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REPORT

[redacted]

King's Lynn Compressor Station FEED Summary Report

Prepared for: National Grid PLC

Prepared by: [redacted]

Project Title: King's Lynn & Peterborough Compressor Station MCPD FEED Project

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ABBREVIATIONS

ADEPT	Asset Development, Evaluation and Planning Tool
AG	Above Ground
BAT	Best Available Techniques
BNG	Biodiversity Net Gain
CAPEX	Capital Expenditure
CBA	Cost Benefit Analysis
CEM	Cost Estimating Methodology
COMAH	Control of Major Accident Hazards
CS	Carbon Steel
CSRP	Control System Restricted Performance
DB	Distribution Board
DCS	Distributed Control System
DLE	Dry Low Emissions
DNO	Distribution Network Operator
D/S	Downstream
EPC	Engineering, Procurement and Construction
ERP3	Emissions Reduction Phase 3
ESD	Emergency Shutdown
F&G	Fire and Gas
FEED	Front End Engineering Design
FV	Full Vacuum
GBP	Great Britain Pounds
GG	Gas Generator
GTC	Gas Turbine Compressor
GT	Gas Turbine
HAZOP	Hazard and Operability
HSSE	Health, Safety, Security, and Environment

HVAC	Heating, Ventilating and Air Conditioning
IA	Instrument Air
IED	Industrial Emissions Directive
I/O	Input/Output
LER	Local Equipment Room
LV	Low Voltage
MCPD	Medium Combustion Plant Directive
MTO	Material Take Offs
MTOD	'Material Take Off Driven' (Proprietary software tool developed by [redacted]
MV	Medium Voltage
NTS	National Transmission System
PCC	Point of Common Coupling
PDS	Process Duty Specification
PMS	Power Management System
PT	Power Turbine
RAM	Reliability, Availability and Maintainability
RIIO	Revenue=Incentives+Innovation+Outputs
RR	Rolls-Royce
SCR	Selective Catalytic Reduction
SIMOPS	Simultaneous Operations
SWBD	Switchboard
SWGR	Switchgear
TCPA	Town and Country Planning Act
UG	Underground
UCP	Unit Control Panel
UKPN	UK Power Networks
USFM	Ultrasonic Flowmeter

U/S	Upstream
VFD	Variable Frequency Drive
VSD	Variable Speed Drive

HOLDS LIST

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1.0 EXECUTIVE SUMMARY

1.1 General

The Medium Combustion Plant Directive (MCPD) requires that existing plant between 1 MW and 50 MW net thermal input must not exceed specified operational emission limit values or be taken out of service before 1 January 2030 or operate under 500 hour emergency use derogation (EUD). This legislation impacts the Rolls Royce Avon driven compressor units on the gas National Transmission System (NTS) including units at King's Lynn Compressor Station.

King's Lynn is a bi-directional compression station which is used to resolve supply/demand imbalance for SE England and currently has:

- 2 off Siemens SGT400 driven compressors (C, D) which operate as lead units;
- 1 off Rolls-Royce Avon Gas driven compressor (B) which operates as partial back-up to C and D;
- 1 off Rolls-Royce Avon Gas driven compressor (A) which is disconnected and partially dismantled;

Unit B compressor does not comply with MCPD and provides limited back up capacity which may result in network constraints based on forecast compression requirements. The station design capacity also cannot be achieved with C and D unavailable.

Figure 1-1: King's Lynn Station Layout (Key Site Equipment)

1.2 MCPD Legislation Compliance Options

The technical options being considered to provide required MCPD compliant compression capability to meet forecast requirements at King's Lynn are as follows:

Do nothing:

a) Retain Avon with run hours restricted 500 hour per year on a 5 year rolling average per the emergency use derogation allowed in MCPD;

RR Avon Retrofit Options:

b) Retrofit emissions compliant DLE combustion system to Avon gas generator;

c) Use of Control System Restricted Performance (CSRP);

d) Installation of a Selective Catalytic Reduction (SCR) unit.

New Build (Replacement of RR Avon Unit B) Options:

a) New Gas Turbine Driven Compressor;

b) New Electric Variable Speed Drive (VSD) Compressor.

For King's Lynn, the provision of one and two additional MCPD compliant units is being considered. The provision of two new units restores the site compression capability as per the original design intent prior to removal from service of Unit A (i.e. 4 off compliant compressor units on site). Additionally, re-wheeling of the Units C/D (i.e. SGT 400s) alongside the retrofit and new build options is being considered in order to provide required compression capability.

Beyond 2030, there may be an increase in the requirement for parallel running of compressors and National Grid would be exposed to considerable network constraint costs without a very high availability at King's Lynn. The installation of two additional MCPD compliant units allows the high compression availability to be achieved.

One MCPD complaint unit can be achieved by either retrofitting of the Avon Unit B or installation of one new build unit. Two MCPD complaint units can be achieved by either the installation of two new build units or one new build unit plus retrofitting of the Avon Unit B (i.e. a hybrid development).

1.3 Study Execution Methodology

Cost Benefit Analysis (CBA) and BAT Assessments shall be used to help inform the preferred MCPD Compliance Option. National Grid will perform the CBA and BAT assessments. [redacted] is responsible for providing the input data for the analysis / assessment. The study execution methodology is illustrated by Figure 1-2.

The study was executed in two phases. During Phase 1, potential locations for new build compressor locations were screened first to select a preferred location. The potential locations were screened based on project development cost, project execution schedule, safety, environmental impact, constructability and impact on existing operations. Based on the assessment, locating the units in the redundant Plinth Area 1 was selected.

During Phase 2, the input data required for the Cost Benefit Analysis (CBA) and BAT assessment was generated for all MCPD Compliance options. A summary of the input data is provided by Table 1-1. National Grid will perform the CBA and BAT Assessments on the above identified MCPD legislation compliance options and use the results to help inform the preferred option.

Figure 1-2: Study Execution Methodology

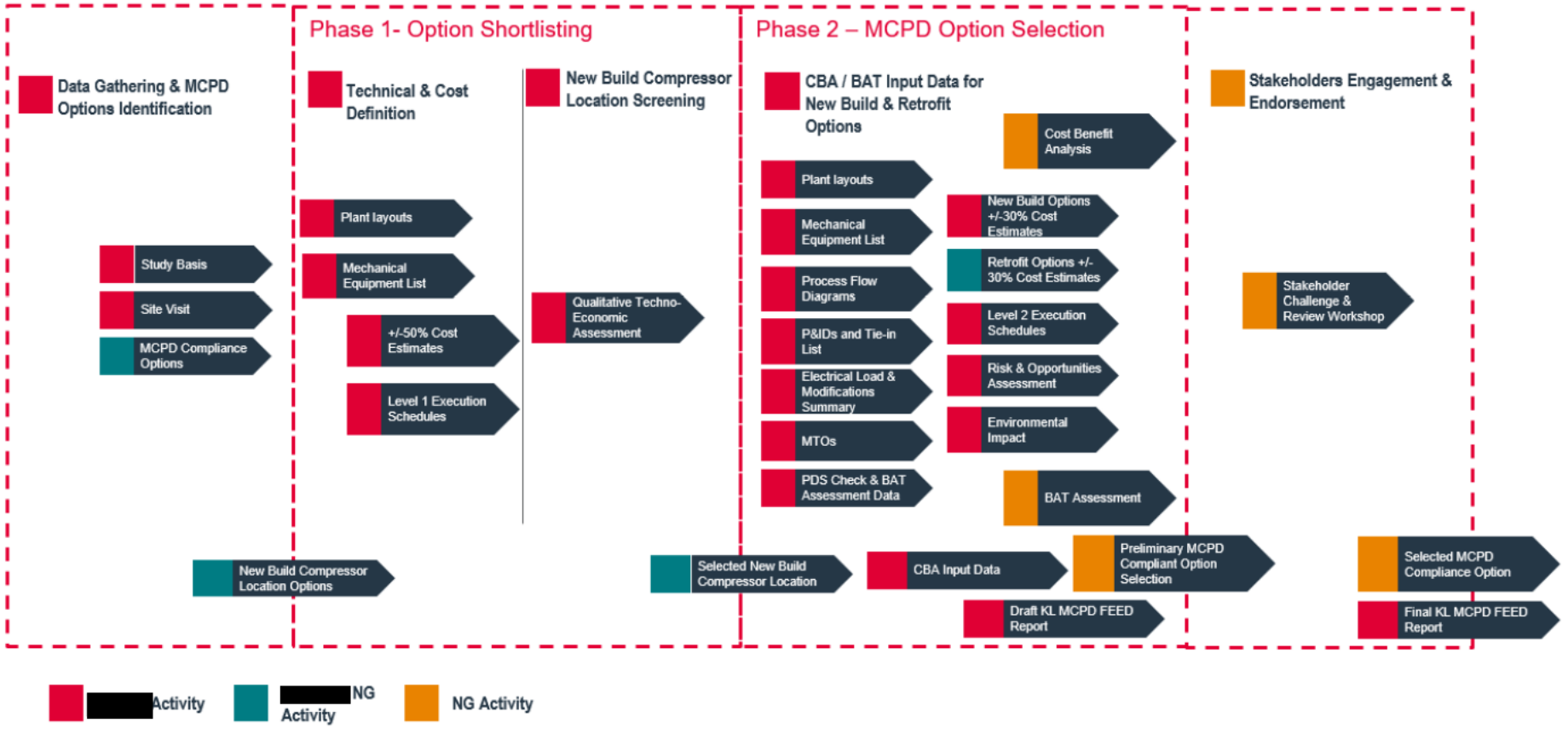


Table 1-1: CBA & BAT Assessment Input Data

Assessment Criteria	MCPD Compliance Option				Notes
	New Build GT Unit(s)	New Build Electric VSD Unit(s)	Retrofit Options	Hybrid Option (New Build + Retrofit)	
Project Development Cost	[redacted]	[redacted]	[redacted]	[redacted]	The cost range for the Hybrid Option covers all retrofit options. Costs include re-wheeling of SGT 400s
Project Development Schedule	All options can achieve the MCPD target date. Retrofit options have more float and thus less schedule risk. The estimated completion date for a single unit new build and two additional units / hybrid options is 1Q2029. The estimated completion date for retrofit options is 4Q2027.				
Risk Exposure	Lower exposure than Electric VSD unit(s) but higher than retrofit options due to project scope.	Carries highest risk exposure due to requirement for new UKPN grid connection	Carries lowest risk exposure.	Risk Exposure is the sum of individual constituents	
Process Duty Specifications	Designed to satisfy required operating envelope.		Can achieve PDS with mitigations	Can achieve PDS	A sensitivity was also evaluated, which considered re-wheeling of existing SGTs in parallel to the MCPD compliance options.
Emissions Assessment	All options are compliant with the relevant MCPD emission limits.				
Embodied Carbon Emissions	Slightly lower than Electric VSD Option	Has highest embodied carbon emissions	Offer lowest embodied carbon emissions.	Emissions are function of individual constituents	
Environmental Impact	Requires land use outside of current site boundary but within National Grid land ownership boundary. Is able to meet Biodiversity Net Gain targets.		No impact on Biodiversity	Impact is a function of individual constituents	

2.0 INTRODUCTION

2.1 General Background

The Medium Combustion Plant Directive (MCPD) requires that existing plant between 1 MW and 50 MW net thermal input must not exceed specified operational emission limit values or be taken out of service before 1 January 2030. This legislation impacts the Rolls Royce Avon driven compressor units on the gas National Transmission System (NTS) including units at King's Lynn Compressor Station. Investment is required to ensure the capability, that the network requires, can be maintained beyond 1 January 2030. Investment may include various combinations of the following options and the investment must be assessed against network capability requirements predicted under various future energy scenarios to ensure the most cost-effective solution for end consumers.

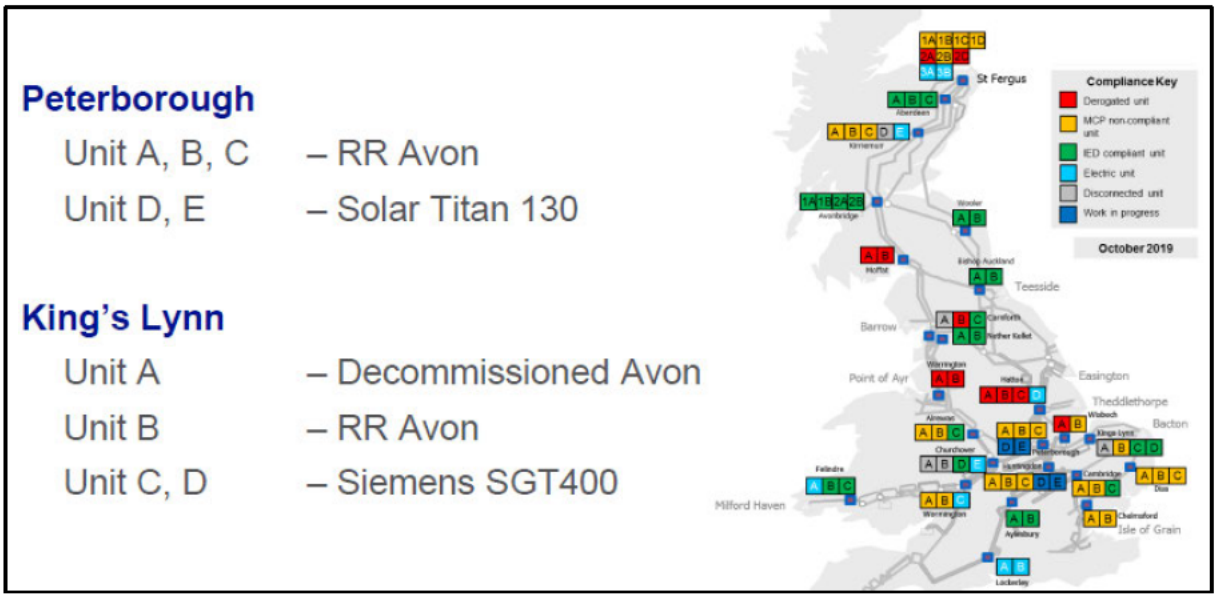
- Upgrading non-compliant units to bring emissions within acceptable legislative limits;
- Replacement of non-compliant units with new low emissions compressors;
- Taking non-compliant units out of service;
- Restrict the performance of non-compliant units through control system restriction such that operational emissions are limited to within legislative limits;
- Limit the use of non-compliant units to a maximum of 500 hours per year under an emergency use derogation as defined in the MCPD legislation (i.e. do nothing).

National Grid submitted a compressor emissions compliance strategy paper to Ofgem in 2019 within which compliance options for each site impacted by the incoming MCPD legislation were presented. Due to the uncertainty around the optimum solution for King's Lynn Compressor Station it was agreed that further review of options would be conducted with the optimum solution for each site presented to Ofgem in two separate Final Options Selection Reports. Agreement on the optimum solution would then allow the project(s) to progress to the next phase of development prior to final funding allowances being agreed via an uncertainty mechanism under the RIIO regulatory framework.

2.2 Site Background

The King's Lynn Compressor Station is located in the East of England and its location on the NTS is shown on the schematic below. A brief outline of the King's Lynn site is also provided in the section below to put the project scope into context.

Figure 2-1: King's Lynn Compressor Station Location



2.2.1 King's Lynn Compressor Station

The King's Lynn is a bi-directional compression station which is used to resolve supply/demand imbalance for SE England and currently has:

- 2 off Siemens SGT400 driven compressors (C, D) which operate as lead units;
- 1 off Rolls-Royce Avon Gas driven compressor (B) which operates as partial back-up to C and D
- 1 off Rolls-Royce Avon Gas driven compressor (A) which is disconnected and partially dismantled

Unit B compressor does not comply with MCPD and provides limited back-up capacity, which may result in network constraints based on forecast compression requirements. The station design capacity also cannot be achieved with C and D unavailable.

2.3 MCPD Legislation Compliance Options

The technical options being considered to meet MCPD legislation at the existing compression stations are as follows:

Do nothing:

a) Retain Avon with run hours restricted 500 hour per year on a 5 year rolling average per the emergency use derogation allowed in MCPD;

RR Avon Retrofit Options

a) Retrofit emissions compliant DLE combustion system to Avon gas generator;

b) Use of Control System Restricted Performance (CSRP);

c) Installation of a Selective Catalytic Reduction (SCR) unit.

New Build (Replacement of RR Avon) Options

a) New Gas Turbine Driven Compressor;

b) New Electric Variable Speed Drive (VSD) Compressor.

For King's Lynn provision of one and two additional MCPD compliant units is being considered. The provision of two units restores the site compression capability as per the original design intent prior to removal from service of Unit A (i.e. 4 off compliant compressor units on site). Additionally, re-wheel of the Units C/D (i.e. SGT 400s) alongside the retrofit and new build options is being considered in order to provide required compression capability.

Beyond 2030, there may be an increase in the requirement for parallel running of compressors and National Grid would be exposed to considerable network constraint costs without a very high availability at King's Lynn. The installation of two additional MCPD compliant units allows the high compression availability to be achieved.

One MCPD complaint unit can be achieved by either retrofitting of the Avon Unit B or installation of one new build unit. Two MCPD complaint units can be achieved by either the installation of two new build units or one new build unit plus retrofitting of the Avon Unit B (i.e. a hybrid development).

2.4 Document Objectives

Cost Benefit Analysis (CBA) and BAT Assessments shall be used to help inform the preferred MCPD Compliance Option. National Grid will perform the CBA and BAT assessments. In order to perform the CBA and BAT Assessment, key technical and cost information is required as input. This report presents a summary of the input data generated for the CBA and BAT Assessments as well as key findings and recommendations resulting from the activity.

2.5 Document Structure

This document is structured as follows:

Section 3.0 summaries the main data and assumptions used for technical development of the alternative MCPD compliance options.

Section 4.0 presents a technical summary of the MCPD compliance options.

Section 5.0 presents a summary of the study execution approach.

Section 6.0 highlights whether the MCPD compliance options are able to achieve the required Process Duty Specifications (PDS).

Section 7.0 summaries the screening of the alternative locations that could be used for the new build MCPD compliance options.

Section 8.0 presents the findings of the HSE assessments performed for the MCPD compliance options.

Section 9.0 presents the estimated +/-30% project development costs for the MCPD compliance options.

Section 10.0 summaries the Level 2 project execution schedules developed for the MCPD compliance options.

Section 11.0 presents the main risks and opportunities identified at this stage for the MCPD compliance options.

Section 12.0 provides a summary of the main conclusions resulting from this phase plus recommendations for future project phases.

Section 13.0 lists the supporting documents produced during this study and also other key references used in the execution of the study.

3.0 STUDY BASIS

Key Reference Documents

203513C-001-RT-0008-0002	King's Lynn Basis of Design [Ref. 1]
203513C-001-RT-0500	King's Lynn Compressor Station Site Visit [Ref. 2]
203513C-000-RT-0300	Cost Estimating Methodology [Ref. 3]
203513C-001-RT-0008-0001	King's Lynn Compressor Station Process Description [Ref. 17]

3.1 General

The study Basis of Design [Ref. 1] catalogues relevant detail and assumptions employed over the course of this study.

The King's Lynn Compressor Station features four gas turbines with associated equipment including filtration, metering, fuel gas pressure reduction and venting, associated pipework and control systems. A high-level illustration of the station is provided in Figure 3-1.

The station sits between pipeline feeders F2, F4 and F27 with piping configuration allowing for pressurisation of the local grid in either direction depending on supply-demand imbalances between Bacton and LNG import. The valving, manifolds and pipework associated with flow direction is located in the "Bi-Directional Pipework Area".

Table 3-1: Station Feeder Pipeline Summary

Feeder	To / From	Nominal Pipe Size (mm)
F2	King's Lynn Compressor Tee	900
F4	Rougham	900
F27	Bacton	1200

Of the four compressor units on site, three are currently operational: Avon Unit B and Siemens SGT400 Units C and D. The fourth compressor, Avon Unit A (1533-75G) is in place, but has been air-gapped and partially dismantled. Table 3-2 summarises details associated with the existing units. The station primarily operates compressor Units C and D in single or parallel operating modes with Unit B in place to provide resilience.

Figure 3-1: King's Lynn Compressor Station Schematic

The compressor station piping is laid out such that the single header associated with the Avon Units, which were operated in series, provides a bypass between station suction and discharge headers. It is on the discharge side of this piping loop where the single station blowdown utility valve is located.

Table 3-2: Existing Operating Compressors Specifications

Unit	Engine	ISO Power (MW)	Installed	Min. Flow (MSCM/D)	Capacity (MSCM/D)
B	Avon 1533	12.3	1971	9	56
C	SGT400	13.4	2003	15	42
D	SGT400	13.4	2003	16	42

3.2 Design Operating Cases

Demand on the compressor station varies throughout the year reflective of the various factors contributing to supply and demand variation on the wider grid. Operating points to be met by the station are summarised in Table 3-3 with varying operating mode as follows:

- Mode 1 – single compressor unit operation;
- Mode 2 – parallel operation between two compressor units;
- Mode 3 – station capacity.

Note that Mode 3 Station Capacity specifications are relevant to unit operations and components out with the individual compressor units. Additionally, all modes are applicable for both flow directions (to/from Bacton).

Table 3-3: Process Design Cases

Case	Operating Mode	P Suct. (Barg)	P Dis. (Barg)	Std Flow (MSCM/D)	T Suct. (°C)
C1	1	50.12	61.37	42.75	10.00
C2	1	47.68	59.85	42.85	8.91
C3	1	53.26	63.03	58.25	10.00
C4	1	57.83	66.07	61.04	2.28
C5	2	56.93	67.94	84.14	1.04
C6	1	55.45	63.92	39.41	11.21
C7	2	54.73	70.90	72.34	10.00
C8	1	52.86	62.12	30.00	12.61
2050	3	38.00	70 / 75	100.00	-

3.3 Site Status

A site visit has been undertaken as part of the project with associated report detailing outcomes and findings of significance (Ref. 2). Refer to Section 3.6 for the main findings from the site visit.

3.4 Site Layout

The station is divided into general areas that feature specific unit operations and equipment. Figure 3-2 provides station overview.

Major site piping is predominantly underground. Main buildings are limited to the Control Building in the South-West corner. The foundations remain of the former Control Building having been recently demolished. Navigation between site areas is facilitated by an asphalt road network and a security fence stands around the site perimeter, featuring remotely operated gates for access and egress.

Use of the differing areas has evolved over the lifetime of the station with various modifications undertaken to upgrade and maintain operation. As such, vacant space is available and replacement of existing or redundant systems offers the opportunity to repurpose parts of the site for new equipment.

