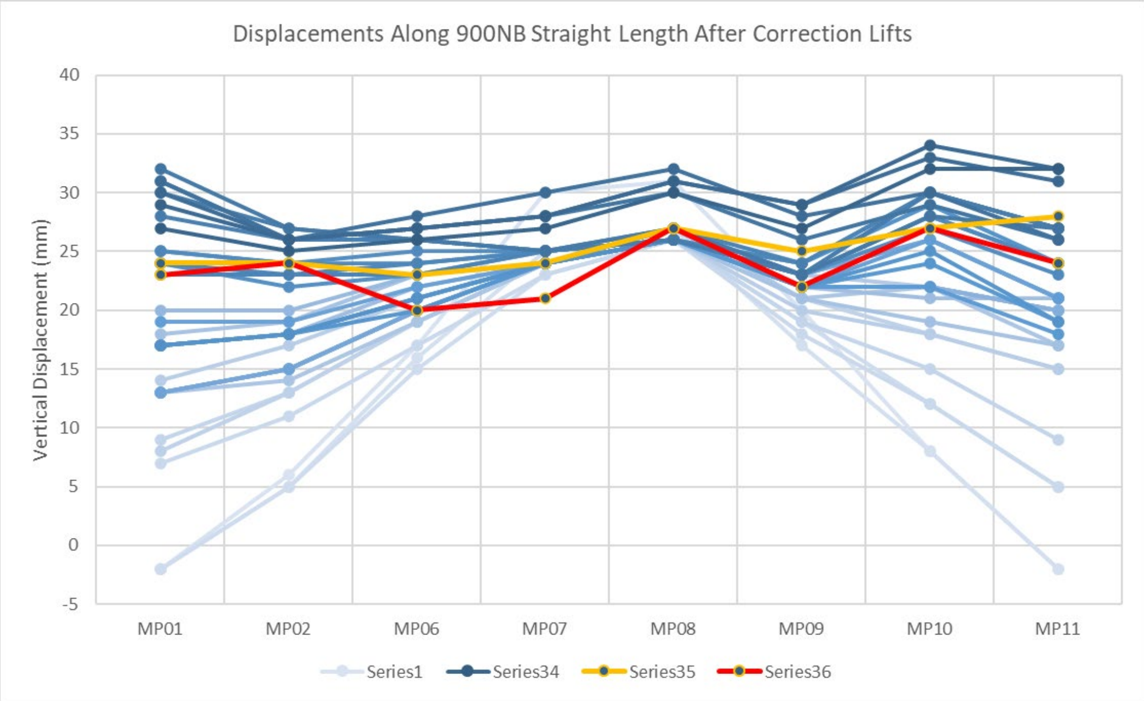

Figure 30 – Trial Area Monitoring Points Displacement Over Time

In Figure 30, the lightest blue line shows the deformed profile of the pipe to be relevelled and each darker shade line represents the profile at various intervals as the geopolymer is being injected (pipe is being levelled). The yellow line represents the survey completed two months after the final injection took place and the red line is 8 months.

The geopolymer material can also be injected in columns to create piles for foundations, however this has not been tested on gas pipework.

The technology was initially being considered at the start of this project to resolve any subsidence issues found on the large diameter in the bi-directional area, however as the project has progressed it has become less of a relevant concern.

The technology could however be considered for stabilisation of small bore pipework or levelling of surface level bases for options 1A or 1B or as an alternative to traditional piling methods for option 2a.

13 Design Reviews

13.1 Optioneering Study

An Optioneering Meeting was held on 25th August 2021 with key National Grid stakeholders and subject matter experts. The purpose of the meeting was to present the initial options that had been developed for consideration in this FEED Engineering Justification study and determine which options were to be progress for inclusion within the cost benefit analysis, FPSAs, and final report.

A number of key points were raised for consideration as the options were progressed, however ultimately the optioneering study concluded that all the initial developed options shall be further developed.

Full minutes and presentation from the Optioneering Study can be found in Appendix B.

13.2 Formal Process Safety Assessments

A combined Formal Process Safety Assessment (FPSA) including HAZID, HAZOP, layout review, safe working design study, and hazardous area review was completed 8th and 9th December 2021. The study team, chaired by independent FPSA chairperson and Process Safety Consultant [redacted], included numerous National Grid subject matter experts and other stakeholders. The full study team is detailed in the Combined FPSA report, C410 REP 002 included in Appendix B.