Figure 3-2: King's Lynn Station Layout (Key Site Equipment)

3.5 Layout Specifications

Site areas are classified as Class 1, 2, 3 or 4 as summarised in National Grid's Site Location and Layout Specification T/SP/G/37 [Ref. 9] with the King's Lynn Compressor Station comprising areas as follows:

- Class 4;
  - Gas scrubbers, K-3011/1-3;
  - Condensate tank, V-1103;
  - Compressor units, A-D;
- Class 3;
  - Fuel Gas pressure reduction area;
- Class 2;
  - FT-31 Ultrasonic Flowmeter;
  - Bi-directional manifolds;
  - F-27 Pig Trap.

Based on site maximum operating pressure of 75 barg, the required minimum separation distances across the site are as summarised in Table 3-4.

Table 3-4: Minimum Separation Distances from Hazardous Equipment

Plant Area Category	Minimum Separation Distance (m)		
	Essential / Hazardous Equipment	Occupied Building	Outermost Security Fence
4	32	39	39
3	16	20	19
2	5	6	5
1	3	3	5

3.6 Site Condition

Condition varies across site with notable deterioration at specific locations. Further detail can be found within the Site Visit Report [Ref. 2]. For the Retrofit Options, as well as the upgrades required to meet the MCPD requirements, additional 're-life' modifications / upgrades are required to the existing Avon Unit B Gas Turbine Compressor to ensure the requisite design life is achieved. The re-life modifications are part of the MCPD project scope, they form part of the on-going National Grid's Asset Health Plan. Refer to Reference 22 for full details of the asset health plans.

3.7 Fleet RAM Study

A National Grid Gas Transmission (NGGT) Fleet RAM Study [Ref. 21] by [redacted] was performed to forecast the expected Compressor Train availability to provide necessary capacity during periods of demand for the entire fleet of National Grid Compressor Trains. Note, this RAM Study is a generic assessment and does not specifically reflect the condition of the existing facilities at the King's Lynn Compressor Station.

The study reviewed both electric and gas turbine driven systems used on the National Grid network. For the Avon Unit B 're-life' condition assessment review, only the results from the Avon Unit fleets within the RAM Study were assessed.

The main objective of the RAM study was to:

- Forecast expected availability.
- Identify main contributors to unavailability and itemise individual sub-unit contributions;
- Identify potential areas of availability improvement in the operation and maintenance of the compressor train.

The following observations were made in regard to the biggest contributors to the Avon Compressor Train's unavailability:

- Failures of the Safety / Protection / ESD sub-unit were the largest contributor to the availability loss;

- The second largest loss-contributor to availability is trips and failures of the Control System. The majority of losses attributed to this sub-unit were caused by major failures with long-lead times;
- The third largest contributor to the availability loss was the Compressor sub-unit;
- Contributions from miscellaneous and Power Turbine sub-units were also significant and like other sub-units, most of the losses were attributed to major and minor failures when spare parts are not available.

The conclusions from the RAM Study (although a generic assessment of the Avon Unit fleet) are consistent with the re-life requirements presented in Section 3.6. As a minimum, the following upgrades are required as part of the Avon Unit B 're-life' modifications to ensure the requisite design life is achieved:

- Safety / Protection/ ESD Systems;
- Control Systems;
- Compressor Package Overhaul.
- Better understanding of the spare parts inventory and overall obsolescence issues.

3.8 Location Development Options

The vacant spaces across site, in combination with site areas identified for potential replacement and relocation, provide a number of locations for possible re-development as depicted in Figure 3-2:

- Option A – Vent Stack Area;
- Option B – Plant 1 Area Plinth (Decommissioned);
- Option C – Existing Avon A & B Units Area.

3.9 Design Life

The design life of each element of the compressor installation shall as a minimum, comply with the asset life requirements listed in Table 3-5 [Ref. 1].

Unit upgrades or life extension reviews (i.e., retrofit options highlighted in Section 2.3) shall also comply with the asset design life requirements shown below.

Table 3-5: Design Life Requirements

Asset	Life (Years)
Compressor	40
Gas Generator	20
Power Turbines	25
Pipework and Valves	30

Protection and Control Systems	15
Enclosures and Buildings	60

3.9.1.1 Maintenance Requirements

As a minimum, the design shall comply with the requirements of National Grid's maintenance policy T/PL/MAINT/99. The design shall facilitate safe isolation and accessibility to enable maintenance activities to be undertaken safely.

There are no total station shutdowns at King's Lynn for maintenance purposes. Each compressor unit is shutdown as required for routine maintenance activities etc. For any major station modifications, this study is premised on the basis that the station can be shut down for approx. 6 months, April to September inclusive, as long as this is planned in advance. The actual durations permitted may vary in practise.

3.9.2 New Build Compressor

For the purposes of this study, the design and footprint for the new build units is based on the footprint of the Solar Titan T130 units recently installed at the Peterborough Compressor Station (i.e., 60m long x 22m wide). This footprint is for a GT driven compressor including the associated cab, plus it also caters for the space requirements for the associated ancillaries (i.e., inlet / outlet isolation valves and piping, recycle valve and piping, fuel gas skid, dry seal gas skid, lube oil system, LER for local LV switchgears and control panels, fire suppression skid). The allocated footprint is considered to be generous / conservative as there is significant scope to optimise the layout and size of the compressor cab etc.

It should be noted that for an electric driven VSD compressor, the main differences to the footprint / layout requirements are as follows:

- The compressor cab would be smaller by approx. 3.5m, as the electric motor occupies less space than a gas turbine;
- No fuel gas skid is required;
- There is no requirement to provide cut-outs on the compressor cab for gas turbine air intake incl. filters and exhaust. Although the cab cut-outs are on the cab roof, there is an opportunity to optimise the compressor cab dimensions;
- A separate LER is required for the VFD unit transformers / harmonic filters etc., Based on preliminary vendor information, the size of this LER would be 13.3m (L) x 1.6m (W) x 2.6m (H). The water-cooling system for the VFD is integrated into the VFD unit LER;
- A new LER for 11kV switchgear that would tie-into the new electrical incomer that is required from UKPN. However, this would be installed adjacent to the existing control building / electrical room and therefore is not part of the compressor unit footprint requirements.

Given the plot plan allocated footprint for the compressor unit is generous / conservative, the same footprint is also considered adequate for an electric driven compressor.

There are opportunities to optimise the package layout (e.g. quantity of structural steel etc.) and this can be carried out during the latter stages of design.

3.9.3 Utilities

There is limited information available on the Utility Systems at King's Lynn. As a result, the following assumptions have been made:

- Fuel Gas:
  - Due to the uncertainties surrounding the existing fuel gas skids and potential for the supply requirements of a new Gas Turbine Driven Compressor (i.e., Solar T130) not being met, the addition of a dedicated fuel gas skid for a new build GT compressor option has been considered as part of the MCPD study.
- Instrument Air:
  - It is assumed that the station instrument air system has capacity to provide supply to all new equipment considered as part of the MCPD study.
- Potable/ Service Water:
  - The station water ring main runs along the length of the north security fence. It is assumed that tie-ins to the water ring main are feasible for the potable / service water supply to the new build compressor options.
- Effluent / Drainage:
  - The King's Lynn site comprises of two separate networks: "Foul Water Sewer" and "Surface Water Drains". It is assumed sufficient capacity is available to tie into the existing networks for the new build compressor options.
- Relief:
  - For the SGT400 Compressors, the vent piping is above ground and ties into a dedicated vent stack effectively by-passing the existing silencer pit which is below ground. The same philosophy, i.e., use of above ground silencers, has been applied for any additional relief venting considered as part of the MCPD Study.

3.10 Cost Estimating Methodology

Two levels of cost estimates were required for this study. +/-50% and /-30%, refer to Section 5.0 for further details.

Full details of the Cost Estimating Methodology are provided by Reference 3.

3.10.1 +/-50% Cost Estimating Method

To achieve the required accuracy for the +/-50% cost estimate, brownfield cost estimates are be based on high level MTOs (Material Take Offs) estimates. For expediency, a hybrid cost estimating method is used, whereby cost elements are classified as greenfield, simple brownfield and complex brownfield. For greenfield and simple brownfield cost elements, a semi-automated MTO method is applied using the [redacted] ADEPT cost estimating tool. For complex brownfield, where more rigorous MTOs are required, the [redacted] MTOD tool is used.

ADEPT (Asset Development, Evaluation and Planning Tool), is a proprietary software tool developed by [redacted] The ADEPT output cost is the P50 cost estimate including contractor and National Grid indirects costs.

The MTOD (Material Take Off Driven) tool is a proprietary software tool developed by [redacted] developed over more than 20 years. It allows for rapid, accurate, consistent, credible and fully transparent estimation of complex brownfield cost estimates based on a MTO approach in accordance. The MTOD output cost is the P50 cost estimate including contractor indirects and National Grid indirects costs.

3.10.2 +/-30% Cost Estimating Method

To achieve the required accuracy for the +/-30% cost estimate, the cost estimates are solely based on preliminary MTOs (Material Take Offs) using the [redacted] MTOD tool. The tool uses the following method:

- This model assumes a PAU with a final tie-in approach to construction or a stick-built approach;
- The +/-30% Cost estimate is a "bottom-up" cost estimate, deriving as much detail as is practicable and useful, from the engineering information produced by the engineering team;
- New build compressor unit procurement costs are supported by budget quotations. This data will be augmented by in-house cost data, using information from a large number of similar current or recent projects;
- The Cost Estimate will be prepared in accordance with the AACEI requirements.

3.10.3 Exclusions

The following cost elements are excluded from the cost estimates and are developed separately by National Grid:

- Operating expenditure (OPEX).

The following costs are omitted from the estimate:

- Forward escalation;
- Financing costs;
- Cost of future exchange rate fluctuations;
- Import duties, Customs charges;
- Customs duties and local taxes;
- Licenses and consents;
- Disposal and decontamination costs;
- Re-sale value of any destructed / removed equipment and bulk materials from demolition scope;
- National Grid's Approved for Expenditure Contingency (Management reserve).

4.0 OPTION DESCRIPTIONS

Key Reference Documents

203513C-001-RT-0503	King's Lynn Compressor Station Option Review Report (Phase 1) [Ref. 7]
203513C-001-RT-0251	King's Lynn Compressor Station Layout Review Report (Phase 2) [Ref. 15]
203513C-001-RT-0250	King's Lynn Compressor Station Layout Review Report (Phase 1) [Ref. 6]
203513C-001-DW-0051-0001	King's Lynn Layout Drawings [Ref. 18]
203513C-001-RT-1600-0001	Kings Lynn Compressor Station Electrical Modifications Summary [Ref. 19]
203513C-001-EL-0261	King's Lynn Compressor Station Mechanical Equipment List (Phase 2) [Ref. 8]
203513C-001-PFD-0010-0001	King's Lynn Process Flow Diagrams [Ref. 20]

4.1 Options Overview

Currently, the King's Lynn station primarily operates units C and D in single or parallel operating modes according to the flow levels required. Unit B is in place to provide resilience, while Unit A is non-operational and has been disconnected since 2017. Given the Avon Compressor Unit B does not comply with MCPD, various options are being considered to upgrade or replace this unit to provide the station with adequate capacity and resilience. Note, as Avon Unit A is non-operational and partially dismantled (compressor has been removed and the control cabling disconnected at both the Cab and Control Room ends), it has not been considered as part of the Avon Retrofit Options. It is perceived that re-commissioning of Unit A is likely to incur additional project costs and schedule risks above and beyond those identified for Unit B. Additionally, it is located closer to the site control building and the SGT 400s, which makes it less attractive from a safety spacing perspective.

Although only one operating unit at King's Lynn is not MCPD compliant, requirement of one or two additional MCPD compliant units is being considered. Beyond 2030, there may be an increase in the requirement for parallel running of compressors and National Grid would be exposed to considerable network constraint costs without a very high availability at King's Lynn. The installation of two MCPD compliant units allows the high compression availability to be achieved. Note, two units have been considered over a larger single unit to meet the high availability requirements as by inspection two smaller units will provide a better overall system availability than one larger unit. Additionally, two smaller units provide more flexibility in how the units are operated (e.g. no issues with meeting turndown rates for lower flow scenarios).

The options considered for the one and two additional MCPD compliant units are as follows:

Single Unit

- Single new build MCPD compliant compressor to replace function currently provided by Avon Unit B;
- Retrofit modification to existing Avon Unit B to comply with MCPD.

Two Units

- Two new build MCPD compliant compressors to replace function currently provided by Avon Unit B and improve station availability;
- Hybrid option to install a single new MCPD compliant compressor and undertake a retrofit modification of existing Avon Unit B to make it MCPD compliant.

Limiting the use of non-compliant Avon unit B to a maximum of 500 hours per year (i.e. "Do Nothing", as defined in the MCPD legislation, is also being considered as an option. Unit B would act as an emergency backup to the SGT400 units.

The SGT400 compressor Units C & D function within a narrow operating envelope, currently set up for high head low volumetric flow rate conditions. Re-wheel of units C & D to provide a wider envelope and greater operating flexibility is also being considered. This re-wheeling is considered in conjunction with both the new build and retrofit options and also with the "Do-Nothing" option.

For the new build options, GT driven or electric driven VSD compression units are considered. In order to limit the number of option permutations, the base case selected is GT driven compression. Use of electric driven VSD compression is then only considered for a limited number of new build options to allow a direct assessment / comparison to be performed between the compressor driver types.

For the hybrid option, as a representation of this option, the combination of a new build GT driven unit plus DLE retrofit to the Avon Unit B has been adopted. The plant layout is not impacted if an electric driven VSD unit or another MCPD retrofit option (i.e., CSRP, SCR) is adopted for the Avon Unit B.

Additionally, for the two new unit options, both compressors are considered to be either GT or electric driven VSD units. Having the same driver for both new units provides operational benefits (e.g. commonality of spares etc.) plus consistency in the on-site modifications and tie-ins required for the new units.

For the purposes of input to the option screening, the following main technical definition was developed for each option:

- Site layout;
- Process Flow Diagrams;
- Interface Schematic and Register, plus Tie-in List and P&ID mark-ups;
- Major equipment requirements including discipline specific considerations i.e., Mechanical, Electrical and Control and Instrumentation.

4.2 Single New Build Location Options

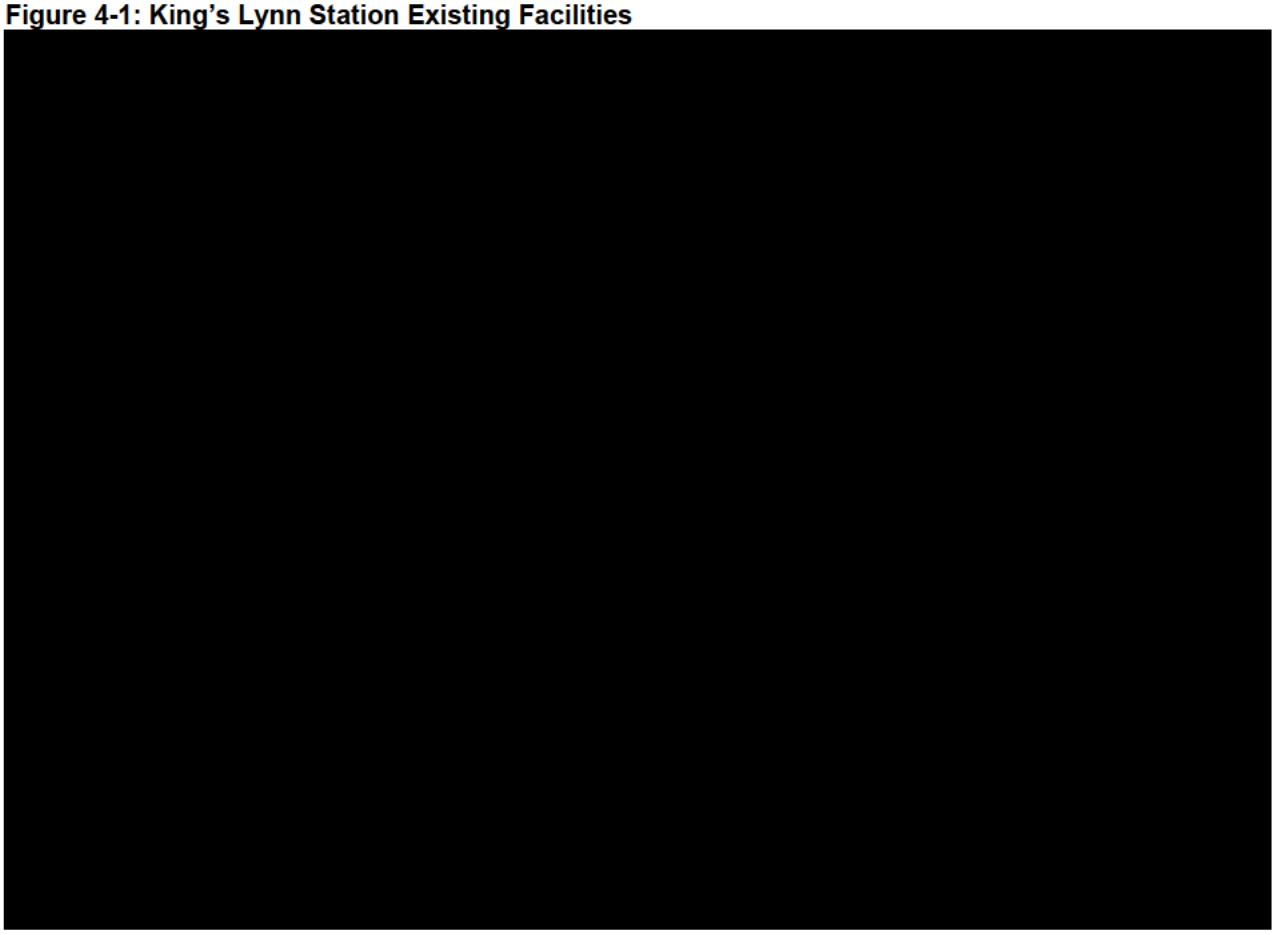
4.2.1 Site Layout Options Review

In considering installation of a single new compressor unit, the primary consideration is impact to site layout. In order to avoid the requirement for additional land acquisition, i.e., use of plot space outside of the existing land ownership boundary, only location options within the current site security fence were considered. Potential location options within the station were reviewed and screened based on various factors (Ref. 15) with the purpose to:

- Demonstrate selected layout provides adequate protection to manned areas on site and to the general public;
- Minimise likelihood of escalation on site between hazardous inventories;
- Ensure wherever possible that the principles of inherent safety are utilised in the layout and set-up of new plant and equipment, in order to eliminate hazards as, opposed to controlling them.

The existing site facilities are illustrated by Figure 4-1.

Figure 4-1: King's Lynn Station Existing Facilities



The compressor station is relatively constrained in available space; however, relocation of specific unit operations or re-purposing of existing space provides potential flexibility. Initial review, considering existing site condition, foundations, piping, cable trenches, etc., generated potential locations as detailed in Table 4-1.

Table 4-1: Single New Compressor Location Options

Option	Location
A	Existing Vent Area (Vent Area relocated to Redundant Plant Area 1 Plinths)
B	Redundant Plant Area 1 Plinths – GT Driven Compressor / Electric Driven VSD Compressor (Note 1)
C	Existing Avon Compressor Area, Unit A & B

Notes:

1. For location B, the use of GT Driven and electric driven VSD unit is considered to allow any potential differences to be highlighted due to driver type. Location B was selected for the sensitivity, due to its better construction access and potential impact on existing operations as a result new cable trench required for the MV power supply to the VSD drive.

High level separation distances for the layout options are provided in Table 4-2 based on detail developed as part of the Layout Review (Ref. 15). As highlighted, each option complies with separation requirements from buildings and hazardous equipment, however, Options B and C require site perimeter fence extension.

Table 4-2: Single New Compressor Separation Distances

Option	Proposed Distance (m)			
	Distance to Buildings (Note 1)	Distance to Essential / Hazardous Equipment (Note 2)	Distance to Outermost Security Fence (Without Modification (Note 3)	Distance to Outermost Security Fence (After Modification (Note 3)
A	85	32	40	N/A
B	160	33	18	40
C	44	56	32	40

Notes:

1. The only building on site is the control building and distances shown are to this building.
2. The distance shown is the distance to the nearest item of hazardous equipment. For Location A, this is the SGT-400 compressors; for Location B, it is both the station ultrasonic flow meter and Bacton no. 27 Feeder Pig Launcher facilities; for Location C, it is the SGT-400 compressors.
3. For Locations B and C, the new unit does not meet the recommended distance to the security fence and hence it is necessary to extend the site fence line to meet the distance requirement.

4.2.2 Interface Schematic and Register

Critical interfaces with existing site facilities for the single new build compressor options include:

- Suction and discharge pipework tie-ins to existing station underground piping network;
- Compressor discharge vent relief route construction incorporated as part of station vent array;
- Potable water supply to water mist package via existing underground ring main;
- Air supply to instrument air actuated valves and compressor seals via existing skid within Instrument Air building;
- Demolition of existing Avon compressor units A and B;
- Electrical supply to new compressor via existing cable trench network extension for GT driven. For the electric VSD unit, a new cable trench plus 11 kV switchgear to distribute power to the new VFD unit. A new LER is also required to house the new 11 kV equipment.

  Note: For any new compressor unit option, during future phases of engineering, it is recommended that dedicated new trenches be evaluated for all services to meet in-trench cable separation distances specified by latest National Grid specifications.
- Integration with station Control and Instrumentation systems, including control and safety panel installation in existing control building, and inter-connection with DCS, ESD, F&G at compressor LER and enclosure.

The interface schematics for the GT and electric driven VSD compressor options are shown in Figure 4-2 and Figure 4-3 below. The associated interface register is presented in Table 4-3.