The study set out to identify the shortcomings and potential hazards associated with the current arrangement and examine inherent safety of each of the proposed solutions. Numerous actions were identified and assigned.

The HAZOP was carried out with significant input from National Grid Senior Network Control Engineer, [redacted]. Utilising typical flow configurations of the bi-directional area as study nodes, the HAZOP ranked all options on their ability to resolve or mitigate potential process safety issues based on targeted HAZOP guidewords extracted from T/SP/HAZ/7 [20].

The HAZID study identified significant hazards that are affected or impacted by the bi-directional area. The full list of HAZID1 guidewords were considered. Typical gas site hazards ("business as usual" hazards) were deferred for consideration during detailed design. A number of actions were assigned to ensure that this study adequately identifies issues that require further consideration during detailed design.

The T/SP/G/37 [21] layout study, safe working design study, and hazardous area review reviewed the pre-prepared G/37 layout and hazardous area drawings to assess the suitability of each the options as well as the existing arrangement in terms of equipment location and layout.

The FPSA study as a whole generally concluded that superficially, Option 3, appears to offer more process safety benefits than the other options. Full details and record of all actions can be found in the Combined FPSA report, C410 REP 002 included in Appendix B.

The study was also cognisant of the 'buildability' of the various options and concluded that options 2A and 2B were not credible due to the length of the station outage required to facilitate their construction.

14 Conclusions & Recommendations

14.1 Option Progression

The high-level options outlined in the report have been subject to rigorous review and the pros, cons and key risks of each have been outlined in this report.

It was intended that the findings of this report and it's appended documents were to be subject to National Grid's cost benefit analysis process, however National Grid curtailed expenditure and did not undertake further CBA analysis once it was apparent that the needs case driver was no longer viable.

The evidence gathered in this study allows National Grid to consider future requirements of the site without the need for immediate remediation action to be taken due to subsidence risks. National Grid still need to address the asset health issues and longer-term capability requirements including flows and capacity. Therefore, the options should be fully scoped out and explored in detail where appropriate.

14.2 Key Risks & Opportunities

Key risks and opportunities have been outlined under each option in Section 6 of this report. Addition technical risks identified throughout the project can be found in the Technical Risk Register in Appendix B.

Details of process safety related risks can be found in the combined FPSA report, C410 REP 002 included in Appendix B.

14.3 Proposed Ongoing Monitoring & Interim Solutions

It is recommended that National Grid develop an ongoing monitoring regime for the Kings Lynn bi-directional area until such a time that chosen design solution can be implemented.

This ongoing monitoring may include:

- Regular visual inspection of the above ground pipework.
- Regular surveying of the monitoring points installed on the buried pipework.
- Regular CP surveys.
- Regular operating and maintenance include valve seal checks.

Additionally, as noted in section 2.4.2 and [redacted] report [redacted]-R0706 Rev 03 recommendations, installation of monitoring points for Feeder No. 4 pigging loop valves is recommended to enable continued monitoring of the area as the as-built drawings show no evidence of piled foundations in this area.

It is recommended that ongoing monitoring is continued at all installed monitoring points for a suitable period to allow sufficient data to be recorded to confirm no ongoing settlement e.g. two winter and two summer measurements.

15 Health and Safety

15.1 General

Health and safety issues will be addressed throughout the design and construction of the project. The modifications will be constructed in accordance with current health and safety legislations, including the Health and Safety at Work Act, the Construction (Design and Management) Regulations 2015 (CDM) and the management of Health and Safety at Work Regulations. The project shall also be executed in accordance with National Grid policies and procedures.

15.2 Hazardous Areas

Hazardous area drawings for each option have been developed and are included in Appendix B of this report.

These were reviewed during the hazardous area review conducted as part of the combined FPSA held 8th and 9th December 2021.

[redacted]

Figure 31 – Option 2A Hazardous Area Drawing

15.3 CDM Risk Register

A CDM Risk Register has been maintained and updated throughout the course of this project. This can be found in Appendix B of this report.