Figure 4-2: New GT Driven Compressor Interface Schematic

[redacted]

Figure 4-3: New Electric Driven VSD Compressor Interface Schematic

[redacted]

Table 4-3: Interface Register

Interface No.	Description	Notes
COMMON INTERFACE POINTS FOR BOTH GT AND ELECTRIC DRIVEN COMPRESSORS		
IP-B1	Control Signal Interface	Control signals (DCS, UCP, ESD, F&G) from new build compressor package interfacing with existing station control & safety systems (Dual ICSS Network / Hardwired Trips) via a new central room station control panel. Control cables utilise existing cable trenching partway, cable trench extension required.
IP-B2	Air Interface	Interface with existing instrument air package. New piping constructed to supply IA/Seal Gas to actuated valves and the new build compressor. Note, status and depiction of existing Air uncertain. Interface definition based on understanding of extent of systems. Further definition to be developed in the next phase of engineering.
IP-B3	400 V Electrical Supply Cabling Interface	Cabling to interface with existing electrical switch room to provide power for Turbine auxiliaries and control cabling. Extension of cable trench required.
IP-B4	Avon Comp. B and A Destruct	Disconnection and destruction of Avon Unit B. Destruct of Avon A unit. Destruct natural gas header, Compressor associated process piping, utility (air and potable water) piping, and electrical cabling. Construction of a new natural gas header to replace existing compressor bypass header section. Note, extent of destruct scope to be defined in the next engineering phase. Depiction in Figure 4-2 and Figure 4-3 is limited.
IP-B5	New Comp. Suction Header Interface	Interface point with existing compressors suction header tie-in point, downstream of USFM.
IP-B6	New Comp. Vent Stack Interface	New vent stack and associated piping to be constructed in the vent stack area. New Nitrogen supply snuffing line to interface with existing nitrogen snuffing package piping.
IP-B7	New Comp. Discharge Header Interface	Interface point with existing compressors discharge header tie-in point.
IP-B8	New Comp. Potable Water (PW) Interface	New potable water piping to interface with Potable Water (PW) ring main. PW required for supply to the new compressor water mist cabinet. Note, interface definition based on understanding of extent of systems. Further definition to be developed in the next phase of engineering.
ELECTRIC DRIVEN VSD COMPRESSOR OPTION		
IP-B9	11kV Electrical Supply Cabling Interface	Installation of new 11kv switchgear on site which Interfaces with new UKPN Switchyard and existing onsite 11kv / 400v transformer.

4.2.3 Major Equipment: Mechanical, Electrical and C&I

Major equipment items comprising the new compressor installation are detailed in the associated equipment list (Ref. 8). Each GT driven compressor option is identical from an equipment installation requirement, varying in compressor location only, with the exception of Option B which compares the GT driven compressor with an electric driven VSD compressor option and Option C which requires the installation of a new vent array with associated snuffing package.

For the electrical scope, regardless of the location and compressor drive, the power supply for the new compressor cab and compressor package auxiliaries is assumed to follow the same philosophy as the existing compression units. i.e., a new main power feeder from the existing LER/ Control building. Differences between the electrical scope for the GT driven and electric driven VSD compressor options are highlighted below.

For the GT driven compressor, the electrical system interfaces are illustrated by Figure 4-4 below.

Figure 4-4: Electrical Tie-in Schematic (Construct/ Destruct) for a new build GT Driven Compressor

As per the Solar Titan T130 compressor units recently installed at the Peterborough Compressor Station, a local LER housing a 120 VDC UPS, MCC and General Small Power and Lighting Distribution Board (DB) is included as part of the new build GT driven compressor option. Therefore, for tie-in to the existing system, a single main feeder cable to the new compressor package is required, which will then be distributed internally by the Vendor. This electrical power distribution system design minimises the number of electrical tie-ins required within the existing facilities.

The new electric motor proposed is a 15 MW electric motor, controlled via a new VFD. The tie in voltage for this option will be at 11 kV which requires substantial modification to the incoming supply from the UKPN. The existing connection is not capable of supporting this level of load, so UKPN is required to install a significant amount of infrastructure to supply this power to the facility. There is also a requirement for a new 11 kV switchboard to distribute the power to the new VFD and to the existing facility, via a 11 kV / 400 VAC step down transformer. A new LER is also required to house the new 11 kV equipment. The power supply for the new turbine hall

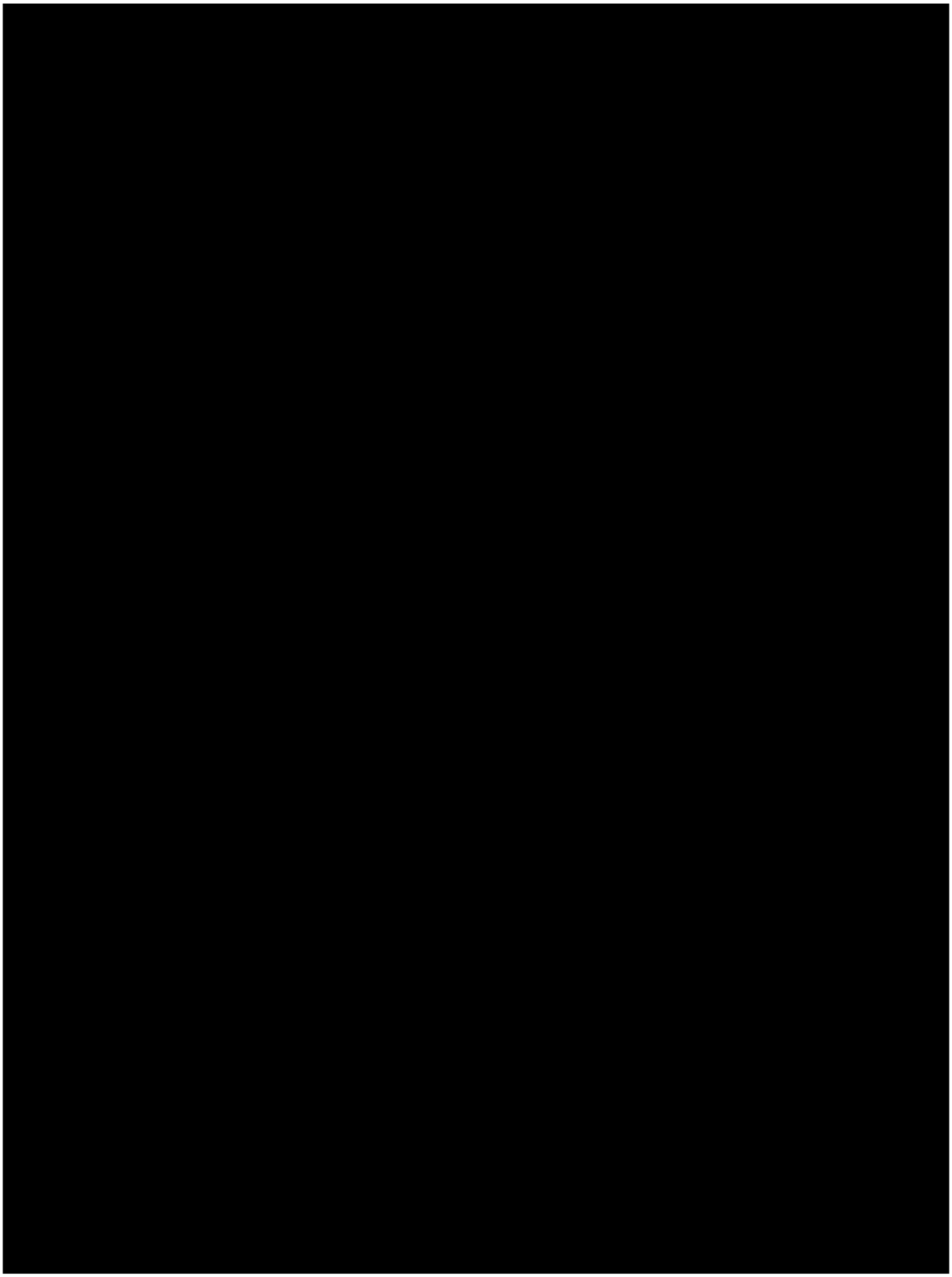
and compressor package auxiliaries has been assumed to follow the same philosophy as the existing turbine halls via a new main power feeder from existing LER/ Control building. There will also be main control cables from the existing LER/ Control building to the new turbine hall and from the new 11 kV LER and the new compressor turbine hall. The tie-in details are illustrated in Figure 4-5 below.

UKPN have provided a preliminary basis for supply of additional power to the King's Lynn site and is based on provision of a 33kV supply to site from the UKPN switchyard, whereas a 11kV supply was requested. Therefore, if the electrical VSD option is adopted, further clarifications with UKPN are required.

Additionally, UKPN provided a design and budget estimate for supply of 30 MVA, electrical power required for two units. No information has been provided for a 15 MVA supply, required for one unit. Therefore, this area will also require further clarification if the electrical VSD option is adopted.

Further details on the electrical scope including preliminary load summaries can be found within Reference 19.

Figure 4-5: Electrical Tie-in Schematic for a new build Electric Driven VSD Compressor



For the Control and Instrumentation scope in respect to a new GT or electric VSD driven compressor, the following modifications / new equipment are required as shown below and in Figure 4-6:

- Station control and safety system expansion / modification:
  - Distributed Control System (DCS);
  - Emergency Shutdown System (ESD);
  - Fire & Gas (F&G).
- Offsite control system expansion / modification:
  - Warwick remote control centre.
- New Field / Local equipment room:
  - Compressor / Driver Unit control panels;
  - Compressor Balance of Plant integration;
  - Interfaces to Station control and safety system;
  - Fire & Gas detection / extinguishant;
  - Public Announcement Extension;
  - Telephone Extension.

Note, it is assumed the existing or new station control and safety systems have the expansion capacity capability. Limitations of obsolescence and technical support associated for expansion of these system are not considered.

Figure 4-6: C&I Sketch - New Build Compressor Package

The following sub-sections provide detail associated with each specific location option and associated differentiating factors.

4.2.4 Option A

Illustrations depicting Option A are available in Figure 4-7 and Figure 4-8; layout and PFD [Ref. 20] respectively. This includes a new compressor unit in the existing King's Lynn Vent Area and a new Vent Area located in the Redundant Plant Area 1 Plinths.

Figure 4-7: Option A, Single New Build Compressor Layout

All options require the construction of new compressor foundations. Additionally, all options require utility supply lines including fuel gas, instrument air and potable water. Location Option A differs from considered alternatives (B and C) as follows:

- Civil scope;
  - Demolition of existing vent, including associated pit and foundations, and construction of compressor foundations;
  - Construction of new vent area local to existing Redundant Plant Area 1 plinths, including sterile area and local nitrogen snuffing package;
  - Construction of surrounding asphalt roads.
- Process tie-ins;
  - Suction header tie-in local to main station distribution header downstream of USFM;
  - Discharge header tie-in at station suction-discharge bypass header, downstream of blowdown utility route;

- Re-routing of station vent relief routes to new vent array, including station blowdown vent, common discharge vent from C-2301/2401 and discharge vent from new compressor;

- Electrical connections;
  - Cable trench extension from local Avon compressor unit area.

Figure 4-8: Option A, Single New Build Compressor PFD

[redacted]

4.2.5 Option B

Depictions of Option B are available in Figure 4-9, Figure 4-10 and Figure 4-11; layouts and PFD respectively, including new compressor unit in the Redundant Plant Area 1 Plinths.

Figure 4-9: Option B1: Single New Build Compressor Location – GT Driven Compressor

Figure 4-10: Option B2: Single New Build - Electric Driven VSD Compressor

Figure 4-11: Option B, Single New Build Compressor PFD (GT / VSD Driven Compressor)

Location Option B differs from considered alternatives (A and C) as follows:

- Civil scope;
  - Demolition of existing redundant plinths, including abandoned underground piping;
  - Extension of local asphalt road;
  - Site boundary fence extension.
- Process tie-ins;
  - Suction header tie-in at underground branch local to station metering area downstream of USFM;
  - Discharge header tie-in at available branch on station discharge manifold;
  - Compressor discharge vent line routed to new vent stack installed within existing station vent array;
- Electrical connections;

  GT and Electric VSD:
  - Cable trench extension (400V) from station scrubber area;

  Electric VSD Only:

- Existing electrical power supply and distribution switchgear at King's Lynn is not adequate to accommodate proposed design load;
- Installation of infrastructure, by UKPN, required for new 33kV incomer including new 33 kV overhead lines to site.
- New UKPN electrical switchyard located adjacent to King's Lynn Station on National Grid owned land to provide new 11 kV supply to site.
- New dedicated trenches required to route 11kV cable from UKPN switchyard to new onsite 11kV switchgear route and 11kV cable from new onsite switchgear to compressor location;

4.2.6 Option C

Option C illustrations are available in Figure 4-12 and Figure 4-13; layout and PFD respectively, including new compressor unit in the existing Avon Compressor Area.

Figure 4-12: Option C, Single New Build Compressor Location

Figure 4-13: Option C, Single New Build Compressor PFD

Location Option C differs from considered alternatives (A and B) as follows:

- Civil scope;
  - Demolition of existing/remaining Avon compressor units and foundations;
  - Site boundary fence extension.
- Process tie-ins;
  - Suction header tie-in at local existing Avon compressor header, upstream of station blowdown valve;
  - Discharge header tie-in at local existing Avon compressor header, upstream of station blowdown valve;
  - Compressor discharge vent line routed to new vent stack installed within existing station vent array;
  - Installation of new station suction side blowdown utility, routing of vent relief route and construction of new station blowdown vent within existing array;
- Electrical connections;
  - Cable trench extension from local Avon compressor unit area.

4.3 Two New Build Units Location Options

4.3.1 Site Layout Review

To meet the increase in requirement for high compression availability post 2030, the installation of two additional MCPD compliant provides additional resilience and also higher availability which may be beneficial given the current predictions for increased flows through King's Lynn Post 2030.

Table 4-4 details the options considered for the two new compressor unit locations. Note, the base case compressor type selected is a GT drive, as the plant layout is not impacted if an electric driven VSD unit is adopted.

Table 4-4: King's Lynn Two New Compressor Location Options

CASE NO.	LOCATION		COMPRESSOR TYPE
	COMPRESSOR 1	COMPRESSOR 2	
1	Existing Vent Area (Option A)	Existing Avons' Area (Option C)	2 X GT Drive
2	Redundant Plant Area 1 Plinths (Option B)	Existing Avons' Area (Option C)	2 X GT Drive
3	Existing Vent Area (Option A)	Redundant Plant Area 1 Plinths (Option B)	2 X GT Drive
4	Redundant Plant Area 1 Plinths (Option B)	Redundant Plant Area 1 Plinths (Option B)	2 X GT Drive

Separation distances for the above location options are provided in Table 4-5 (Ref. 15). As highlighted, each option complies with separation requirements from buildings and hazardous equipment, however, all options require site perimeter fence extensions, with Option 4 requiring the use of plot space outside of the current site security, but within the current National Grid land ownership boundary.

Table 4-5: Two New Compressor Separation Distances

Option	Proposed Distance (m)			
	Distance to Buildings (Note 1)	Distance to Essential / Hazardous Equipment (Note 2)	Distance to Outermost Security Fence (Without Modification (Note 3)	Distance to Outermost Security Fence (After Modification (Note 3)
1	44	32	32	40
2	44	33	18	40
3	85	32	18	40
4	160	33	-5	40

Notes

1. The only building on site is the control building and distances shown are to this building.
2. The distance shown is the distance to the nearest item of hazardous equipment.
3. For all options, the new units do not meet the recommended distance to the security fence making extension necessary. The distances shown is the governing / worst case scenario distance from either compressor location for each option.

4.3.1 Interface Schematic and Register

Critical interfaces with existing site facilities for the two new build compressor options are similar to the single new build compressor listed in Section 4.2.2. Two new build compressors will additionally include:

- Construction of two separate new Compressor discharge vent relief routes incorporated as part of the station vent array, including the nitrogen snuffing lines to the vent stack area.

The interface schematics for the two unit GT and electric driven VSD compressor options are shown in Figure 4-14 and Figure 4-15 below. The associated interface register is presented in Table 4-6.

Figure 4-14: Two New Build GT Driven Compressors Interface Schematic

Figure 4-15: Two New Build Electric Driven VSD Compressors Interface Schematic

Table 4-6: Interface Register – Two Unit Compressors

Interface No.	Description	Notes
COMMON INTERFACE POINTS FOR BOTH GT AND ELECTRIC DRIVEN COMPRESSORS		
IP-4a1 / IP-4b1	Control Signal Interface	Control signals (DCS, UCP, ESD, F&G) from new build compressors #1 & #2 package interfacing with existing station control & safety systems (Dual ICSS Network / Hardwired Trips) via a new central room station control panel. Control cables utilise existing cable trenching partway, cable trench extension required.
IP-4a2 / IP-4b2	Air Interface	Interface with existing instrument air package. New piping constructed to supply IA/Seal Gas to actuated valves and the new build compressor. Note, status and depiction of existing Instrument Air/Seal Gas uncertain. Interface definition based on understanding of extent of systems. Further definition to be developed in the next phase of engineering.
IP-4a3 / IP-4b3	Avon Comp. B & A Destruct	Disconnection and destruction of Avon Unit B. Destruct of Avon A. Destruct natural gas header, Compressor associated process piping, utility (air and potable water) piping, and electrical cabling. Construction of a new natural gas header to replace existing compressor bypass header section. Note, extent of destruct scope to be defined in the next engineering phase. Depiction in Figure 4-14 and Figure 4-15 is limited.
IP-4a4 / IP-4b4	New Comp. Suction Header Interface	Interface point with existing compressors suction header tie-in point, downstream of USFM.
IP-4a5 / IP-4b5	New Comp #1. Vent Stack Interface	New vent stack and associated piping to be constructed in the vent stack area. New Nitrogen supply snuffing line to interface with existing nitrogen snuffing package piping.
IP-4a6 / IP-4b6	New Comp. #2 Vent Stack Interface	New vent stack and associated piping to be constructed in the vent stack area. New Nitrogen supply snuffing line to interface with existing nitrogen snuffing package piping.
IP-4a7 / IP-4b7	Electrical Supply Cabling Interface	Cabling to interface with existing electrical switchroom to provide power for Turbine auxiliaries and control cabling to the new build compressor #1 & #2 packages. New cable trench to be constructed.
IP-4a8 / IP-4b8	New Comp. Discharge Header Interface	Interface point with existing compressor discharge header tie-in point.
IP-4a9 / IP-4b9	New Comp. Potable Water (PW) Interface	New potable water piping to interface with PW ring main. PW required for supply to the new compressors water mist cabinet. Location of second New Build Compressor is located above PW ring main. PW line to be re-routed if option is selected.
ELECTRIC DRIVEN VSD COMPRESSOR OPTION		
IP-4b10	11kV Electrical Supply Cabling Interface	Installation of new 11kv switchgear on site which Interfaces with new UKPN Switchyard and existing onsite 11kv / 400v transformer.

4.3.2 Major Equipment: Mechanical, Electrical and C&I

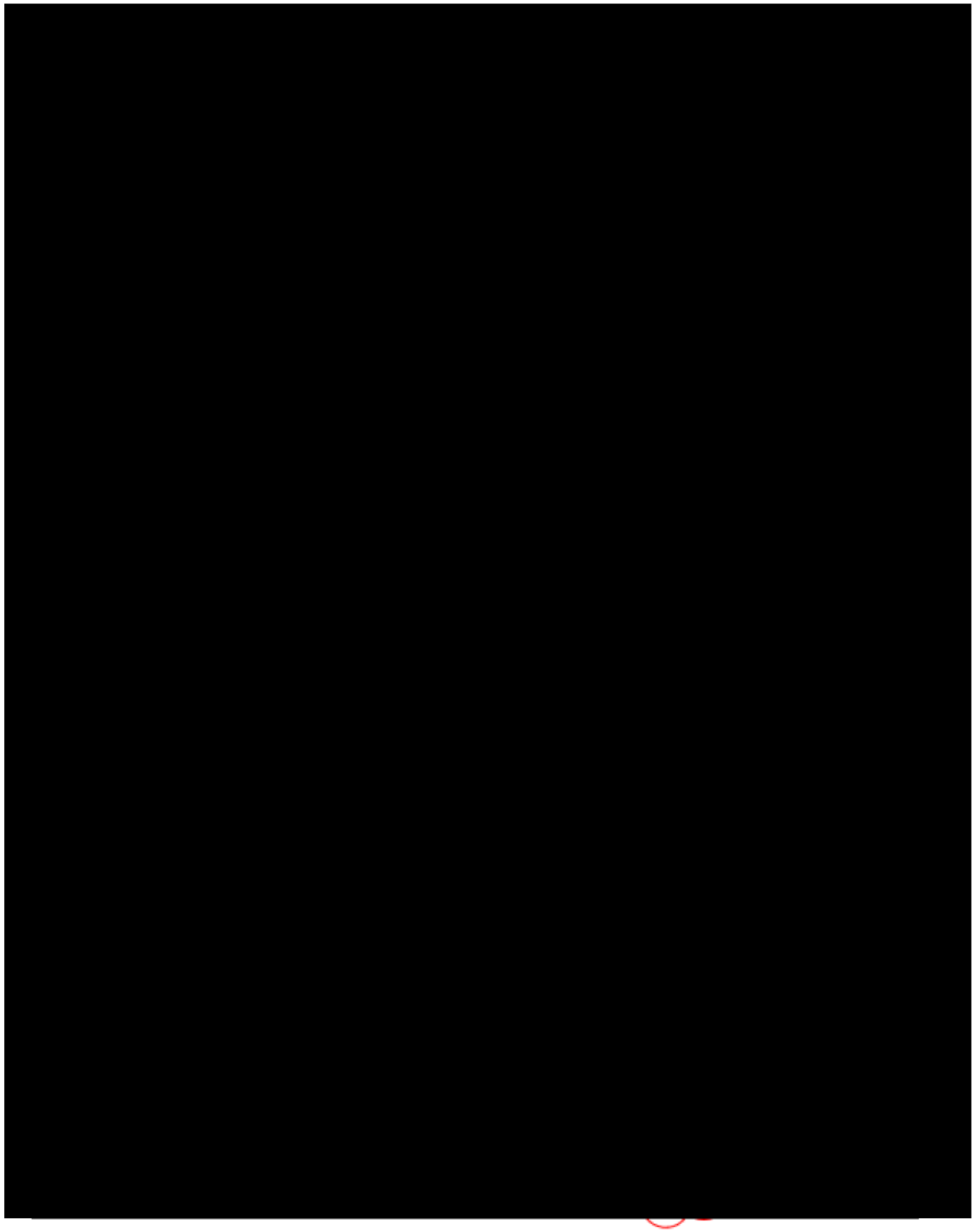
Major equipment items comprising the two unit new compressor installation are detailed in the associated equipment list (Ref. 8). Each GT driven compressor option is identical from an equipment installation requirement, varying in compressor location only, with the exception of

Option 4 which compares the GT driven compressor with an electric driven VSD compressor option and Option 1 and 3 which requires the installation of a new vent array with associated snuffing package.

For the electrical scope, regardless of the location and compressor drive, the power supply for the new compressor cab and compressor package auxiliaries is assumed to follow the same philosophy as the existing compression units. i.e. a new main power feeder from the existing LER/ Control building. Differences between the electrical scope for the GT driven and electric driven VSD compressor options are highlighted in Section 4.2.3. For the two new build options, differences in the tie-in detail are highlighted below in Figure 4-16 and Figure 4-17.

Figure 4-16: Electrical Tie-in Schematic (Construct/ Destruct) for two new GT Driven Compressors

Figure 4-17: Electrical Tie-in Schematic (Construct/ Destruct) for two new Electric Driven VSD Compressors



Further details on the electrical scope including preliminary load summaries can be found within Reference 19.

For details on the Control and Instrumentation scope in respect to a new GT or electric VSD driven compressors, refer to Section 4.2.3 and Figure 4-6 for all modifications / new equipment requirements.

The following sub-sections provide detail associated with each specific location option and associated differentiating factors.

4.3.3 Option 1

Illustration depicting Option 1 is shown in Figure 4-18. This includes a new build compressor at the following locations:

- Existing Vent Area;
- Existing Avons' Area.

This option is a combination of the single new build options A and C. Further technical definition is found in Sections 4.2.4 and 4.2.6.

Figure 4-18: Option 1, Two New Build Compressor Locations

4.3.4 Option 2

Illustration depicting Option 2 is shown in Figure 4-19. This includes a new build compressor at the following locations:

- Redundant Plant Area 1 Plinths;
- Existing Avons' Area.

This option is a combination of the single new build options B and C. Further technical definition is found in Sections 4.2.5 and 4.2.6.

Figure 4-19: Option 2, Two New Build Compressor Locations

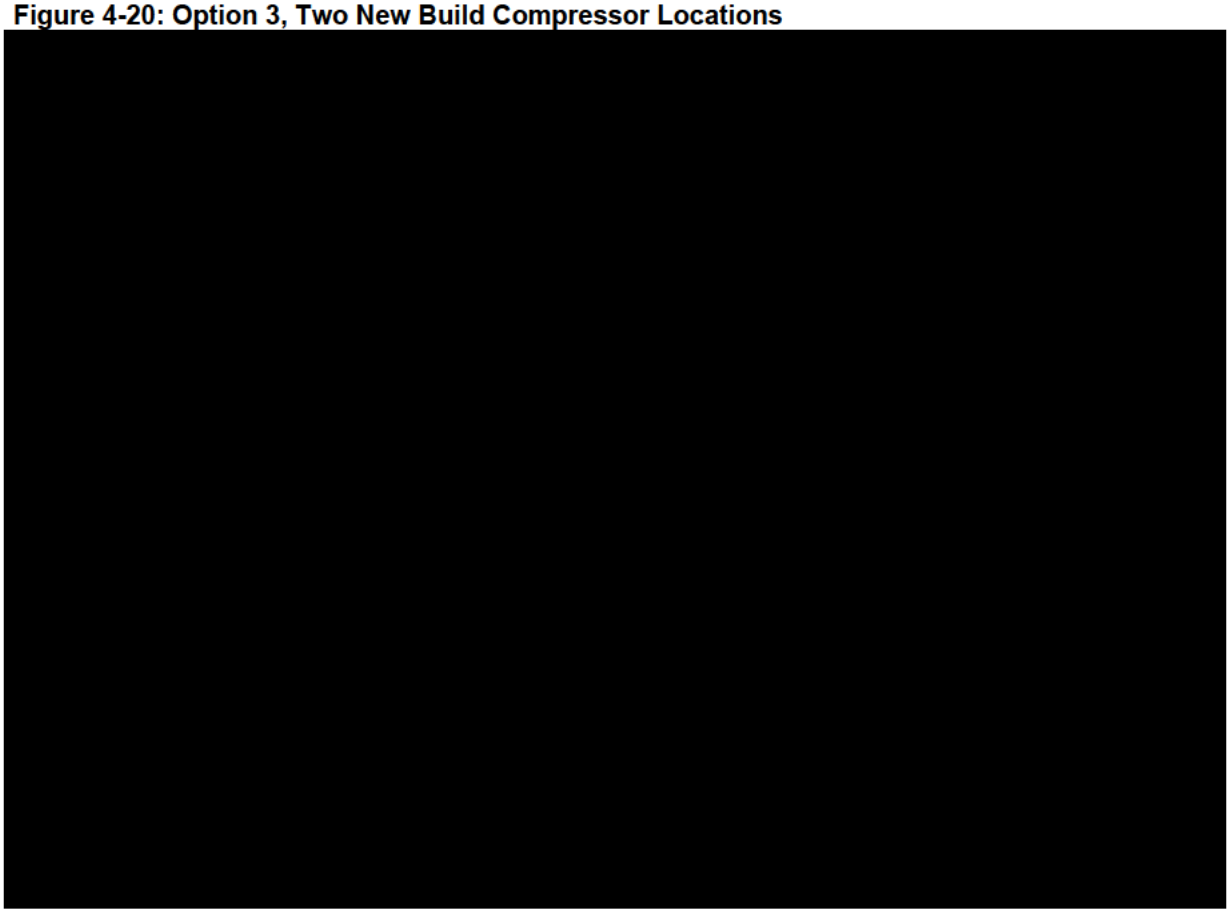
4.3.5 Option 3

Illustration depicting Option 3 is shown in Figure 4-20. This includes a new build compressor at the following locations:

- Redundant Plant Area 1 Plinths;
- Existing Vent Area.

This option is a combination of the single new build options A and B. Further technical definition is found in Sections 4.2.4 and 4.2.5.

Figure 4-20: Option 3, Two New Build Compressor Locations



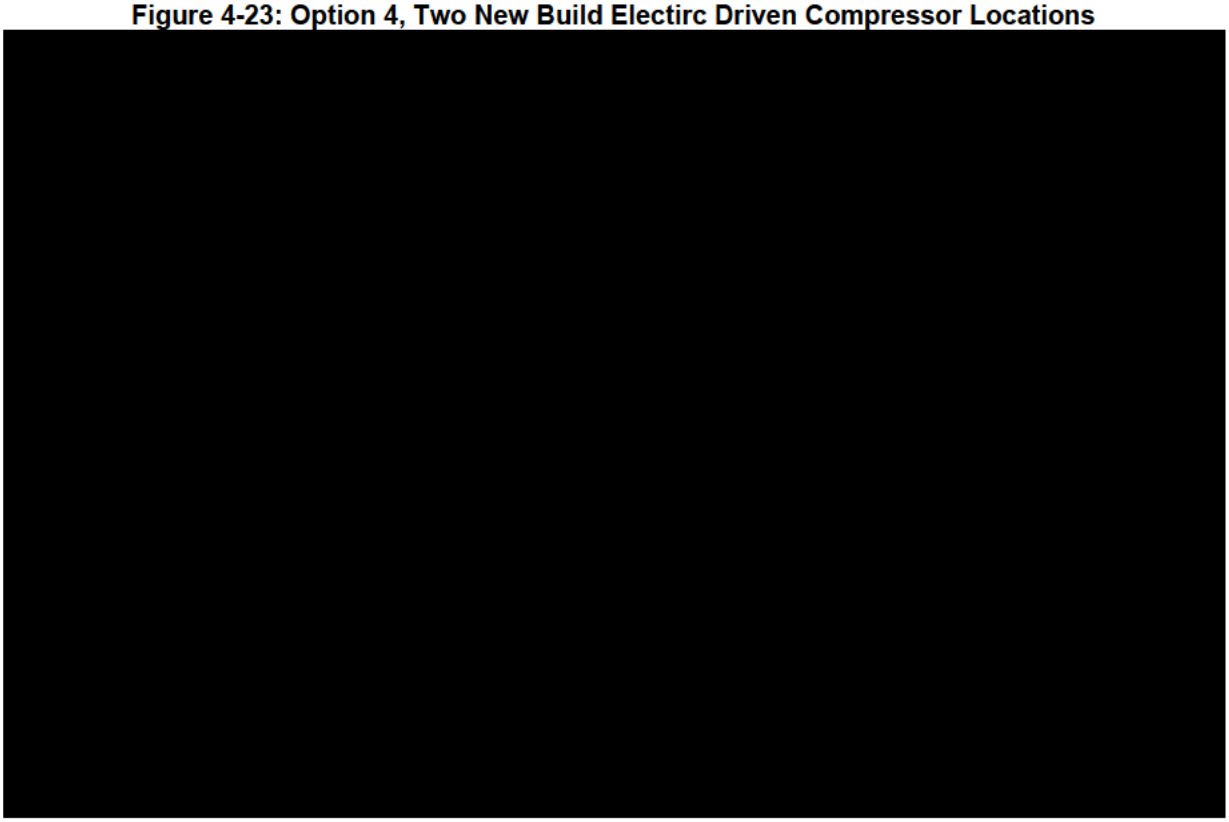
4.3.6 Option 4

Illustrations depicting Option 4 are shown in Figure 4-21 and Figure 4-22; PFD and layout respectively. This includes two new build compressors located on Redundant Plant Area 1 Plinths.

Figure 4-21: Option 4, Two New Build Compressors PFD

Figure 4-22: Option 4, Two New Build GT Driven Compressor Locations

Figure 4-23: Option 4, Two New Build Electirc Driven Compressor Locations



Location Option 4 differs from considered alternatives (1, 2 and 3) as follows:

- Civil scope;
  - Larger site boundary fence extension, although within the current National Grid land ownership boundary.
  - For the electric VSD compressor option, a new UKPN owned switchyard is also constructed adjacent to the site boundary.
- Process Tie-In:
  - Second New Build Compressor is positioned above the Potable Water ring main line. If this option is selected, the potable water line will need to be re-routed.

4.4 Retrofit Options

4.4.1 Single Unit Option – Site Layout Review

The King's Lynn Retrofit Options for a Single Unit are detailed in Table 4-7. The retrofit options being considered will upgrade Avon Unit B with the latest technology to ensure MCPD compliance.

Table 4-7: King's Lynn Compressor Retrofit Options

CASE NO.	LOCATION	TECHNOLOGY DETAIL
D	Existing Compressor B	Retrofit emissions compliant DLE combustion system to Avon gas generator
E	Existing Compressor B	Retrofit Control System Restricted Performance (CSRP)
F	Existing Compressor B	Install Selective Catalytic Reduction (SCR) unit

Figure 4-24 shows the location of Avon Unit B, plus the plot space required by the SCR facilities including ammonia storage and unloading facilities. For the DLE and CSRP options, no additional equipment is installed outside of the Avon Unit B Compressor Building.

For the SCR option, ammonia offloading facilities are located such that the existing road network can be utilised and there is direct access to the main gate. The SCR related ammonia facilities have been installed as far away as possible from other process facilities and also as far away from the security fence as possible to minimise the potential for escalation (although not a domino effect) should an accidental hydrocarbon fire occur and to limit potential for offsite impact.

A horizontal unit as opposed to vertical SCR unit is preferred as it will limit the weight imposed on the existing Cab and thus support structures required to support the SCR unit.

Figure 4-24: Retrofit Options (SCR) Location

For the existing Avon Unit B Compressor, Table 4-8 shows that all retrofit options are able to meet the recommended distances to buildings and other hazardous process areas, however, it does not meet the recommended distance to the security fence. A small section of the fence would need to be moved further away to meet the recommended distance.

There is sufficient land within the existing National Grid land ownership boundary to meet the separation distance requirement. So, land acquisition would not be required to meet the separation distance requirement. However, given that the unit does not currently meet the recommended separation distance to the security fence, this non-compliance is not expected to be an issue. Therefore, no site fence modification is envisioned.

For information, the available separation distances for the ammonia storage required by Option F (SCR) is also shown. It should be noted that T/SP/G/37 (Ref. 9) target separation distances are applicable to hydrocarbon containing facilities and not chemical equipment.

Table 4-8: Retrofit Options Separation and Spacing Distances

Option	Proposed Distance (m)			
	Distance to Buildings (Note 1)	Distance to Essential / Hazardous Equipment (Note 2)	Distance to Outermost Security Fence (Without Modification (Note 3)	Distance to Outermost Security Fence (After Modification (Note 3)
D (DLE)	70	55/ 50	32	N/A
E (CSRP)	70	55/ 50	32	N/A
F (SCR)	70	55/ 50	32	N/A
F (Ammonia Storage)	90	76/ 65	28	N/A

Notes:
1. The only building on site is the control building and distances shown are to this building.
2. Distance to existing SGT-400 (C-2401) Compressor above ground process pipework / SGT -400 above ground vent pipework.
3. The existing unit does not meet the recommended distance to the security fence – No site fence modification is envisioned.

4.4.2 Single Unit Option - Interface Schematic and Register

Critical interfaces with existing site facilities for the compressor retrofit options include:

- As part of the Avon Unit B re-life scope, the unit actuated valves will be replaced / overhauled. In order to comply with the latest National Grid specifications, the valve actuation will be changed from fuel gas to instrument air as part of the MCPD project scope. Hence, tie-in to the existing station instrument air package are required.
- Integration with station Control and Instrumentation systems, including control and safety panel installation in existing control building, and inter-connection with DCS, ESD, F&G at compressor LER and enclosure.
- Electrical supply to Avon Unit B for the existing turbine hall retained for all options. Interface with existing power cabling to expand network for additional feeders to support the new CSRP and SCR package.

The interface schematics for the retrofit only options are shown in Figure 4-25, Figure 4-26 and Figure 4-27. The associated interface register is presented in Table 4-9.

Figure 4-25: Option D, DLE Retrofit Interface Schematic

Figure 4-26: Option E, CSRP Retrofit Interface Schematic

Figure 4-27: Option F, SCR Retrofit Interface Schematic

Table 4-9: Retrofit Interface Register

Interface No.	Description	Notes
COMMON INTERFACE POINTS FOR RETROFIT OPTIONS		
IP-D1 / IP-E1	Control Signal Interface (COMMON EXCEPT SCR)	Control signals (UCP) from retrofit option interfacing with existing station control & safety systems (Hardwired Trips & DCS/UCP Comms & ESD/DCS) via a new central room station control panel. Control cables utilise existing cable trench. It should be noted that a new compressor control system will be installed as part of the asset health scope.
IP-D4 / IP-E2 / IP-F4	Instrument Air (IA) Interface - IA Package	Interface with existing instrument air package. New piping constructed to supply IA to Avon Unit B Compressor.
IP-D5 / IP-E3 / IP-F5	Instrument Air (IA) Interface – Avon Unit B	As part of the Avon Unit B re-life scope, the unit actuated valves will be replaced / overhauled. In order to comply with the latest National Grid specifications, the valve actuation will be changed from fuel gas to instrument air as part of the MCPD project scope.
OPTION D – DLE RETROFIT OPTION		
IP-D2	DLE - Turbine Power Interface	DLE unit interface with existing power supply. Assuming I ke for like change out of components, therefore, no major new electrical equipment. Power supply for the existing turbine hall will be retained as it is.

IP-D3	Turbine - DLE Interface	Retrofit of DLE unit to Avon Unit B Engine.
IP-D6	DLE Fuel Gas Interface	Modification of existing fuel gas piping to interface with new piping constructed to supply fuel gas to the DLE package.
OPTION E – CSRP RETROFIT OPTION		
IP-E4	CSRP - Turbine Power Interface	CSRP unit interface with existing 400V power supply. Power supply for the existing turbine hall retained as is. Additional feeders to support the new CSRP package have been included.
OPTION F – SCR RETROFIT OPTION		
IP-F1	Control Signal Interface	Control signals (UCP) from SCR retrofit option interfacing with existing station control & safety systems (Hardwired Trips & DCS/UCP Comms & ESD/DCS) via a new central room station control panel. Fire & Gas detectors signal (F&G) from SCR package interface directly with existing station C&I systems. Control cables utilise existing cable trenching.
IP-F2	SCR - Turbine Power Interface	DLE unit interface with existing power supply. Power supply for the existing turbine hall retained as is. New SCR package requires several power feeders to support a variety of pumps, blowers, fans and control panels.
IP-F3	Turbine - SCR Interface	Avon Unit B Area SCR Retrofit. Flue Gas from Avon Unit B Stack to new SCR Package.

4.4.1 Single Unit Option – Major Equipment: Mechanical, Electrical and Control and Instrumentations

Major equipment items for the retrofit options are detailed in the associated equipment list (Ref. 8).

As part of the SCR package, new civil foundations and surface drainage facilities will be provided as required. It is necessary to install ammonia storage and unloading facilities. This introduces a new toxic hazard to the site. The selected ammonia concentration for the SCR facilities is 24.5% (Ref. 15). Ammonia solution concentrations between 10%-35% carries limited risk to site personnel and very low potential for offsite impact. At these concentrations, it is still a corrosive hazard but is managed / handled with gloves and a mask. The process flow diagram for the SCR option is shown in Figure 4-28. Note, as the DLE and CSRP Options do not feature changes to process equipment (modifications limited to existing equipment within the compressor cab), Process Flow Diagrams have not been created for these options.

Figure 4-28: Retrofit Options PFD (SCR)

Detailed requirements for the Electrical and Control and Instrumentations scope are listed below for each Retrofit Option. Note it is assumed that the existing or new station control and safety systems have the modification capacity capability. Limitations of obsolescence and technical support associated for expansion of these system are not considered.

4.4.1.1 Option D

Option D, considers a DLE Engine Retrofit to the existing Avon Unit B package. Therefore, as this is a modification to an existing package, assuming like for like change out of components, there will not be any major new electrical equipment within this option. Power supply for the existing turbine hall will be retained.

For the Control and Instrumentation scope, the following modifications / new equipment are required as shown below and in Figure 4-29:

- Station control and safety system modification
  - DCS;
  - ESD;
  - F&G.
- Offsite control system modification

- Warwick remote control centre.

- New Unit Control panels
  - DLE Unit control panel/s;
  - Interfaces to station control and safety system;
  - Unit Control panel field cabling installation;

Figure 4-29: C&I Sketch - Option D DLE Retrofit

4.4.1.2 Option E

Option E considers a CSRP upgrade to the existing Avon Unit B package. Therefore, as this is a modification to an existing package, assuming like for there will not be any new major electrical equipment within this concept. Power supply for the existing turbine hall will be retained as it is.

For the Control and Instrumentation scope, the following modifications / new equipment are required as shown below in Figure 4-30.

- Station control and safety system modifications:
  - DCS;
  - ESD;
  - F&G.

- Offsite control system modification
  - Warwick remote control centre.
- New Unit Control panels
  - CSRP Unit control panel/s;
  - Interfaces to Station control and safety system;
  - Unit Control panel field cabling installation.

Figure 4-30: C&I Sketch - Option E CSRP Retrofit

4.4.1.3 Option F

Option F considers a major modification to the existing Avon Unit B package, addressing installation of a new SCR package. The power supply for the existing turbine hall has been assumed to be retained in line with the current philosophy, but the new SCR package requires several power feeders to support a variety of pumps, blowers, fans and control panels. These have been allocated to existing spare equipped cubicles that will be modified to suit the connected load.

Figure 4-31 and Figure 4-32 illustrate the tie-ins required for the SCR Retrofit Option.

Figure 4-31: Option F Tie-ins Main LV SWBD

Figure 4-32: Option F Tie-ins Turbine Auxiliary MCC

For the Control and Instrumentation scope, the following modifications / new equipment are required as shown below in Figure 4-33.

- Station control and safety system modification
  - DCS;

- ESD;
- F&G.

- Offsite control system modification
  - Warwick remote control centre.
- New Unit Control panels
  - SCR Unit control panel/s;
  - CEMS Unit Control panel/s
  - Interfaces to station control and safety system;
  - Unit Control panel field cabling installation;
  - Ammonia Storage/delivery system integration;
  - F&G detection - (e.g. confined space CO detection as necessary) / cabling installation.

Figure 4-33: C&I Sketch - Option F SCR Retrofit

Further details on the electrical scope including preliminary load summaries can be found within Reference 19.

4.5 Hybrid Two Unit Option

A representative hybrid option, Option 5, which is a combination of a new build GT driven unit at Redundant Plant Area 1 Plinths plus DLE retrofit to the Avon unit B is shown in Figure 4-34. The plant layout is not impacted if an electric driven VSD unit or another MCPD retrofit option (i.e., CSRP, SCR) is adopted for the Avon unit B.

Figure 4-34: PFD – Hybrid Option 5

The Electrical and Control and Instrumentation modifications required for this option is the same as Option D plus Options B1 or B2 depending upon the selected driver for the new build unit.

4.5.1 Interface Schematic and Register

The critical interfaces with existing site facilities for the Hybrid options are a combination of a new build GT driven unit at Redundant Plant Area 1 Plinths plus DLE retrofit to the Avon unit B shown in Figure 4-2, Figure 4-3 and Figure 4-25.

5.0 STUDY EXECUTION METHODOLOGY

5.1 General

As noted in Section 4.0, several potential on-site locations can be considered for the new build units. In order to limit the number of option permutations plus make best use of the detailed CBA and BAT Assessment to be undertaken by National Grid, a phased approach was adopted for the study execution as follows:

- Phase 1: The potential on-site locations for the new build units were screened first. Both gas turbine driven and electric VSD driven units plus one and two new units were considered as part of the Phase 1 assessment;
- Phase 2: For the identified preferred location of the single and two new build units plus the retrofit options, input data required for the CBA and BAT assessment was generated in order to assist National Grid to select a preferred MCPD compliant option for the King's Lynn Compressor Station.

The study execution methodology is illustrated by Figure 1-2.

5.2 Phase 1

The potential locations for the new build units were screened based on preliminary cost estimates (i.e., +/-50% accuracy), preliminary project execution schedules (i.e., Level 1) and a qualitative techno-economic assessment.

The methodology used for screening of new build locations options was a qualitative traffic light based assessment, performed against the following key project execution / development criteria:

- Project Development Cost:
  i.e. what is the relative development cost of each option.
- Project Execution Schedule:
  i.e. is the target date for MCPD achievable.
- Impact on existing Operations:
  i.e. duration of total site shutdowns and/or unavailability of back-up compression facilities.
- Safety Assessment:
  i.e. does the new location comply with plant separation criteria recommended by National Grid Specification for Site Location and Layout Studies and Reviews T/SP/G/37.
- Environmental Impact:
  i.e. are there any significant environmental impacts associated with the new compressor locations.
- Constructability:
  i.e. what is the relative construction complexity of each option with regards to the number of brownfield modifications required, access to the construction location etc.

It should be noted that the compressor driver options being considered for the new unit options are proven and technically mature, therefore technical maturity / risk is not a differentiator and hence was not considered for the qualitative assessment.

The following traffic light grading / classification was used:

Traffic Light	Grading / Classification
	Meets the specified criteria and / or offers the best option for the criteria.
	Marginally fails to meet the specified criteria and / or is slightly worse against the criteria than the best option.
	Fails to meet the criteria and / or is significantly worse against the criteria than the best option.

As the single and two new build units options are not directly comparable, the qualitative assessment was performed separately for the single or two unit options. Refer to Section 7.0 for the results of the screening.