15.4 Design Approval / Appraisal

All design work in detailed design shall go through design approval and appraisal in accordance with National Grid specification T/PM/G/35 [22].

Any changes to the design specification during the study shall be reviewed by the project team to assess the implications and identify the impact. These changes shall be recorded during the design progress meetings and design change register.

16 Records and Documentation

All recorded information, documentation, certification of materials and components, and any other appropriate information that can be used as a permanent record to prove the new facilities are fit for purpose, shall be kept, as required, by National Grid.

All records kept shall be in accordance with National Grid specifications. These records shall typically include:

- As-built drawings
- Welding and fabrication records
- Full material certification
- Data sheets
- Inspection records
- Weld acceptance certificates
- Weld procedures
- Letters of conformity
- Design calculations
- Test pressure records

17 References

[1] IGE/TD/12 Edition 2 Reprint with Amds, *Pipework Stress Analysis for Gas and Industrial Plant,* IGEM, 2012.

[2] *CDM Regulations 2015, Managing Health and Safety in Construction - Construction (Design and Management) Regulations 2015,* Health and Safety Executive, 2015.

[3] HSWA, *Health and Safety at Work Act 1974,* 1974: legislation.gov.uk.

[4] PSSR 2000, *The Pressure System Safety Regulations 2000,* legislation.gov.uk, 2000.

[5] PSR, *Pipeline Safety Regulations (PSR) 1996,* legislation.gov.uk, 1996.

[6] Gas Act, UK Public General Acts, 1986.

[7] DSEAR 2002, *Dangerous Substances and Explosive Atmospheres Regulations (DSEAR) 2002,* Legislation.gov.uk, 2002.

[8] IGEM/TD/1 Edition 5, *Steel Pipelines and Associated Installations for High Pressure Gas Transmission,* IGEM, 2008.

[9] IGEM/TD/13 Edition 2, *Pressure Regulating Installations for Transmission and Distribution,* IGEM, 2011.

[10] T/PM/HAZ/9, *Management Procedure for The Application of Formal Process Safety Assessments During Engineering Design and Project Delivery Phases,* National Grid, 2014.

[11] T/PM/COMP/20, *Management Procedure for Compressor Installations for the National Transmission System,* National Grid, 2013.

[12] T/SP/PW/11, *Specification for Pipework Systems Operating at Pressures Exceeding 7 barg,* National Grid, 2013.

[13] T/SP/TR/18, *Specification for Engineering of Pipelines and Installations Operating at Above 7 barg,* National Grid, 2010.

[14] T/PM/PS/3, *Management Procedure for Ensuring Compliance with the Pressure Systems Safety Regulations 2000 General Compliance Duties,* National Grid, 2015.

[15] T/SP/V/6 (GIS/V6:2019), Steel Valves for Use with Natural Gas at Normal Operating Pressure Above 7 Bar and Sizes Above DN15, National Grid (GIS), 2019.

[16] T/SP/P/8, *Specification for Welding of Steel Onshore Natural Gas Installations Designed to Operate at Pressures Greater Than 7 barg,* National Grid, 2010.

[17] T/SP/CE/2, *Specification for the Design, Construction and Testing of Civil and Structural Works - Geotechnical, Ground Works and Foundations,* National Grid, 2014.

[18] T/PM/ENV/20, *Management Procedure for The Application of Formal Environmental Assessments During Engineering Design and Project Delivery Phases,* National Grid, 2013.

[19] T/SP/ENV/30, Sustainability and Net Zero for Gas Transmission Projects, National Grid, 2021.

[20] T/SP/HAZ/7, *Specification for the Application of Hazard and Operability Studies (HAZOPS) During Engineering Design Phases,* National Grid, 2013.

[21] T/SP/G/37, *Specification for Site Location and Layout Studies and Reviews,* National Grid, 2013.

[22] T/PM/G/35, *Management Procedure for the Management of New Works, Modifications, and Repairs on the National Transmission System (Including Temporary Modifications),* National Grid, 2014.

Appendix A Received Documents

Document Title	Document Number	Included (Y/N)
Valve Operating and Maintenance Register 2017	-	Y
Valve Operating and Maintenance Register 2020	-	Y
Asset List Valve Serial Numbers	-	N
Valves & Civils Plant Status Items	-	N
GNCC SCADA Config Screenshots	-	N
Material Data Sheets	Various	N
Operational Drawings		
Operational Flow Diagram	7210/08/02/00/0001/001	Y
General Arrangement	7210/08/03/00/0001/001	Y
Hazardous Area Drawing	7210/08/03/00/0004	Y
Pressure System No. EA72100N (Sheet 1)	m7210x17x1	Y
Pressure System No. EA72100N (Sheet 2)	m7210x17x2	Y
As-built Drawings / Historic Records		
Original 1970s Records	Various	N
[redacted] Drawings 1998	Various	N
Feeder 2 Isolation Valves As-builts 2019	Various	N
Feeder 4 Pigging Loop As-builts 2003	Various	N

Appendix B Project Documents

Document Title	Document Number	Included (Y/N)
TQ, RFI and Deviation Register	[redacted]585-REG-7210-9000	Y
TQ – Fatigue Cycles	[redacted]585-TQ-7210-0001	Y
TQ – V01 Replacement	[redacted]585-TQ-7210-0002	Y
TQ – Buried Flanges	[redacted]585-TQ-7210-0003	Y
RFI - Bi-directional Area Valve Foundations	[redacted]585-RFI-7210-0001	Y
RFI - Small Bore Pipework Stress Relieving	[redacted]585-RFI-7210-0002	Y
RFI - Drainage Mitigation Works	[redacted]585-RFI-7210-0003	Y
RFI - Feeder No. 2 Isolation Valves As-builts	[redacted]585-RFI-7210-0004	Y
RFI - Maintenance Plant Status Issues	[redacted]585-RFI-7210-0005	Y
RFI - Bi-directional Area Valve Functionality Requirements	[redacted]585-RFI-7210-0006	Y
RFI - Bi-directional Area Operational Data	[redacted]585-RFI-7210-0007	Y
CDM Risk Register	[redacted]585-REG-7210-0500	Y
Technical Risk Register	[redacted]585-REG-7210-0100	Y
Design Coordination Meeting 01 Minutes	[redacted]585-MOM-7210-0001	Y
Design Coordination Meeting 02 Minutes	[redacted]585-MOM-7210-0002	Y
Design Coordination Meeting 03 Minutes	[redacted]585-MOM-7210-0003	Y
Design Coordination Meeting 04 Minutes	[redacted]585-MOM-7210-0004	Y
Design Coordination Meeting 05 Minutes	[redacted]585-MOM-7210-0005	Y
Design Coordination Meeting 06 Minutes	[redacted]585-MOM-7210-0006	Y

Document Title	Document Number	Included (Y/N)
Design Coordination Meeting 07 Minutes	[redacted]585-MOM-7210-0007	Y
Optioneering Meeting Minutes	[redacted]585-MOM-7210-0100	Y
FPSA Report	C410 REP 002	Y
FEA Site Sensitivity Assessment	-	Y
[redacted] Stress Analysis Report – Code Stress	[redacted]-R0706-21	Y
[redacted] Stress Analysis Report – Fatigue Analysis	[redacted]-R0711-21	Y
[redacted] Stress Analysis Report – Removal of Pits	[redacted]-R0713-21	Y
[redacted] Stress Analysis Report – Finite Element Analysis (Resolution of Code Stress Exceptions)	[redacted]-R0724-21	Y
Cathodic Protection Survey Report	CPEL-1934-D01	Y
Power Mechanical Survey Report	6485	Y
Power Mechanical Refurbishment Proposal	SE-6485	Y