5.3 Phase 2

In order to help inform the preferred MCPD complaint option, a detailed Cost Benefit Analysis (CBA) and BAT Assessment will be performed by National Grid for all MCPD Compliance options using the following information:

- Development cost (i.e., +/-30% Cost Estimates). Refer to Section 9.0 for details;
- Development schedule (i.e., Level 2 Project Execution Schedules). Refer to Section 10.0 for details;
- Risk and opportunities associated with each option. Refer to Section 11.0 for details;
- Ability of the Options to comply with required Process Duty Specifications. Refer to Section 6.0 for details;
- Site Layout Review. Refer to Section 8.2 for details;
- Assessment of the embodied carbon emissions associated with the construction of the options. Refer to Section 8.3 for details;
- BAT Assessment Input Sheet. Refer to Section 8.4 for details;
- Environmental impact (i.e., impact on site biodiversity) of the options. Refer to Section 8.5 for details;

Both one and two MCPD compliant options will be considered by the CBA. For the two unit options, two new build units and one new build plus one an upgraded Avon Unit B will also be considered.

6.0 STATION DUTY SPECIFICATIONS

Key Reference Document

203513C-001-RT-0008-0001	King's Lynn Risk Compressor Station Process Description [Ref. 17]

6.1 General

This section presents a summary of the findings with regards to whether the gas turbine compressor (GTC) packages installed at the King's Lynn Compressor Station can achieve the defined site Process Duty Specification (PDS) operating duties in current and / or potentially modified configurations post the MCPD project implementation. The PDS operating points are presented in Section 3.2 and full assessment, including basis and assumptions, is presented by Reference 17.

Table 6-1 provides a summary of the PDS operating cases being evaluated as part of the CBA and it also provides a cross-reference to the MCPD compliance options described in this report.

Table 6-1: CBA Options

Option No.	Description	1. Decommissioned 2030	2. 500 hr	4. 1533 DLE	5. 1533 CSRP	6. 1533 SCR	8. New Unit (GT)
	3 Unit Site						
1	Counterfactual (Do Nothing) + One 500 Hour Avon (requires AH upkeep)	1	1				
2	One Derated (CSRP) Avon	1			1		
3	One SCR Retrofitted Avon (based on 1533)	1				1	
4	One 1533 DLE retrofit	1		1			
5	One New GT (Brownfield) + Decommission Avon	2					1
	4 Unit Site						
6	Two New GT Units (Brownfield) + Avon Decommissioned	2					2
7	One New GT Units (Brownfield) + One 500 Hour Avon (requires AH upkeep)	1	1				1
	Following pCBA results & Ofgem Feedback (20/09)						
8	Decomission Avon	2					

Notes

1. ***Base Case includes availability enhancements to Avon (Unit B).***
2. ***Only GT based solutions will be included in the preliminary CBA. If a new unit is preferrable following initial CBA, a further assessment of a VSD will be evaluated.***
3. ***All options assume SGT 400 Units will be re-wheeled as part of the MCPD Project (Refer to Project Scope Query PAC1051190-PDSQ-006).***
4. ***Unit A to be decommissioned for all options.***

6.2 Compressor Package Design Configuration

The following gas turbine driver and compressor packages were considered in the Compressor Performance Review. New build units will be specified and designed to achieve the required process duty specifications and therefore no performance assessment is necessary.

SGT-400 Units Options

Two SGT-400 driver package options were reviewed as part of the performance evaluations:

a) SGT-400 (13MW version), as installed (Note 1);

b) SGT-400 Alt CT (Alternative Compressor Turbine) (13MW version).

Notes:

1. The stated compressor site rating of 13MW is subject to variation based on conditions and assumes a 6% degradation margin compared to a new clean machine. The 13.4 MW quoted in Table 3-2 is the ISO rating at 15°C and considers no losses, whereas the performance assessment has been based on a rating in specific operating circumstances, accounting for losses and ambient temperature variation (i.e., 13 MW).
2. Option b) is a potential SGT-400 upgrade, to provide greater capacity for number of starts in a service life, utilising the alternative turbine blade material option (upgrade typically undertaken during an overhaul). This option has been considered based on National Grid's observation that the existing SGT-400s currently suffer from turbine blade issues due to number of starts.

The SGT-400 performance is based on the Siemens Energy's SIPEP performance desk, considering; typically 100mmWG inlet and 75mmWG exhaust losses, typical network gas composition for fuel gas and default NOx & CO emissions limits for both options.

Avon Unit B Options

The following Avon Unit options were reviewed as part of the performance evaluations:

a) Avon (1533 rating & GEC EAS 133 Power Turbine (PT)), as installed;

b) Avon (1533 rating & GEC EAS 133 PT), fitted with Selective Catalytic Reduction (SCR) unit;

c) Avon (1533 rating & GEC EAS 133 PT), fitted with Control System Restricted Performance (CSRP);

d) Avon (1533 rating & GEC EAS 133 PT) fitted with Alba Power or Siemens Dry Low Emissions (DLE) combustion upgrade.

The Avon unit, as installed performance is based on the Rolls Royce's Avon 1533 data considering 100mmWG inlet and 75mmWG exhaust losses.

For the SCR unit option, the addition of the SCR to the exhaust system will increase the exhaust system pressure losses. As a conservative approach, the total exhaust pressure loss is assumed to increase to 300mmWG, based on experience and discussion with a SCR vendor. The increased exhaust pressure loss is considered to reduce the maximum power output by 1.22%, based on performance of similar gas turbines.

The CSRP option performance is based on the installed unit site performance, with the maximum power output factored by 0.934, based on National Grid's predicted Avon performance.

The power output for the Avon, with either the Alba Power or Siemens DLE upgrade fitted, is assumed unchanged to installed unit site performance.

Relocated Avonbridge Unit

There is an Ex Avonbridge/ Bathgate Compressor Station SGT-400 available that could be relocated to King's Lynn and used instead of retrofitting of the Avon Unit B.

However, it was determined that the King's Lynn operating points are not a good match for the Avonbridge compressor unit. The King's Lynn PDS duties require greater flow and less head, than the original Avonbridge duties the compressor was selected for. The differences are too significant that even a compressor re-wheel will not make its use viable. The King's Lynn design duty point flows are approximately twice the Avonbridge unit design duties. Additionally, given the considerably higher actual volumetric flowrate duties require at King's Lynn, it is considered that inlet and outlet compressor nozzles sizes etc. will also be too small for the required duties.

Hence, due to the Avonbridge compressor being unsuitable in its current configuration, its use was not considered further. Use of the existing Avonbridge gas turbine driver with a new compressor package has also not been considered due to concerns with performance guarantee issues with the use of a used gas turbine driver package.

6.3 Compressor Train Performance Summary

Table 6-2 provides a summary of the required compressor power demand vs available GT power for the different compressor package configurations of for each PDS duty. It should be noted that C3 and C4 duties are the most frequent operating points plus C5 and C7 duties require two units in operation.

Table 6-2: Compressor Train Performance Summary

Duty	No. Units Oper.	SGT-400	SGT-400 Alt CT	SGT-400 (Re-wheel)	SGT-400 Alt CT (Re-wheel)	AVON 1533	AVON 1533 - SCR	AVON 1533 - CSRP	AVON 1533 - DLE
C1	1	✓	✓	✓	✓	✓	✓	✓	✓
C2	1	✓	✓	✓	✓	✓	✓	✗	✓
C3	1	✗	✗	✓	✗	✓	✓	✗	✓
C4	1	✗	✗	✓	✓	✓	✓	✓	✓
C5	2	✓	✓	✓	✓	✓	✓	✓	✓
C6	1	✓	✓	✓	✓	✓	✓	✓	✓
C7	2	✓	✓	✓	✓	✓	✗	✗	✓
C8	1	✓	✓	✓	✓	✓	✓	✓	✓
C3 Alt	2	✓	✓	N/A	✓	N/A	N/A	✓	N/A
C4 Alt	2	✓	✓	N/A	N/A	N/A	N/A	N/A	N/A
C7 Alt	2	✓	✓	✓	✓	✓	✓	✓	✓

Power Margin Key:	Achievable >6% power margin	Potentially Achievable <6% power margin	Not Achievable

The existing Avon Unit B, as installed or with DLE upgrade fitted, is able to achieve all PDS operating points. Although, the gas turbine power margin for C2, C3 and C7 duties, is <6%. This is considered sufficient to ensure the duties can be achieved once the gas turbine overhaul/ manufacturing power output tolerances and unit degradation between overhauls are considered.

It should be noted that C2, C3 and C4 operating points are specified as single unit operation only, so two units can be operated in parallel to mitigate when one unit cannot achieve the duty point.

The C7 duty, is a two-unit operating duty, and can be mitigated by rebalancing compressor flows (decreasing Avon Unit flow and increasing SGT-400 unit flow) as alternative C7 Alt duty point.

Based on the above assessment, the following is concluded:

- The Avon Unit B compressor, as installed, or with DLE upgrade fitted, is able to achieve all PDS operating points, with acceptable power margin, if mitigations for C2, C3 and C7 duties are considered.

- Fitting an SCR to the existing Avon Unit B reduces its available power margin for all duties, and therefore its operational flexibility, including preventing the C7 duty being achieved, although in mitigation, the C7 Alt duty can still be achieved.
- The CSRP upgrade fitted to the existing Avon Unit B compromises the operationally flexibility the unit can offer, but this may be acceptable with potential reduction in C7 duty flow, depending on the level of gas turbine degradation.
- A single existing SGT-400 unit is unable to achieve the C3 and C4 duties, as compressor selection appears to have been based on a high head/ lower flow duty point design. The C3 and C4 duties can be achieved with two existing SGT-400 units operating in parallel.
- A re-wheel of the SGT-400 compressors improves operating performance.
- If the SGT-400s are upgraded to Alt CT configuration, the associated power output reduction would reduce the overall flexibility and power margin the SGT-400 can offer, such that available power is similar to installed Avon unit.

7.0 NEW BUILD LOCATION OPTIONS SCREENING

Key Reference Documents

203513C-001-RT-0300	King's Lynn Compressor Station Cost Estimates (Phase 1 +/-50%) (Ref. 4)
203513C-001-PLG-0300	King's Lynn Compressor Station Level 1 Schedules (Phase 1) (Ref. 5)
203513C-001-RT-0250	King's Lynn Compressor Station Layout Review Report (Phase 1) (Ref. 6)
203513C-001-RT-0503	King's Lynn Compressor Station Options Review (Phase 1) (Ref. 7)

7.1 General

There are several potential alternative locations for siting of the new build compression units at King's Lynn as covered in Section 4.0. As detailed in Section 5.0, a phased approach was adopted for the option screening. The potential on-site locations for the new build units were screened first. Both gas turbine driven and electric VSD driven units plus one and two new units were considered as part of the Phase 1 assessment. The new build options locations considered are indicated below.

It should be noted that an electric driven compressor could be used for any location and Option B is only being assessed to allow a direct comparison to be made for the purpose of identifying any differential benefits / disadvantages etc.

Single unit options (Refer to Section 4.2 for Site Layouts):

- Option A: GT driven unit located in existing vent area with vent relocated to Redundant Plant Area 1 Plinths;
- Option B1: GT driven unit located on Redundant Plant Area 1 Plinths;
- Option B2: Electric VSD unit located on Redundant Plant Area 1 Plinths;
- Option C: GT driven unit located on Existing Avons' Area.

Two unit options (Refer to Section 4.3 for Site Layouts):

- Option 1: One located in Existing Vent Area (Option A) & one located in Existing Avons' Area (Option C);
- Option 2: One located on Redundant Plant Area 1 Plinths (Option B) & one located in Existing Avons' Area (Option C);
- Option 3: One located in Existing Vent Area (Option A) & one located on Redundant Plant Area 1 Plinths (Option B);
- Option 4: Two new units Located on Redundant Plant Area 1 Plinths (Option B).

The potential locations for the new build units were screened based on preliminary cost estimates (i.e., +/-50% accuracy), preliminary project execution schedules (i.e., Level 1) and a qualitative techno-economic assessment, as detailed in the sections below.

7.2 Cost Estimates

The Phase 1 Cost Estimate Report (Ref. 4) provides detailed cost breakdown between the options. Table 7-1 summarises the total P-50 CAPEX associated with each new build compressor option, with a +50%/-50% accuracy. Refer to Section 3.10 for details of the Cost Estimation Methodology (CEM).

Table 7-1: Phase 1 New Build Unit Cost Estimates (+/-50%)

Option	P-50 CAPEX Cost Estimate (kGBP)
New Build Single Unit Options	
A	[redacted]
B1	[redacted]
B2	[redacted]
C	[redacted]
Two New Build Single Unit Options	
1	[redacted]
2	[redacted]
3	[redacted]
4	[redacted]

The development cost for all single unit options are relatively similar. Option B2 is shown to be lower but this excludes the cost of a new 132kV incomer required for the electric driven VSD compressor, as this information was not available at the time of the development of the +/-50% cost estimates. Upon inclusion, costs of all options are expected to align.

It should be noted that Phase 1 costs are superseded by the more detailed costs estimates produced as part of Phase 2. Refer to Section 9.0.

Similarly, costs for the two new unit options are also aligned with equivalent regard for the cost associated with the incomer for the electric VSD compressor.

Therefore, cost cannot be considered to be significant differentiator between the new build unit option locations.

7.3 Execution Schedules

The Level 1 Schedules (Phase 1) Report (Ref. 5) provides the basis and an activity based schedule for the options. Section 10.2 also provides a summary of the basis used. Table 7-2 provides a summary of the estimated project completion dates.

Table 7-2: New Build Unit Option Level 1 Schedules

Option	Project Completion Date
New Build Single Unit Options	
A	4Q2029
B	1Q2029
C	1Q2029
Two New Build Single Unit Options	
1	4Q2029
2	4Q2031
3	1Q2029
4	1Q2029

The following should be noted about the above estimated project completion dates:

- The delivery time for GT and Electric VSD driven compression is the same and hence there is no difference in project completion date between the driver alternatives;
- The Level 1 schedule development excludes the duration for the new 132kV incomer required for the electric driven VSD compressor, as this information was not available at the time of the development of the Level 1 schedules;
- For the two unit options, in order to highlight the difference between parallel and sequential compressor installation, the Option 2 project completion date is based on sequential installation / construction of compressors being adopted. This offers production availability advantages as it ensures that a back-up unit is available for the whole construction duration. The first unit installation is achieved prior to 2030. The other two unit options assume parallel installation. If parallel installation / construction is adopted for Option 2, then project completion date would be similar to Options B and Option 3.

The Level 1 schedules indicate that the project completion by 2030 can be achieved and that there is also some schedule float. Thus, project executions schedule is not a differentiator between the new build unit option locations.

It should be noted that Phase 1 Execution Schedule are superseded by the more detailed schedules produced as part of Phase 2. Refer to Section 10.0.

7.4 Single Compressor Unit Qualitative Assessment

The qualitative assessment of the single new unit location options is presented by Table 7-3. Refer to Section 5.2 for details of the methodology and explanation of the traffic light based assessment.

Table 7-3: Single New Unit Location Options Qualitative Assessment

Assessment Criteria	Single New Unit Location Options			
	Option A (Existing Vent Area)	Option B1 (GT Unit in Redundant Plant Area 1)	Option B2 (Elec VSD Unit in Redundant Plant Area 1)	Option C (Existing Avons' Area)
Project Development Cost				
Project Development Schedule				
Impact on Existing Operations				
Safety Assessment				
Environmental Impact				
Constructability				

The major differentiators between single new unit options is summarised as follows:

- Option C has a significantly greater impact on existing operations. There is a total duration of approx. 2.5 years when a back-up compressor would not be available during demolition of existing Avon unit and construction of the new unit. This entails significant impact on the site production availability;
- Option A requires demolition of the existing vent area and construction of a replacement, necessitating a total site shutdown and is thus considered to have a greater impact on site than Option B;
- Although Options B and C require the existing security fence line to be extended, impacting the immediate surrounding environment, extensions are small and fall within existing National Grid land ownership boundaries. Therefore no significant issues envisaged;
- The electric motor driven option does not introduce any additional incremental site environmental emissions under normal operation and is thus ranked highest from an environmental perspective;
- Option B is considered least complex regarding constructability with good existing road, vehicle and crane access. Additionally, construction activities are relatively remote of current operating plant, minimising disruption / interference / impact to operations activities;
- Option B2 requires additional cable trenching for 11kV supply to be routed through existing plant areas, however, this can be managed;
- Options A and C require construction close to the current operating plant necessitating more co-ordination and interfacing with operations during construction. These options

also require significant demolition activities / scope ahead of construction, including additional ground preparation for crane operations and vehicle access;

- All options can meet the plant separation criteria recommended by National Grid Specification for Site Location and Layout Studies (Ref. 6). Thus, safety is not a differentiator between the options.

Based on the above assessment, the following is concluded / recommended:

- Option C is not preferred due to significant construction and operational disadvantages and it offers no advantages over the other options;
- Option B is preferred to A as it is better from a construction and operations impact perspective. Option A does not offer any advantages over Option B;
- Option B selected as the location for the new build unit;
- Gas turbine driven and electric motor driven VSD alternatives to be considered for Option B;
- Option B2 presents increased project execution schedule risk compared to B1, due to the required external new 11 kV supply to site, but is ranked better against the environmental impact criteria.

7.5 Two New Compressor Units Qualitative Assessment

The qualitative assessment of the two new units location options is presented by Table 7-4. Refer to Section 5.2 for details of the methodology and explanation of the traffic light based assessment.

Table 7-4: Two New Unit Location Options Qualitative Assessment

Assessment Criteria	Two New Unit Location Options			
	Option 1 (Existing Vent Area & Avons' Area)	Option 2 (Avons' Area & Redundant Area 1))	Option 3 (Existing Vent Area & Redundant Area 1)	Option 4 (Redundant Area 1)
Project Development Cost				
Project Development Schedule				
Impact on Existing Operations				
Safety Assessment				
Environmental Impact				
Constructability				

The major differentiators between the two new unit options is summarised as follows:

- Options 1 and 2 have a significantly greater impact on the existing facilities than the other options. There is a total duration of approx. 2.5 years when a back-up compressor would not be available during the demolition of the existing Avon unit and the construction of the new units. Therefore, there would be significant impact on the site production availability. This could be mitigated by sequential installation / construction of compressors being adopted. However, this involves a longer on-site construction schedule and mean both new units would not be installed before 2030;
- Option 3 requires the demolition of the existing vent and construction of a new vent system, which necessitates a total shutdown of the site and thus is considered to be worse than Option 4;
- All options can meet the plant separation criteria recommended by National Grid Specification for Site Location and Layout Studies (Ref. 5). Thus, safety is not a differentiator between the options.
- All options require the existing security fence line to be extended with associated impact to the local environment. For options 1, 2 and 3, the extensions are small and fall within existing National Grid land ownership boundaries. Therefore no significant issues are envisaged. Options 1 and 3 are ranked the best as they only require an small extension on one side. Option 2 requires small extensions on two sides while Option 4 requires a significant extension, including a site road extension outside of the current boundary.
- Option 4 is considered least complex from a constructability perspective as it has good existing road, vehicle and crane access. Additionally, the construction activities will occur remote of the current operating plant and hence there will be minimum disruption / interference / impact to operations activities.
- For Option 1, all the construction activities are close to the current operating plant and therefore more co-ordination and interfacing will be required with operations. It also requires a significant amount of demolition activities / scope before construction can commence. Additionally, it requires additional ground preparation for crane operations and vehicle access.
- Both Options 2 and 3 involve some construction activities close to the current operating plant. Hence, they are better than Option 1 but not as good as Option 4.

Based on the above assessment, the following is concluded / recommended:

- Location Options 1 and 2 are not preferred as they have significant construction and operational disadvantages and offers no advantages over the other options.
- Location Option 4 is preferred to 3 as it is better from a construction and operation impact perspective. Option 3 is only better than option 4 from an environmental impact perspective but this impact can be mitigated. Hence, Option 4 is preferred to Option 3 as the two compressor location option.
- Therefore, Option 4 should be selected as the location for the new build units. Both gas turbine driven and electric motor driven VSD alternatives can be considered for Option 4. As both new units are located in the same location, the number of tie-ins required with the existing facilities are minimised, i.e. brownfield scope is minimised. Additionally, for electric driven units, as both compressors are located in the same

location, it minimises the number of new cable trenches required for the 11 kV power supply. As noted for the single new compressor unit, electric driven VSD alternatives present increased project execution schedule risk compared to gas turbine drives but do not introduce any additional incremental site environmental emissions under normal operation.

8.0 HSE ASSESSMENT OF OPTIONS

Key Reference Documents

203513C-001-RT-6200-0002	King's Lynn Carbon Interface Tool Summary Report Phase 2 [Ref. 12].
203513C-001-CN-6200-0001	King's Lynn Compressor Station BAT Input Sheet (Phase 2) [Ref. 13].
203513C-001-RT-6200-0001	King's Lynn Compressor Station Biodiversity Net Gain Assessment [Ref. 14].
203513C-001-RT-0251	King's Lynn Compressor Station Layout Review Report (Phase 2) [Ref. 15].

8.1 General

This section details the key outputs from site layout reviews and environmental assessments undertaken to support the options screening plus the cost benefit analysis. For options carried forward to Phase 2, the environmental assessments that were undertaken include Carbon Interface Tool, BAT Input Proforma and Biodiversity Net Gain.

With regards to health and safety, it was confirmed that no formal assessments (e.g., HAZID) were required at this conceptual phase of the project, however, a layout review was performed to check compliance with the guidelines provided in the National Grid Specification for Site Location and Layout Studies and Reviews T/SP/G/37 (Ref. 9). Additionally, safety issues that may present a significant business risk were identified as part of the Risk Workshop, refer to Section 11.0 for further details. No significant safety issues were identified as part of the Risk Workshop.

8.2 Site Layout Review

T/SP/G/37 (Ref. 9) provides target separation distances for natural gas facilities and is applicable to new installations or modifications to existing installations with an inlet pressure above 7 bar.

For the King's Lynn MCPD project, as the new facilities will be installed at an existing site, a site location review has not been performed. All options use available space within the current site security fence for locating new equipment, except for the two compression units options. Additionally, all location options considered avoid the requirement for additional land acquisition. Therefore, there is no fundamental change to the operations and functionality of the King's Lynn site, which would require a site location review.

Refer to Section 4.0 for the site layouts associated with each option.

The site layout was performed to:

- Justify that the layout selected is the one that gives the best protection to manned areas on site and to the general public:
- Minimise the likelihood of escalation on site between hazardous inventories:

- Ensure where-ever possible that the principles of inherent safety are utilised in the layout and set-up of new plant and equipment, in order to eliminate hazards, as opposed to controlling them.

The site layout review (Ref: 15, 18) concluded the following:

- Separation and Spacing:

All options are able to meet the recommended distances to building and other hazardous process areas. However, no option is able to meet the recommended distance to the security fence.