Appendix C Premtech Drawings

Drawing Title	Document Number	Included (Y/N)
Drawing Register – Revised FPSA Issue	[redacted]585-REG-7210-0000	Y
Option 0 - Do Nothing - Engineering Line Diagram	[redacted]585-ELD-7210-0101	Y
Option 0 - Do Nothing - General Arrangement	[redacted]585-GEN-7210-0102	Y
Option 0 - Do Nothing - Isometric	[redacted]585-ISO-7210-0103	Y
Option 1A - In-situ Remediation - Engineering Line Diagram Minor Refurbishment	[redacted]585-ELD-7210-0201	Y
Option 1A - In-situ Remediation - General Arrangement Minor Refurbishment	[redacted]585-GEN-7210-0202	Y
Option 1A - In-situ Remediation - Minor Refurbishment - Isometric	[redacted]585-ISO-7210-0203	Y
Option 1A - In-situ Remediation - Minor Refurbishment - Material Take Off	[redacted]585-MTO-7210-0240	Y
Option 1A - In-situ Remediation - Hazardous Areas	[redacted]585-HAZ-7210-0250	Y
Option 1A & 1B - In-situ Remediation - Valve 01 Replacement Detail	[redacted]585-DET-7210-0220	Y
Option 1A & 1B - In-situ Remediation - Site Establishment	[redacted]585-GEN-7210-0230	Y
Option 1A & 1B - In-situ Remediation – G37 Separation Distances	[redacted]585-GEN-7210-0255	Y
Option 1B - In-situ Remediation - Engineering Line Diagram Major Refurbishment	[redacted]585-ELD-7210-0210	Y
Option 1B - In-situ Remediation - General Arrangement - Major Refurbishment	[redacted]585-GEN-7210-0211	Y
Option 1B - In-situ Remediation - Major Refurbishment - Isometric	[redacted]585-ISO-7210-0213	Y
Option 1B - In-situ Remediation - Major Refurbishment - Material Take Off	[redacted]585-MTO-7210-0241	Y
Option 1B - In-situ Remediation - Hazardous Areas	[redacted]585-HAZ-7210-0251	Y
Option 2A - Re-build In Situ - Engineering Line Diagram	[redacted]585-ELD-7210-0304	Y

Drawing Title	Document Number	Included (Y/N)
Option 2A - Re-build In Situ - General Arrangement - Compliant Arrangement	[redacted]585-GEN-7210-0305	Y
Option 2A - Spec Compliant Re-build In Situ - Isometric	[redacted]585-ISO-7210-0306	Y
Option 2A - Spec Compliant Re-build In Situ - Material Take Off	[redacted]585-MTO-7210-0340	Y
Option 2A - Spec Compliant Re-build In Situ - Hazardous Areas	[redacted]585-HAZ-7210-0360	Y
Option 2A - Spec Compliant Re-build In Situ - G37 Separation Distances	[redacted]585-GEN-7210-0365	Y
Option 2A & 2B - Re-build In Situ - Site Establishment	[redacted]585-GEN-7210-0330	Y
Option 2B - Re-build In Situ - Engineering Line Diagram	[redacted]585-ELD-7210-0301	Y
Option 2B - Re-build In Situ - General Arrangement	[redacted]585-GEN-7210-0302	Y
Option 2B - Re-build In Situ - Isometric	[redacted]585-ISO-7210-0303	Y
Option 2B - Re-build In Situ - Material Take Off	[redacted]585-MTO-7210-0341	Y
Option 2B - Re-build In Situ - Hazardous Areas	[redacted]585-HAZ-7210-0350	Y
Option 2B - Re-build In Situ - G37 Separation Distances	[redacted]585-GEN-7210-0355	Y
Option 3 - Re-build in New Location - Engineering Line Diagram	[redacted]585-ELD-7210-0401	Y
Relocated Bi-Directional Area Phase 5 - Final Tie-Ins - General Arrangement	[redacted]341-GEN-7210-8051	Y
Relocated Bi-Directional Area Phase 2 - Bi-directional Arrangement - Isometric	[redacted]341-ISO-7210-8023	Y
Phase 2 - Bi-Directional Arrangement - Material Take Off (Option 3)	[redacted]341-MTO-7210-8025	Y
Phase 3 - Dome End Isolations - Material Take Off (Option 3)	[redacted]341-MTO-7210-8033	Y
Phase 4 - Interconnecting Pipework - Material Take Off (Option 3)	[redacted]341-MTO-7210-8042	Y

Drawing Title	Document Number	Included (Y/N)
Option 3 - Re-build in New Location - Hazardous Areas	[redacted]585-HAZ-7210-0450	Y
Option 3 - Re-build in New Location - G37 Separation Distances	[redacted]585-GEN-7210-0455	Y
Option 3 - Site Establishment	[redacted]341-GEN-7210-8004	Y