For the retrofit options, the existing Avon Unit B does not meet the recommended distance to the security fence. Thus, this is not considered to be an issue and therefore no site fence modification is envisioned. The location of the ammonia storage facilities is not expected to be a concern as T/SP/G/37 (Ref. 9) target separation distances are applicable to hydrocarbon containing facilities and not chemical equipment.

For the new build options, a small section of the security fence will need to be moved further away to meet the recommended distance. Moving of the fence boundary does not require any additional land ownership and the relocated fence line would still be within the existing National Grid land ownership boundary. Therefore, there are no significant concerns.

- Positioning of Hazardous Plant:

All new hazardous plant is separated from non-hazardous and other existing hazardous facilities and therefore minimising any incremental safety risk. No additional vessels containing hazardous fluids are being introduced, thus any potential domino effects are also minimised.

For the SCR option, it is necessary to install ammonia storage and ammonia unloading facilities. This introduces a new toxic hazard to the site. T/SP/G/37 (Ref. 9) target separation distances are not applicable to chemical equipment, thus there are no target separation distance requirements specific to ammonia containing equipment. The selected ammonia concentration for the SCR facilities is 24.5%. Ammonia solution with concentrations between 10% – 35% carries limited risk to site personnel and very low potential for offsite impact. At these concentrations, it is still a corrosive hazard but is managed / handled with gloves and a mask.

The SCR related ammonia facilities have been installed as far away as possible from other process facilities and also as far away from the security fence as possible to minimise the potential for escalation (although not a domino effect) should an accidental hydrocarbon fire occur and to limit potential for offsite impact. Further review of the potential ammonia hazards will be necessary should this option be adopted.

Additionally, for all options, the new hazardous plant is located within the existing site boundaries and within the existing National Grid land ownership boundary. This also ensures that any impact on public, i.e. local towns, roadways, pathways, third parties etc. should be negligible. Hence, there should be no significant impact on existing site planning and operating permits.

- Maintenance and Access:

Existing site road networks are used where possible plus extended, if required. All new road extensions are within the existing site boundary. The main access route to site

remains unchanged. Therefore, all options have good access for construction, maintenance and incident response etc.

- Emergency Access and Escape:

The access to site for emergency (e.g. firefighting) and other services will remain unchanged from the current operations, i.e. via the main gate located at the South West end of the site. An alternative access gate at the North West end of the site, adjacent to where the old control building was located is also available. Both, these access gates can be used by all options.

As noted above, existing site roads will be extended, where necessary, for vehicular access to the new facilities locations.

The routes for escape from site will also remain unchanged from the current operations, i.e. either via the main gate or emergency gates located in the security fence. Therefore, there is no change to the current evacuation philosophy.

No major safety concerns were identified for any of the options, therefore health and safety is not considered to be a major driver for the MCPD project option selection.

8.3 Carbon Interface Tool Assessment

An assessment of the embodied carbon emissions associated with the construction of the design for each of the options being considered was undertaken using National Grid's Carbon Interface Tool (CIT), 2020 version. Use of the CIT supported the calculation of embodied carbon emissions in alignment with the PAS2080 - Carbon Management in Infrastructure standard. The CIT considers A1-A5 embodied carbon emissions. i.e. raw material supply (A1), transport (A2) and manufacturing (A3) plus site construction (A5) and transport (A4).

Figure 8-1 and Figure 8-2 (Ref. 12) provide a high-level comparison of the embodied carbon associated with each of the new build and retrofit options being considered.

It should be noted that whole life carbon emissions (incl. operational) are not considered at this stage as it is not a factor in the National Grid option selection.

Figure 8-1: PAS 2080 A1-A3 Carbon Comparison of Options

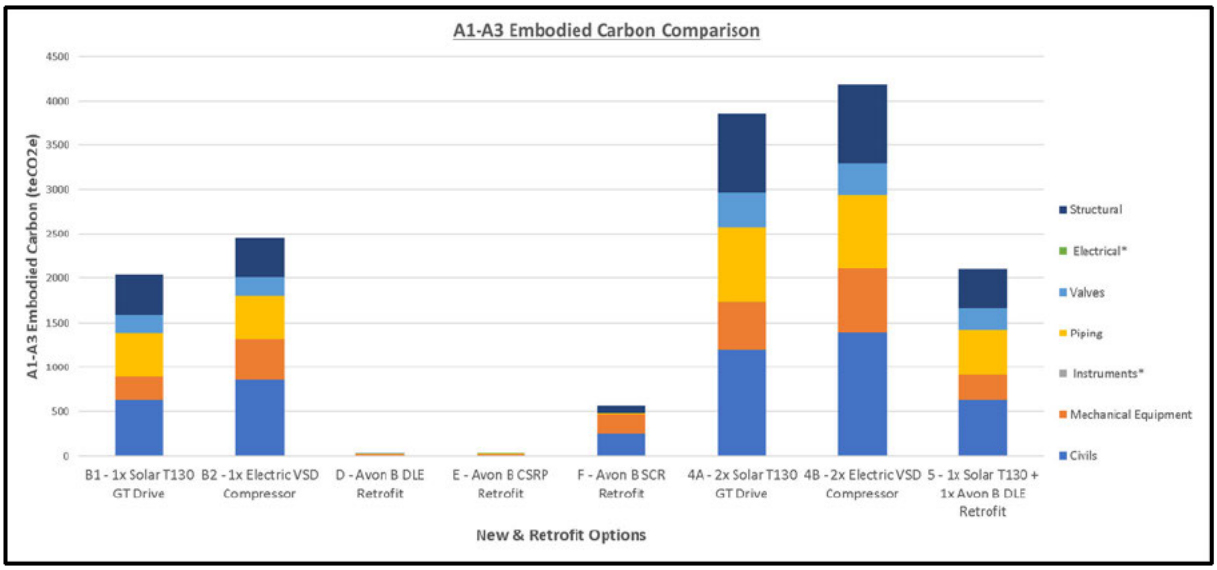
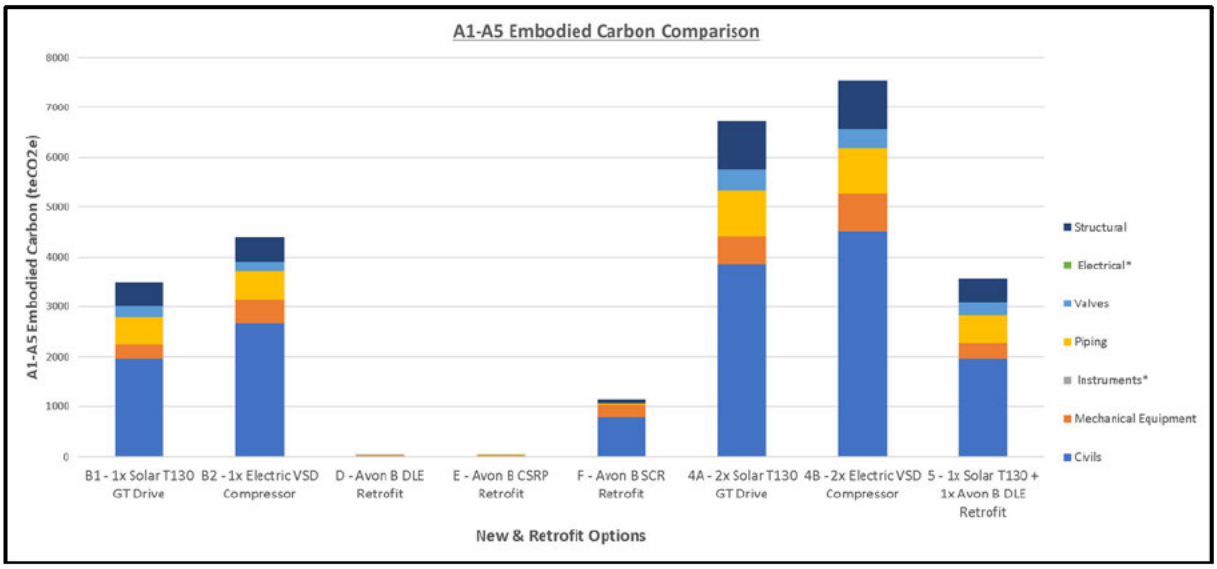


Figure 8-2: PAS 2080 A1-A5 Carbon Comparison of Options



From the results above, it can be concluded that:

- Considering A1-A3 emissions, civils, piping and structural steel items contribute the most to the carbon emissions associated with each option, followed by mechanical equipment.
- All retrofit options (D, E and F) offer significantly lower A1-A5 emissions compared to the new-build options (B1, B2, 4A, 4B and 5)
- Retrofit options D & E have the lowest A1-A5 carbon emissions, whilst retrofit option F (SCR) has notably higher A1-A5 carbon emissions associated mainly with civil and mechanical equipment emissions.
- Comparing the single new unit options (B1 and B2), the electric drive option has a slightly higher A1-A5 carbon emissions, associated mainly with higher civil and mechanical equipment emissions.
- Comparing the two-unit options (4A, 4B and 5), Option 5 offers significantly lower A1-A5 carbon emissions than 4A and 4B, which is to be expected considering this option is comprised of a combination of options B1 and D (which has a very low associated A1-A5 carbon). As was found for new single unit options (B1 and B2), the two-unit electric drive option (4B) presents slightly higher A1-A5 carbon emissions compared to option 4A.

8.4 BAT Input Proforma

To support with the compressor machinery train BAT assessment being completed by National Grid, the BAT Assessment Data Collection Proforma (Ref 13) was completed for the different options being considered.

The populated Proforma (Ref 13) details the following calculated data for each compressor unit at each of the PDS points (Refer to Section 6.0) of interest in the scenarios assessed:

- Net thermal input (MW) power usage at site conditions

- Electrical power usage (MW) for electric compressor driver
- Direct mass emissions (g/s) of CO_2, CO and NOx.

The design cases assessed in the BAT Proforma (Ref 13) are as detailed in Ref. 13.

Table 8-1 summarises the relevant MCPD NOx emission limits, the existing permitted emission limits for NOx and CO (where applicable), and the emission concentrations used to calculate the mass emissions rates input into the BAT Proforma. Refer to Reference 13 for full details of the source data and assumptions applied in calculating the required input data. Refer to Section 6.0 of the different design cases assessed when the lead units are available/unavailable.

The two unit options inherently involve higher number of run hours and therefore the same run hours as a single unit do not apply. Additionally, for a new build electric VSD driven unit, a BAT Input Proforma is not required.

Table 8-1: Emission Concentrations – MCPD, Permitted, Assessed

UNIT [1]	APPLICABLE MCPD NOX LIMIT (MG/NM^3)	CURRENT PERMIT NOX LIMIT (MG/NM^3)	NOX CONC. OF PROFORMA INPUT DATA (MG/NM^3)	CURRENT PERMIT CO LIMIT (MG/NM^3)	CO CONC. OF PROFORMA INPUT DATA (MG/NM^3)
Existing Avon	150	170	153.3 [9]	700	420.7 [9]
CSRP Avon	150	170	143.9 [9]	700	420.7 [9]
DLE Avon	150	170	51.3 [5]	700	100
SCR Avon	150	170	[10]	700	[11]
SGT-400 (Re-wheel)	150 [4]	n/a	59.5[6]	n/a	100 [6]
New Build GT Driven Unit	50	n/a	30[7]	n/a	30 [7]

[1] Concentrations stated at MCPD reference conditions: 273.15 K, 101.3 mbar, 15% O_2, dry gas.

[2] Emission limits as per current EPR permit for Unit B Avon (Ref 24).

[3] For Avon retrofit options, emission limits stated are for the existing permitted Unit B Avon, prior to any retrofit works having been implemented.

[4] Existing MCPD NOx limit considered applicable on the basis that refurbishment/re-wheeling costs are below 50% of what a new comparable MCP would cost. If refurbishment/re-wheeling costs are anticipated to exceed this 50% threshold, the applicable ELV should be reviewed.

[5] Converted from ppm (Ref 25) to mg/Nm^3 at MCPD reference conditions. Assumed dry gas. CO concentration based on the maximum calculated % NTI being above 75% at all PDS points.

[6] Converted from ppm (Ref 26) to mg/Nm^3 at MCPD reference conditions. Assumed ppm concentrations provided at MCPD conditions.

[7] Confirmed in BAT Proforma Meeting Minutes (Ref 27).

[8] Emission limits as per the MCPD (Ref 28), applicable unless <500 hours operation proposed.

[9] Highest concentration determined across all PDS points for given unit.

[10] SCR emissions were calculated on a mass emissions basis (90% NOx reduction compared to Existing Avon mass emission rates). On this basis, it is reasonable to assume the NOx concentrations achieved will be compliant with the MCPD limit.

[11] SCR CO emissions calculated on mass basis using Existing Avon emission curves and inputting [redacted] calculated NTIs. Based on SCR unit requiring slightly higher NTI across PDS points compared to Existing Avon, and decreasing CO concentration with increasing NTI, it is anticipated that CO concentration will not breach permitted limit of 700 mg/Nm^3. However, it is advised that this is confirmed with the SCR vendor.

To illustrate some differences in the emissions calculated for the different options and PDS points assessed, a comparison of the aggregated CO_2, CO and NOx mass emission rates calculated for the units operational in the three PDS points selected (C5, C7, C7-Alt, in order of increasing aggregate NTI is presented in Figure 8-3 to Figure 8-8.

The data presented below is split into the following scenarios:

- Lead unit (either SGT-400 or new T130) is **available** – see Figure 8-3 to Figure 8-5.
- Lead unit is **unavailable** – see Figure 8-6 to Figure 8-8.

Please note the C7-Alt case only applies to the Avon counterfactual and retrofit options when the lead unit is unavailable, hence, no data is presented below where the lead unit is available, or for Options 5, 6, 7 (Avon present but not used) & 8, as no Avon units are required for these options, as shown in Table 6-1.

Please note, for Option 8, there is no back-up unit available for PDS points C5 and C7 where one of the lead SGT-400's is unavailable, meaning only the remaining SGT-400 is available to run. As per the BAT Proforma (Ref 13), C5-Max and C7-Max emissions were calculated for Option 8 to represent maximum flow that can be achieved with a single SGT-400 when either lead unit is unavailable.

Figure 8-3: Comparison of Aggregated CO_2 Emissions – Lead Unit Available

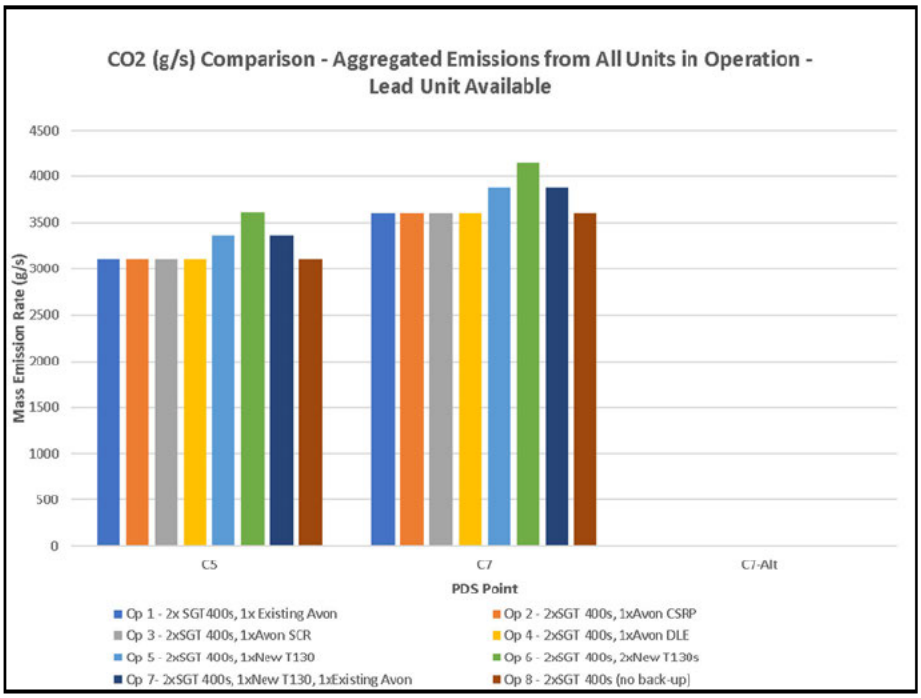


Figure 8-4: Comparison of Aggregated CO Emissions – Lead Unit Available

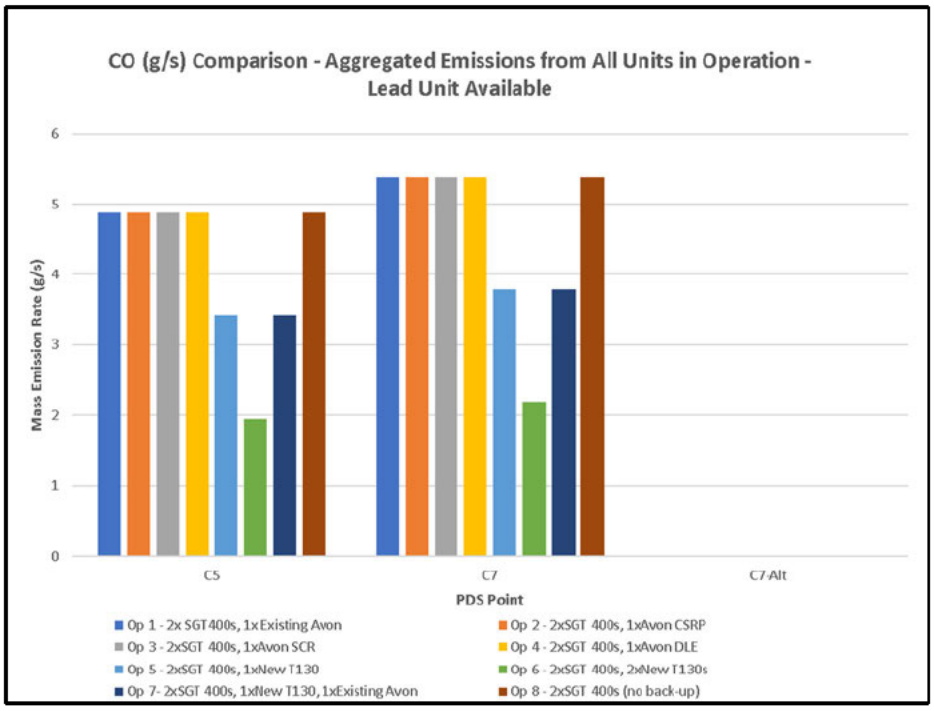


Figure 8-5: Comparison of Aggregated NOx Emissions – Lead Unit Available

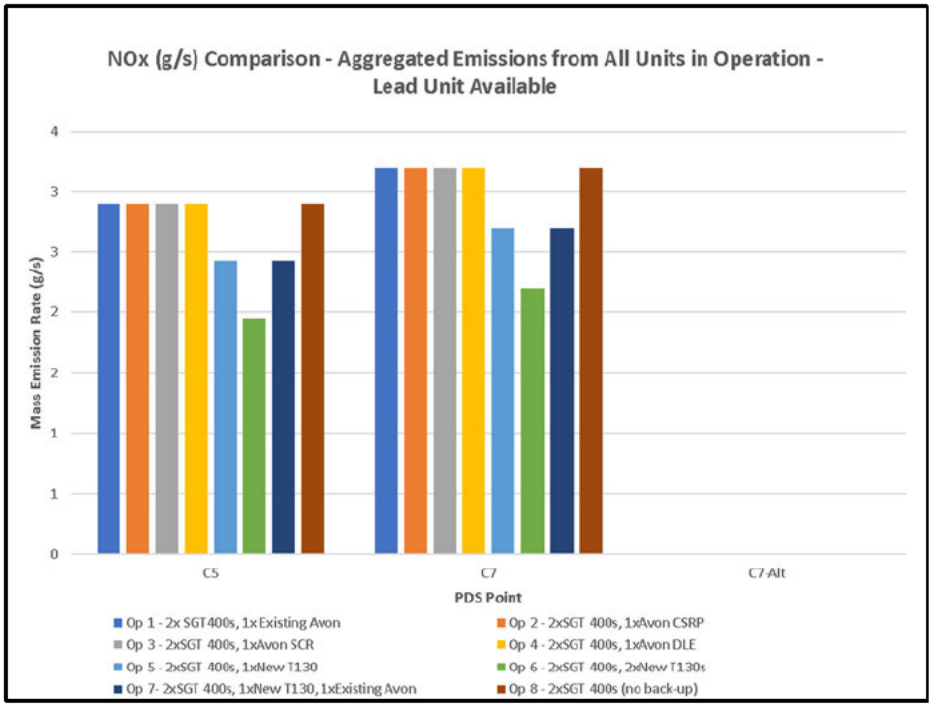


Figure 8-6: Comparison of Aggregated CO_2 Emissions – Lead Unit Unavailable

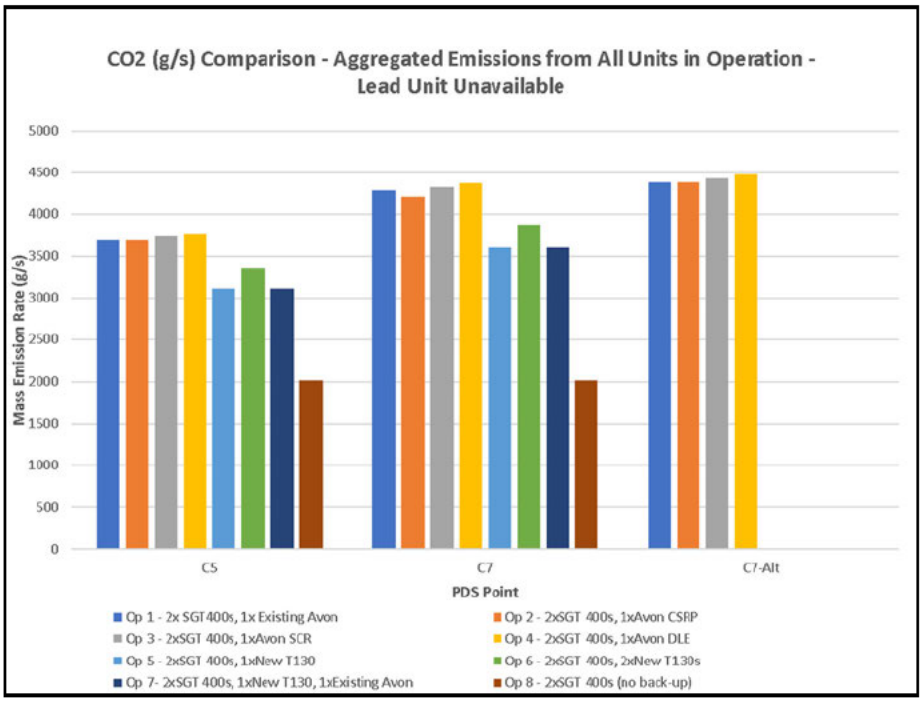


Figure 8-7: Comparison of Aggregated CO Emissions – Lead Unit Unavailable

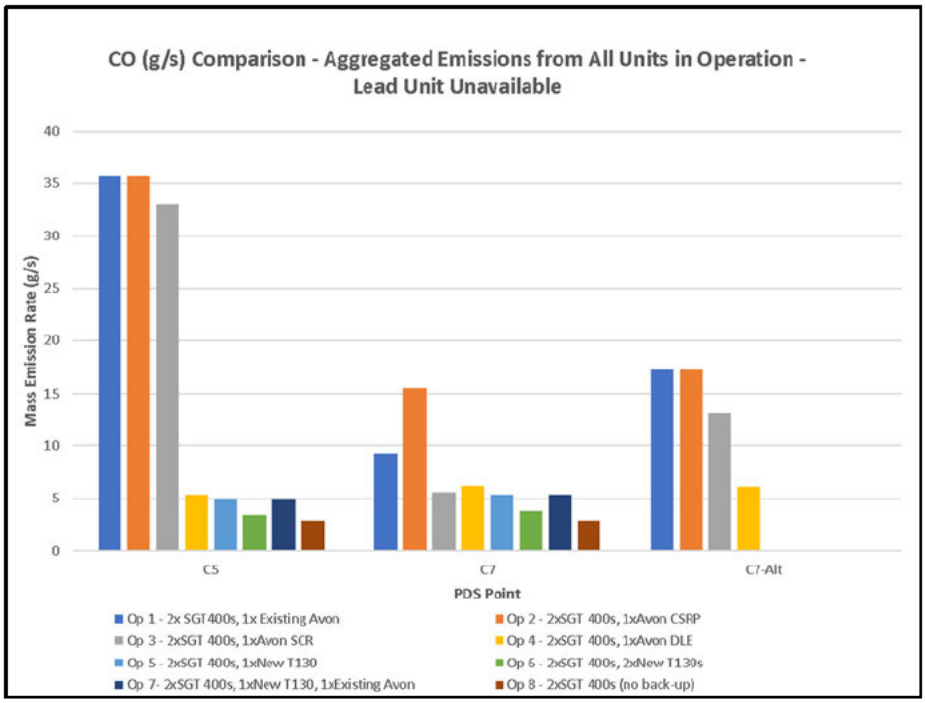
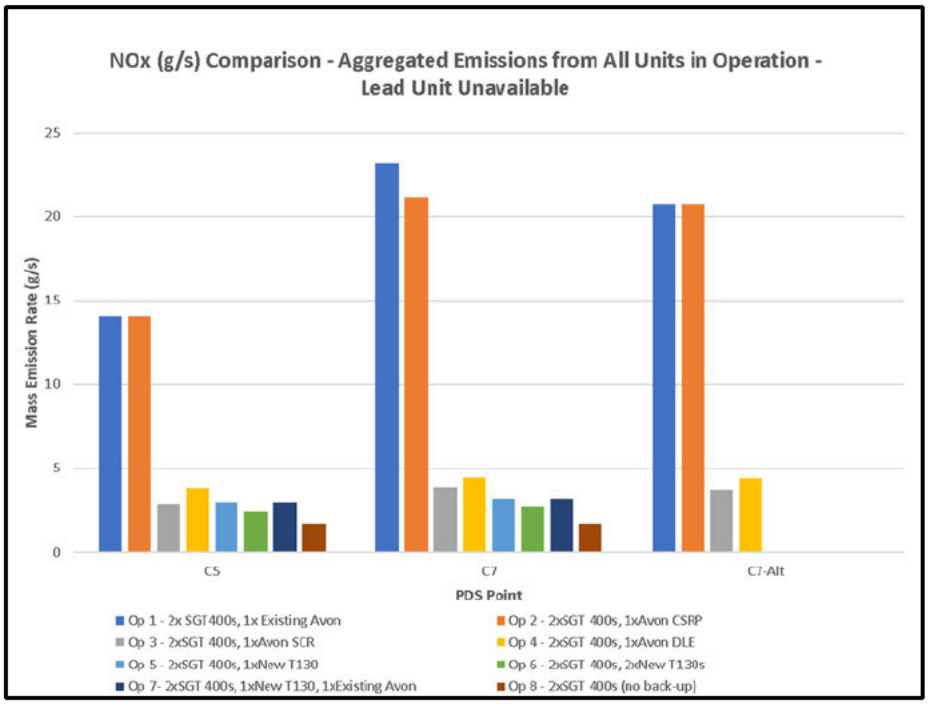


Figure 8-8: Comparison of Aggregated NOx Emissions – Lead Unit Unavailable



It is evident from the data presented above that there are differences in the CO_2, CO and NOx emission rates calculated for each PDS point across the operational scenarios assessed. However, the patterns identified above are not consistent across each option and pollutant, and rather than reviewing the mass emission rates in isolation, the data should be considered alongside the operational hours of each individual unit across all PDS points.

Consideration of impact of operational hours on total mass emissions released was excluded from this scope. It is assumed that the data presented in the BAT Proforma will be considered in the wider context of what is considered BAT for the installation when used by National Grid to inform the BAT assessment being undertaken.

As summarised in Table 8-1, each of the units (retrofitted Avon options and new) assessed are compliant with the relevant MCPD emission limit for NOx based on the base data used to assess their emissions. It should be noted that the existing Avon unit assessed (counterfactual, not retrofitted), exceeds the 150 mg/Nm^3 emission limit applicable to existing MCPD, however, on the basis this unit will be limited to operating below 500 hours per annum, the MCPD NOx emission limit is not applicable.

8.5 Biodiversity Net Gain Assessment

In line with the Town and Country Planning Act (TCPA) 1990 as amended by the Environment Act 2021, any National Grid construction project with a temporary or permanent impact on the natural environment must achieve a minimum of 10% Biodiversity Net Gain (BNG).

A BNG assessment was completed (Ref 12) using the National Grid Net Gain Assessment Matrix to score the impact of each option based on the type of development and availability of National Grid land. Please refer to the BNG assessment report (Ref 12) for full details of the assessment completed. A summary of the assessment results for single unit options is shown in Table 8-2 and for two unit options in Table 8-3:

Table 8-2: Single Unit Options BNG Assessment

Option	Impact Score	Delivery Score	BNG Score	Summary
B1	Med (3)	Small area of National Grid land available / offsite requirements- (3)	9	Although the total footprint of land required for Option B2 is higher than for Option B1, given the difference in land take is small, they have not been scored differently according to the National Grid matrix. Impact scored as Medium (3) as new compressor will be built under TCPA and will impact on a range of habitats (removal of woodland and grassland) at a single National Grid site. Works are not within/ will not directly impact any formally designated sites. Some sensitive ecological receptors/habitats were identified in the outer consultation boundary around site but not considered likely to be directly impacted due to distance. Delivery scored as "Small area of National Grid land available / offsite requirements- (3)" as all permanent site extensions are taking place on land already owned by National Grid, however, there is a temporary requirement to use adjacent farmland during the construction phase. There is limited opportunity within the National Grid site for providing an overall BNG, and therefore off-site replacement of lost habitats will likely be required. Local Planning Authority strategies / mechanisms in place.
B2	Med (3)	Small area of National Grid land available / offsite requirements- (3)	9	
D, E & F	0	0	0	As options D, E, and F involve retrofitting existing systems and either have no additional footprint or footprint on existing hard standing, they have no impact on biodiversity. Areas of hard standing or otherwise sealed surfaces have little or no biodiversity value and can be scored zero. No BNG required.

Table 8-3: Two Units Options BNG Assessment

Option	Impact Score	Delivery Score	BNG Score	Summary
4A	Med (3)	Small area of National Grid land available / offsite requirements- (3)	9	Although total footprint of land required for the Option 4 designs is higher than for single unit Option B designs, the difference is not significant enough to score them differently according to the National Grid matrix. Additionally, the total footprint of land required for Option 4B is higher than for Option 4A, however given the difference in land take is small, they have not been scored differently according to the National Grid matrix. Impact scored as Medium (3) as new compressor will be built under TCPA and will impact on a range of habitats (removal of woodland and grassland) at a single National Grid site. Works are not within/ will not directly impact any formally designated sites. Some sensitive ecological receptors/habitats were identified in the outer consultation boundary around site (918 m away) but not considered likely to be directly impacted due to distance. Delivery scored as "Small area of National Grid land available / offsite requirements- (3)" as all permanent site extensions are taking place on land already owned by National Grid, however, there is a temporary requirement to use adjacent farmland during the construction phase. There is limited opportunity within the National Grid site for providing an overall BNG, and therefore off-site replacement of lost habitats will likely be required. Local Planning Authority strategies / mechanisms in place.
4B	Med (3)	Small area of National Grid land available / offsite requirements- (3)	9	
5	Med (3)	Small area of National Grid land available / offsite requirements- (3)	9	As Option 5 is a two-unit option with only one unit requiring additional plot space, it has a BNG impact equivalent to Option B. Impact scored as Medium (3) as new compressor will be built under TCPA and will impact on a range of habitats (removal of woodland and grassland) at a single National Grid site. Works are not within/ will not directly impact any formally designated sites. Some sensitive ecological receptors/habitats were identified in the outer consultation boundary around site but not considered likely to be directly impacted due to distance. Delivery scored as "Small area of National Grid land available / offsite requirements- (3)" as all permanent site extensions are taking place on land already owned by National Grid, however, there is a temporary requirement to use adjacent farmland during the construction phase. There is limited opportunity within the National Grid site for providing an overall BNG, and therefore off-site replacement of lost habitats will likely be required. Local Planning Authority strategies / mechanisms in place.

Options B1 and B2 (one new unit), Options 4A and 4B (two new units), and Option 5 (footprint equivalent to one new unit) have a BNG score of 9 and a medium impact on biodiversity. Options D, E and F (retrofitting existing units) have a BNG score of 0 and no impact on biodiversity.

Amongst the options with a medium impact on biodiversity, Option 4B has the greatest footprint and would require the largest area of permanent land clearance, whilst Options B1 and 5 have the smallest footprint. Option B2, 4A and 4B will have an impact on a pond which has been identified as a potential habitat for European protected species great crested newt. Despite this, the difference is not significant enough to score them differently according to the National Grid matrix and thus they have the same overall BNG score.

It is worth noting that Option 5 is a two-unit option with an additional footprint equivalent to one unit, as the Unit B Avon will use the existing Avon footprint. Therefore, the land use associated with this two-unit option is expected to have the same impact on biodiversity as one unit.

As Options D, E, and F have no impact associated with land use, they are the most favourable options from a biodiversity perspective.

It can be concluded that there is no significant difference between the options with a medium impact on biodiversity. All options require permanent land use within the National Grid site, as well as temporary land use out with the National Grid site. In addition, the difference between the total footprint required for each option is relatively small.

There is limited opportunity within the National Grid site for providing an overall BNG, and therefore off-site replacement of lost habitats will likely be required for all options with a medium BNG score.

The additional cost for the replacement of lost habitats cannot be estimated at this stage. The King's Lynn site is required to be baselined in detail to understand the environmental value of the affected land before exploring options for achieving BNG. It may not be necessary to acquire new land to achieve this, for example, National Grid projects have contributed to local schemes in the past. Given the area and type of habitat impacted by each option, and with Local Planning Authority strategies / mechanisms in place, it is likely that all of the options could reasonably achieve 10% BNG in line with the TCPA.

When the final development options have been determined, BNG requirements will be further refined and updated including establishing baseline conditions, better quantification of the impacts, as well as development and implementation of enhancement and mitigation plans.

9.0 PHASE 2 OPTIONS COST ESTIMATES

203513C-001-RT-0301	King's Lynn Compressor Station Cost Estimates (Phase 2 +/-30%) [Ref. 10]

9.1 General

Class 4 +/-30% P-50 CAPEX estimates were developed for the new build compressor and Avon Unit B retrofit options. The basis and methodology for the estimates are detailed in Section 3.10.2.

For the electric driven VSD compressor options (Options B2 & 4B) there is insufficient capacity in the current site electrical supply. A connection agreement will need to made with UK Power Network (UKPN) to supply to the King's Lynn compressor station with a new incomer. UKPN provided a preliminary quote of [redacted] to carry out these works (Ref. 23).

Note, the Phase 1 +/- 50% Cost Estimates are superseded by Phase 2 +/- 30% Cost Estimates presented in this Section.

9.2 +/-30% Cost Estimates

Table 9-1: provides a summary of the +/-30% Cost Estimates for each option taken from King's Lynn Compressor Station Cost Estimates (Phase 2 +/-30%) [Ref. 10].

For the new build unit options, the project development costs are comparable. As expected, the cost of the retrofit options is significantly lower than the new build options even after allowing for associated re-life / asset heath costs. The lowest cost options are the 'Decommission Avon Unit and 'Limit Avon Operation to 500 hour' options.

Table 9-1: Summary +/-30% Cost Estimates

DESCRIPTION	P50 TOTAL INSTALLED COST (KGBP) (NOTES 1, 2)	COMMENTS
Counterfactual (Do Nothing)		
Decommission Avon Unit	[redacted]	CBA Option 8
Limit Avon Operation to 500 hour	[redacted]	CBA Option 1
Single MCPD Complaint Unit Options		
Option B1: New Build GT Unit	[redacted]	CBA Option 5
Option B2: New Build VSD Electric Unit	[redacted]	Note 4, 5
Option D: DLE Retrofit	[redacted]	CBA Option 4
Option E: CSRP Retrofit	[redacted]	CBA Option 2
Option F: SCR Retrofit	[redacted]	CBA Option 3
Two MCPD Complaint Units Options		
Option 4A: New Build GT Units	[redacted]	CBA Option 6
Option 4B: New Build VSD Electric Units	[redacted]	Note 4, 5
Option 5: One New Build GT Unit + DLE Retrofit	[redacted]	
One New GT Units + One 500 Hour Avon	[redacted]	CBA Option 7

Notes:

1. Cost are total installed cost including procurement, off-site fabrication. onsite construction / installation, commissioning, contract in-directs. Logistics, National Grid costs etc. Refer to Reference 10 for full details of the scope of each option plus breakdown of costs.
2. Costs include, as appropriate, relief / asset health costs for options that require continued use of the Avon B unit plus re-wheeling of the SGT 400 units..
3. Costs include, as appropriate, demolition costs for Avon B unit for options that do not require continued use of the Avon B unit. All options include demolition cost of the Avon A unit as that is redundant and thus will not be used.
4. For the Electric VSD Compression options, cost are included for budget estimate provided by UKPN for provision of a new incomer to site. UKPN provided a budget estimate for supply of 30 MVA, electrical power required for two units. No information has been provided for a 15 MVA supply. Thus, for the purposes of this study, the same budget cost has been used for both alternatives. The UKPN budget estimate excludes civils works and building required for the new UKPN switchyard. Costs for this scope has been estimated and included in the estimates.
5. The UKPN budget estimates are based on provision of a 33kV supply to site from the UKPN switchyard, whereas an estimate based on a 11kV supply was requested. Therefore, the UKPN budget estimate may be lower than expected.

In order to provide an indication of the scope of each option, Table 9-2 below provides an estimate of material tonnages for selected new build and retrofit options.

Table 9-2 - Material Tonnage Estimates

OPTIONS	MATERIAL TONNAGES (TE)						
	Equipment	Piping	Valves	Electrical	Instruments	Civil Works	Structural
Single MCPD Complaint Unit Options							
Option B1: New Build GT Unit	214	244	96	Note 1	Note 1	Note 1	215
Option B2: New Build VSD Electric Unit	282	242	95	Note 1	Note 1	Note 1	215
Option D: DLE Retrofit	-	5	<1	Note 1	Note 1	Note 1	0
Option E: CSRP Retrofit	-	5	<1	Note 1	Note 1	Note 1	0
Option F: SCR Retrofit	51	8	<1	Note 1	Note 1	Note 1	38
Two MCPD Complaint Units Options							
Option 4A: New Build GT Units	403	411	192	Note 1	Note 1	Note 1	430
Option 4B: New Build VSD Electric Units	471	403	176	Note 1	Note 1	Note 1	430

Notes:

1. Civil Works, Instruments, and Electrical components quantified in estimate using non-Mass measurements e.g. No. of units or m3, therefore, tonnage not shown.
2. Tonnage in relation to Avon Compressor Re-life or Destruction scope not included in the estimates.

10.0 PHASE 2 OPTIONS EXECUTION SCHEDULES

Key Reference Documents

203513C-001-PLG-0301	King's Lynn Compressor Station Level 1 Schedules (Phase 2) [Ref. 11]

10.1 General

Level 2 schedules for the Phase 2 options were developed to highlight any differences in overall project execution duration for the alternative options for use in the cost benefit analysis.

10.2 Basis for Schedules

The basis and the main assumptions used to develop the Level 2 schedules were as follows:

- The Kings Lynn Ofgem Re-Opener period is 31/12/2022 to 30/06/2023.
- At the conclusion of this Re-Opener period, an option will be selected for the King's Lynn MCPD project.
- A second Ofgem Re-Opener period of 2 months is required to agree funding allowances. This period will be after Execute (i.e. EPC) tenders have been received.
- The project will be executed in the following project phases:
  - Pre-FEED;
  - FEED;
  - Detailed Design;
  - Construction.
- The tendering periods required plus durations of these project phases for the new build options will be longer than the retrofit options given the significantly greater scope.
- The Pre-FEED can start before option approval / selection, i.e. before Ofgem Re-Opener period closure, if it is required in order to achieve project completion before the MCPD target date of 2030.
- The following National Grid internal approvals / governance periods are required:
  - 2 months between pre-FEED and FEED (F3 Sanction). This can occur in parallel to the FEED ITT period.
  - 2 month governance cycle (F4 sanction) immediately before the second Ofgem re-opener to confirm remaining funding allowances. This sanction process commences post receipt of Execute bids.
  - 2 months governance cycle at the end of construction/commissioning (T6 Sanction).
- Pre-FEED ITT and award activities are kicked off immediately following option selection being finalised, i.e. conclusion of Re-opener period.
- Activities that involve total shutdown of the compressor station can only occur during the period April – September. For the retrofit options, it is assumed that Unit B is also

taken offline for upgrade / refurbishment only in this period too, to ensure that it is available during winter months etc,

- On site construction activities not requiring a total shutdown of the compressor station can occur all year round, i.e. constructions and operations SIMOPS is allowed.
- The delivery time for GT and EM VSD driven compression is 16 months (ex. Works) and this includes string test. The delivery time for the equipment and bulks required for the retrofit options will be significantly shorter. A duration of 6 months is assumed based on information provided by Reference 6 and previous project experience.
- Purchasing of equipment etc. will occur post FEED, i.e. no early investment. However, in order to reduce the overall procurement cycle for the new compression unit, it is assumed that the procurement specs / documents and compressor unit ITT technical bid evaluations will be performed during FEED. A period for vendor engagement will occur during FEED. Therefore, the purchase order can be placed soon after the Execute activities commence.
- For the retrofit options, the project execution activities for the MCPD facilities and 're-life' facilities will be done in parallel and managed by a single design and installation contractor.
- Adequate manpower is available to support the construction activities, i.e. there are no manpower restrictions. A 7 day working week / 12 hours a day is assumed for the preliminary schedules, This provides opportunity to increase site working hours if delays are experienced.
- Required permits and planning permissions are not on the critical path. It is assumed these activities will be performed in parallel to the engineering activities and will be managed such that they will not be on the critical path and thus will not impact the overall schedule.
- For Electric Driven VSD Compression options, the duration required for connection agreement with UKPN is assumed to be 12 months. The time required for installation of the new incomer to site is assumed to be 2 years (Ref. 23). It is assumed that UKPN installation activities will be undertaken in parallel to the onsite construction activities.
- Discussions with UKPN and design of the required new supply can occur prior to F4 Sanction. However, the formal agreement with UKPN cannot be concluded plus construction and installation of the new supply cannot commence prior to F4 sanction in order to minimise cost commitments prior to approval of funding allowance by Ofgem and F4 Sanction.
- National Grid's T2 Cyber delivery strategy does not permit compressor engine overhauls and cab refurbishments to be conducted at the same time as control system replacements due to overlap of working areas. Thus, upgrades required for compressor re-life have to be split into two seasons.
- For SCR options, the procurement, installation and commissioning activities durations are based on preliminary information from a supplier. It is assumed that some civils works required for the SCR can be performed with the Avon B unit still on-line, i.e. no total site shutdown, and that only significant foundation works will require a shutdown. It is additionally assumed that other compressor upgrades required for re-life of the unit would also be undertaken as the same time as the SCR retrofit.

10.3 Level 2 Schedules

Table 10-1 provides a summary of the estimated project completion dates. The schedules indicate that the project completion by 2030 can be achieved by all options and that there is also some schedule float. Retrofit options have more float and thus less schedule risk.

Table 10-1: Overall Execution Durations

Option	Project Completion Date	Comments
Single Unit Options		
B1 (New Build GT)	1Q2029	Note 1
B2 (New Build Electric VSD)	1Q2029	Note 2
D (DLE)	4Q2027	Note 3
E (CSRP)	4Q2027	Note 4
F (SCR)	4Q2027	Note 5
Two Unit Options		
4A (New Build GTs)	1Q2029	Note 6
4B (New Build Electric VSDs)	1Q2029	Note 7
5 (Hybrid: GT + DLE)	1Q2029	Note 8

Notes

1. Two total site shutdowns are required, which can both be scheduled for April – September period. The first for cable trench extensions, which could occur during the period for new compressor civils works or during the period of new compressor installation. The second for hook-up of the new compressor.
2. The installation of the new incomer to site by the UKPN is not on the critical path and thus the project completion date is the same as Option B1.
3. Two unit outages are required, one for the compressor overhaul and refurbishment activities and one for the DLE facilities installation and associated control system upgrades. A site shutdown will also be required to tie-in the new compressor control systems to existing station control systems etc.

   It is assumed DLE technology will be tested / proven and commercially available by Q3 2023, before the commencement of pre-FEED / FEED project stages. It should be noted that during the compressor control system replacement, no other compressor cab infrastructure or machinery train overhauls can take place at the same time, due to an overlap in working areas. This is in accordance with National Grid Cyber Delivery Strategy.
4. Two unit outages are required, one for the compressor overhaul and refurbishment activities and one for the CSRP facilities installation and associated control system upgrades. A site shutdown will also be required to tie-in the new compressor control systems to existing station control systems etc. It should be noted that during the compressor control system replacement, no other compressor cab infrastructure or machinery train overhauls can take place at the same time, due to an overlap in working areas. This is in accordance with National Grid Cyber Delivery Strategy.
5. Two unit outrages are required, one for the compressor overhaul and refurbishment activities and one for the SCR facilities installation and associated control system upgrades. A site shutdown will also be required to tie-in the new compressor control systems to existing station control systems etc.

The project completion date is the same as Options E and F, even though this option requires on site civils works to be undertaken prior to the SCR facilities installation. This is because all options are reliant on the April – September window for the total site shutdown. It should be noted that during the compressor control system replacement, no other compressor cab infrastructure or machinery train overhauls can take place at the same time, due to an overlap in working areas. This is in accordance with National Grid Cyber Delivery Strategy.

6. Construction activities will take longer than Option B1 but the completion dates are very similar.
7. Completion date is the same as Option 4A, the installation of the new incomer to site by the UKPN is not on the critical path.
8. The overall completion date for hybrid option, i.e. one new build unit and upgrade of Avon B unit is the same as the single new build options as it is driven by the installation of the new build unit. This option is based on a new build GT driven unit plus DLE retrofit to the Avon B unit but it would be the same if the other retrofit options were considered instead.

   Currently the schedule assumes that new build and retrofit scopes are treated as a single project. The upgrade of the Avon B unit is done in two phases / site shutdowns. During the first phase, the compressor overhaul and refurbishment activities are completed. During the second phase, the DLE facilities installation and associated control system upgrades are completed. The site shutdown required for the second phase coincides with that required for the new build compressor.

   If an electric driven new build compressor is selected with a retrofit option, the overall completion date would be the same as Option B2.

11.0 PHASE 2 OPTIONS RISK ASSESSMENT

Key Reference Documents

203513C-001-RT-0200/B King's Lynn Risk Workshop Report [Ref. 16]

11.1 General

The King's Lynn Compressor Station Risk Workshop was held on Thursday 26th May 2022 at National Grid's offices in Warwick. The risk assessment results serve as input to onwards mitigation discussions and wider project risk management activities to reduce or eliminate the potential project value erosion.

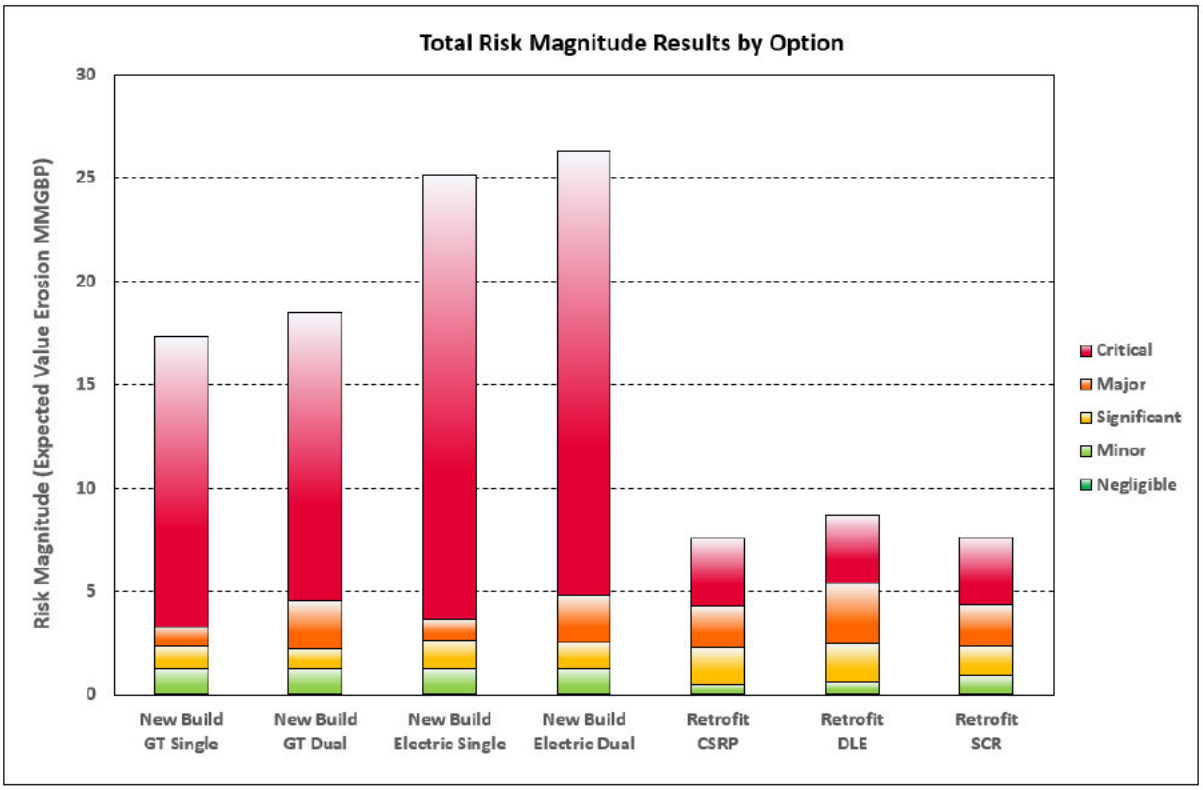
This section provides an overview of the results and outcome of the King's Lynn Compressor Station Risk Workshop, further detailed information can be found in [Ref. 16]. The purpose of the Risk Workshop was to highlight differential risks between the options and thus allow the information to be used as part of selecting the preferred MCPD compliance option for the King's Lynn Compressor Station.

11.2 Workshop Results

The technical options considered during the Risk Workshop are described in Section 2.3.

Figure 11-1 provides a summary of the total risk magnitude by option, as calculated from the sum of the individual risks identified in the risk register [Ref. 16]. These results should be used as an indicative comparison of the options only, as they are based on indicative risk impact ranges and probabilities.

Figure 11-1: Total Risk Magnitude and Risk Breakdown of the Options



For dual unit options, a hybrid approach can also be adopted (i.e., one new unit plus one retrofit option). In this case, the risk magnitudes can be considered to be the sum of the individual options.

From Figure 11-1 for the new build options, the Electric VSD Compressor option carries the highest risk magnitude. This is attributed to the risk concerning the HV grid connection requirement. At present, this scope is unknown / undefined and reliant on a third party (UKPN) executing the works within a timely manner. Early engagement with UKPN, prior to a final investment decision, will help to mitigate this risk. For the Retrofit options, the Dry Low Emissions (DLE) option carries the highest risk magnitude (although only marginally) as it is considered a new technology for National Grid. Test bed trials are currently ongoing, which may help to mitigate future operability concerns.

The majority of the risks identified concern CAPEX increase or schedule delay, with a smaller number of risks concerning production outage and availability issues. Therefore, it can be surmised at this stage of the project that cost and schedule increase is one of the primary areas of concern and onwards risk management focus.

The following summarises the **critical** risks that have been identified during the risk assessment process:

HV Connection Scope and Extension – The Electric VSD Compressor Option requires a HV grid connection. As this scope is unknown / undefined and reliant on a third party (UKPN) executing the works within a timely manner, there is a potential for cost and schedule escalation to enable a HV grid connection. Schedule is therefore the primary impact area due to potential third party delays.

Coordination and Alignment with External Stakeholders – As part of the project phase gate milestones, coordination with external stakeholders is required (Ofgem etc.,). For the New Build Options, there may be a potential delay in gaining alignment on a preferred option and as a result, a schedule delay (initial engagement between Ofgem and National Grid indicate a strong preference from Ofgem for Retrofit Options).

Coordination and Alignment with Internal Stakeholders – As part of the project phase gate milestones, coordination with internal stakeholders is required. For the Retrofit Options, there may be a potential delay in gaining alignment on a preferred option and as a result, a schedule delay (currently the New Build Options are the preferred option for internal stakeholders).

Network Outage Scheduling and Coordination – The planned network outage period for construction/ commissioning activities (e.g., tie-ins) on the project is assumed to be 6 months (April – September) [Ref. 3]. For the New Build Options, there is a greater risk of potential schedule delay (based on longer outage duration requirements for tie-ins) due to the allowed outage period being shorter than anticipated or at less optimum time for construction.

Geopolitical Issues – For all Options, there are country specific and worldwide geopolitical issues affecting equipment supply and workforce. However, for the New Build Options in particular, a critical risk has been identified regarding potential cost escalation.

The following summarises the **major** risks that have been identified during the risk assessment process:

Refurbishment Scope for Avon Unit – For the Retrofit Options, a major risk was identified around the Avon Unit refurbishment scope. As this is a conceptual phase project, no in-depth condition assessment surveys have been carried out for the existing Avon Unit B. Therefore, there is uncertainty in the 're-life' scope modifications currently identified and whether all areas of concern have been captured. There is potential for 're-life' component scope growth and as a result, CAPEX increase. This risk can be mitigated by undertaking detailed condition assessments and facilities surveys prior to project execution.

New Technology Reliability – For the DLE Retrofit Option, the technology being implemented is considered new for National Grid. As a result, there are potential unknown operability issues (e.g., wider system dynamic issues) which may arise. If these operability issues / teething troubles are discovered during the initial operating period, this may result in poor availability. However, test bed trials are currently ongoing which may help to mitigate / alleviate these concerns.

Space in Existing Cable Trenches – All options require the routing of new cables via existing trenches, however, there is variation in volume and type of cabling required between options. The existing trench space is currently unknown and cable routes may already be at capacity, therefore, adequate segregation may not be possible. For the New Build Options, this has been ranked as a major risk as these options are likely to have issues with separation distances.

Post Workshop Note: National Grid has provided additional information on separation distance requirements between cables (both power and C&I). As a result, the following basis shall be adopted in the next phase of engineering:

- New trenches will be required for any new unit options.
- Existing trenches have adequate space for all the retrofit options (although this may require the removal of redundant cable to free up space).

Land Use / Extension – For the New Build Options, the existing site boundary requires extension to meet the 39m target separation distance for natural gas facilities, as outlined T/SP/G/37 [Ref. 1]. To facilitate this, permitting and consent is required, alongside environmental and commercial negotiations. This could result in potential scheduling delays with managing multiple stakeholders and gaining consent. However, this is a greater risk for the two-unit New Build Options, as a larger footprint is required. Although the additional land ownership is within the National Grid land ownership boundary, it is at the limit [Ref. 4]. If further detailed studies indicate a greater site boundary extension is required, then additional land ownership will be required which has not been accounted for.

Geopolitical Issues – For all Options, there are country specific and worldwide geopolitical issues affecting equipment supply and workforce. For the Retrofit Options in particular, a major risk has been identified regarding cost escalation based on potential scope growth of unknown additional brownfield modifications.

All other risks are classified as either **significant**, **minor**, or **negligible** and are detailed in full (including identified opportunities) within the risk register provided in Reference 16.

It should be noted that for the CSRP option, a significant schedule risk was identified in regard to obtaining environmental permitting approvals. This is because the CSRP technology is currently unproven for emissions reduction and thus could result in a potential schedule delay.

12.0 CONCLUSIONS AND RECOMMENDATIONS

12.1 General

This section provides a summary of the main conclusions resulting from this phase plus recommendations for future project phases.

12.2 Conclusions

The main conclusion resulting from this study are as follows:

- Use of new build units and retrofitting of the Avon Unit B with SCR, DLE or CSRP to achieve MCPD compliance for the King's Lynn station is technically feasible. All options can achieve the required process duty specifications (PDS) plus comply with National Grid's recommended site layout / spacing requirements.
- Significant potential risks were identified for both new build and retrofit options:
  - Interface and costs associated with the new HV grid connection required for the electric driven new build options;
  - Scheduling of total site shutdowns for tie-in, hook-up and commissioning of new MCPD project facilities;
  - Geopolitical issues affecting supply and cost of equipment and workforce for project execution.
  - The degree and scope of refurbishment required to the existing Avon Unit B for the 're-life' necessary for the retrofit options.
  - The reliability of DLE technology as this is a new technology for National Grid.
  - Availability of space in existing cable trenches for new cables required to be installed as part of the MCPD project.
  - Permit approval consents for the additional land required, outside of current site fence boundaries, for new build options.

  These risks can be mitigated by planning and more detailed assessments during the next project phase. Refer to the recommendations below.
- There are several potential alternative locations for siting of the new build compression units at King's Lynn. Use of the redundant Plinth Area 1 was selected based on project development cost, project execution schedule, safety, environmental, constructability and impact on existing operations considerations.

  This area can be used for one or two new build unit options as well as gas turbine driven or electric VSD driven compressors.
- For the single MCPD compliant unit installation, the retrofit options offer project development cost, project execution schedule and environmental benefits (i.e. lower embodied carbon emissions and impact on site biodiversity). As noted above, there are no significant site safety (i.e. site layout) or PDS compliance concerns with any the options. However, new build units offer better operational flexibility and availability.

The project development cost, project execution schedule plus embodied carbon emissions and impact on site biodiversity for new build GT driven and new build electric VSD driven units is comparable. However, a new build electric VSD driven unit carries more potential project risk due to the interface with UKPN but offers lower onsite environmental emissions during operation.

All retrofit options have comparable project execution schedule and impact on site biodiversity. However, the SCR option has a higher project development cost and embodied carbon emissions than the DLE and CSRP options. As noted above, the DLE option carries more potential risk due to it being considered to be a new technology, whereas the CSRP option offers less operational flexibility.

- For the two MCPD compliant unit installation, the hybrid option (i.e. one new build unit plus retrofitting of the Avon B unit) offers project development cost, project execution schedule and environmental benefits (i.e. lower embodied carbon emissions and impact on site biodiversity). However, two new build units offer better availability.

  The benefits / disadvantages offered by GT driven units versus electric VSD driven units for two new build units are the same as noted above for one new build unit. Additionally, for the hybrid option, the benefits / disadvantages of the different retrofit options are noted above for one MCPD compliant unit installation.

12.3 Recommendations

The main recommendations arising from this study are as follows:

King's Lynn Process Duty Specifications:

- It has also been determined that the DLE, SCR and CSRP retrofit options are also able to achieve the required duty specifications but with mitigations required for certain operating points. These mitigations involve either operating two units when operating point only calls for one unit operation or better balancing of flows between two duty units. These mitigations are feasible and National Grid operations need to confirm that they can be implemented.

King's Lynn MCPD Project Scope:

- Detailed multi-discipline site surveys should be undertaken, and condition assessments of all existing facilities performed, including underground pipework, cables and available space in cable trenches, in order to define in detail all modifications / upgrades necessary to be performed for 're-life' of the compressor station.
- Where necessary, as build drawings / mark-ups should be produced for the existing facilities, including production for new drawings for instrument air and potable water systems. This includes the redundant / demolished Avon Unit A isolation points.
- Detailed capacity assessment of the existing fuel gas system, instrument air system and potable / fire water system should be performed. All tie-in requirements / locations plus interfaces should then be confirmed.
- A detailed execution schedule for the MCPD project should be developed including detailed assessments of the asset health implementation scope in order to produce an optimised execution schedule which considers synergies between different work scopes and thus minimise site shutdown durations etc.

King's Lynn MCPD Project Execution / Optimisation:

- At the beginning of the next phase, the concept phase risk register should be filtered to show just the identified potential risks for the selected MCPD compliance option. Then, all relevant risks identified as critical, major or significant should be subject to onwards risk management and development of risk action plans appropriate mitigations under future phases of the project.
- Depending upon the selected MCPD compliance option, detailed safety assessment / QRA studies should be undertaken to confirm that existing site fence extension is not required for the retrofit options and the extent site extension required for new build units.
- Potential opportunities to coordinate activities and sharing of workforce etc. with other MCPD projects should be investigated as this may offer potential development cost and execution schedule savings.
- Potential opportunities to coordinate activities and sharing of workforce etc. between the MCPD project and other King's Lynn site projects should be investigated as this may offer potential development cost and execution schedule savings.
- The available network outage periods for construction/ commissioning activities (e.g., tie-ins) should be identified and agreed and factored into the project execution schedule. Opportunities should be considered for early installation of piping isolation valves at tie-in location etc. that will minimise durations for later required network outages.

Fleet RAM Study:

If a retrofit option is selected, the recommendations from [redacted] Fleet RAM Study [Ref. 21] should be considered and implemented in order to enhance the availability of the existing Avon B unit. As a minimum, the following upgrades are required as part of the Avon Unit B 're-life' modifications to ensure the requisite design life is achieved:

- Safety / Protection/ ESD Systems;
- Control Systems;
- Compressor Package Overhaul.
- Better understanding of the spare parts inventory and overall obsolescence issues.

BAT Technologies:

Current BAT technologies and other innovations (i.e. zero loss dry gas seals) should be explored at the next phase to ensure design is BAT compliant.

DLE Retrofit Option:

- If this option is selected, a back-up retrofit option should be carried forward until test bed trials have been satisfactorily completed and it is confirmed that DLE technology does not carry significant new technology risk.

SCR Retrofit Option:

- If this option is selected, a detailed review of the potential ammonia hazards should be performed in order to confirm location of the ammonia storage and offloading facilities plus identify changes to existing operating procedures that will be necessary.

CSRP Retrofit Option:

- If this option is selected, it should be confirmed that this technology will be accepted by permitting authorities as a emissions reduction technology.

New Build Unit(s) Option:

- For the purposes of this study, the new unit design has been assumed to the same as the T130 units recently installed at Peterborough Compressor Station and therefore a conservative approach was adopted. Thus, if a new build unit(s) are selected as the MCPD compliance option, then the compressor package design should be reviewed and optimised in terms of size / capacity of the unit, footprint and foundation requirements, structural support / access platform requirements, acoustic cladding attenuation requirements etc.
- For the electric VSD driven unit, the interfaces with UKPN should be confirmed and location of new 33 kV substation plus associated on site routing of underground HV cabling finalised. Additionally, it should be confirmed that UKPN can provide a 11 kV incomer to site as this is preferred.
- The new build options require use of land outside of the current site boundary. The additional land required, however is already under National Grid ownership. However, the site is required to be baselined in detail to understand the environmental value of the affected land before exploring options for achieving BNG plus the development and implementation of enhancement and mitigation plans. It may not be necessary to acquire new land to achieve this, for example, National Grid projects have contributed to local schemes in the past. The additional cost for the replacement of lost habitats should then be determined.

  The area of additional land required should be minimised and early engagement with stakeholders should be performed plus permitting and consent requirements should be started early to avoid any schedule delays.
- The new build options also require the set-up of a construction camp adjacent to the site. Early engagement with landowners should be undertaken to secure the land and allow rental costs to be agreed.
- For GT driven units, the current basis is a new fuel gas package. There is an opportunity to use the existing package, however it would potentially need modification. A detailed assessment should be undertaken to assess this opportunity.
- In order to meet in-trench cable separation distances specified by current National Grid specifications, space availability in existing trenches should be established and if necessary, completely new trenches utilised.
- For the two new unit option, there may be a requirement to re-route the firewater piping which is currently located under the fence line. The extent of the modifications required should be evaluated in detail plus tie-in location for the new units identified.

13.0 REFERENCES

REFERENCES	
Ref 1	King's Lynn Compressor Station Study Basis of Design, doc. no. 203513C-001-RT-0008-0002 Rev C.
Ref 2	King's Lynn Compressor Station Site Visit Report, doc. no. 203513C-001-RT-0500, Rev B.
Ref 3	Cost Estimating Methodology, doc. no. 203513C-000-RT-0300, Rev B.
Ref 4	King's Lynn Compressor Station Cost Estimates (Phase 1 +/-50%), doc. no. 203513C-001-RT-0300 Rev B.
Ref 5	King's Lynn Compressor Station Level 1 Schedules (Phase 1), doc. no. 203513C-001-PLG-0300 Rev B.
Ref 6	King's Lynn Compressor Station Layout Review Report (Phase 1), Rev. B, doc. no. 203513C-001-RT-0250 Rev B.
Ref 7	King's Lynn Compressor Station Options Review (Phase 1), doc. no. 203513C-001-RT-0503 Rev B.
Ref 8	King's Lynn Compressor Station Mechanical Equipment List (Phase 2), Rev. B, doc. no. 203513C-001-EL-0261
Ref 9	T/SP/G/37, Rev. 03/13, "Specification for Site Location and Layout Studies and Reviews", National Grid, dated June. 2013
Ref 10	King's Lynn Compressor Station Cost Estimates (Phase 2 +/-30%), doc. no. 203513C-001-RT-0301 Rev B.
Ref 11	King's Lynn Compressor Station Level 2 Schedules (Phase 2), doc. no. 203513C-001-PLG-0301 Rev C.
Ref 12	King's Lynn Carbon Interface Tool Summary Report Phase 2, doc. no. 203513C-001-RT-6200-0002 Ref. B.
Ref 13	King's Lynn Compressor Station BAT Input Sheet (Phase 2), doc. no. 203513C-001-CN-6200-0001 Ref. B.
Ref 14	King's Lynn Compressor Station Biodiversity Net Gain Assessment, doc. no, 203513C-001-RT-6200-0001 Ref. C.
Ref 15	King's Lynn Compressor Station Layout Review Report (Phase 2), doc. no. 203513C-001-RT-0251 Rev B.
Ref 16	King's Lynn Risk Workshop Report, doc. no. 203513C-001-RT-0200 Rev C.
Ref 17	King's Lynn Compressor Station Process Description, doc. no. 203513C-001-RT-0008-0001 Ref B.
Ref 18	King's Lynn Compressor Station Plot Plans / Layout Drawings (Phase 2)doc. no. 203513C-001-DW-0051-0001 Ref C.
Ref 19	Kings Lynn Compressor Station Electrical Modifications Summary doc. no. 203513C-001-RT-1600-0001 Rev C.
Ref 20	King's Lynn Process Flow Diagrams doc. no. 203513C-001-PFD-0010-0001 Rev B
Ref 21	[redacted] Fleet RAM Study Report, Doc. no. 1429403, Rev 2 (14-03-2022)

Ref 22	King's Lynn MCPD Compressor Emissions, Asset Health Requirements, doc. no. PAC1051190-14-41-00-7210-NGG-0042 Rev 1.
Ref 23	UK Power Networks Budget Estimate for King's Lynn Site, Letter dated 14th July 2022, Ref: 8600026035 / QID 3000040885
Ref 24	EPR Variation Notice (EPR/BS8028IR/V003) dated 29/03/10
Ref 25	Avon DLE Technical Note, Document Number: PAC105119C-14-41-00-0000-NGG-0026 (Dated 19/01/2022)
Ref 26	Combustion Gas Turbine (API 616-4TH) Data Sheet, No. A3B4/01-02 (NC0013)
Ref 27	BAT Input Proforma Meeting Minutes, Dated 13/05/2022 (Received on 13/05/2022)
Ref 28	Directive (EU) 2015/2193 of the European Parliament and of the Council of 25 November 2015 on the limitation of emissions of certain pollutants into the air from medium combustion plants