Annex
A16.05 Compressor Emissions Compliance Strategy

As a part of the NGGT Business Plan Submission

nationalgrid

Contents

1 Executive Summary

1.1 This document is National Grid Gas Transmission’s (NGGT) Compressor Emissions Compliance Strategy (CECS), covering emissions compliance related works on compressors and other assets affected by emissions legislation. It details NGGT’s decision-making processes and plans for complying with the Industrial Emissions Directive (IED) and the Medium Combustion Plant Directive (MCPD) through RIIO-2 and beyond to the MCPD compliance date, 1 January 2030.

1.2 We have heard from our stakeholders that it is important to do the right thing for society by reducing the impact of our activities on the environment. We believe our nation should have a clean, reliable energy system to help address the effects of climate change, improve the quality of the air we breathe and power growth and prosperity in our economy for future generations. We also know that stakeholders want to be able to take gas on and off the system where and when they want, providing heat and energy to domestic consumers. This strategy sets out how we intend to balance these needs, reducing our environmental impact through compliance with air quality legislation, whilst ensuring there is adequate compression capability on the gas network to ensure the needs of stakeholders are met.

1.3 We believe the proposals presented within this document deliver the most cost-effective network solution to meet the current and future needs of our stakeholders. Our integrated programme, developed through stakeholder engagement and a robust approach to options assessment, represents a total funding request of £210.3m (18/19 price base) across the RIIO-2 period with £156.7m as upfront funding and £53.6m through an uncertainty mechanism. Our current view of emission compliance spend for RIIO-3 is £139m. A further £174.4m is subject to a UM across RIIO-2 and RIIO-3 at the St Fergus site.

1.4 Twenty-eight[1] of our seventy-one[1],[2] operational compressors today are affected by the MCPD. These are some of the oldest compressors we operate, many of which are beyond their design life. There are three high-level options for achieving compliance: decommissioning, derogation (i.e. limited/emergency use) or ‘make compliant’. Making a unit compliant could be done by replacement of the unit with compliant ones, applying emissions abatement technology or restricting the control system to reduce emissions.

1.5 All options to achieve compliance and deliver air quality improvements result in a cost to the consumer with associated impacts on the level of network capability. Therefore, we have taken an overall network approach to determine the option that meets stakeholder network capability requirements and achieves compliance in the most cost-effective way.

1.6 We have carefully assessed the options using a robust cost benefit analysis complemented by qualitative assessments and stakeholder feedback to determine the optimum option for compliance for a range of future scenarios. We believe our plans represent an optimal compressor investment and system operation plan for compliance with emissions legislation whilst meeting the long-term needs of the network.

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[1] Including King’s Lynn Unit A, an Avon unit that was disconnected in 2018. It is shown as operational due to the timing of our business plan creation.

[2] Does not include new units being built at Peterborough and Huntingdon.

1.7 Table 1 summarises the proposed volume of emissions-driven investment decisions on the gas transmission network to 2030[3].

Table 1 Summary of compressor emissions compliance plan

	RIIO-1	RIIO-2	RIIO-3 (1 January 2030 compliance date)
New Units	Huntingdon x 2 Peterborough x 2	Hatton x 1 Wormington x 2	King's Lynn x 2 Peterborough x 1 St Fergus x 3
Derogations	Carnforth B Hatton A, B and C Moffat x 1 Warrington A and B Wisbech A	Carnforth B Hatton A Wisbech A	Cambridge x 1 Chelmsford x 1 Diss x 2 Hatton A Huntingdon C Wisbech A
Decommissioning[4]		Hatton B and C Huntingdon A and B Peterborough A and B St Fergus 2A, 2B, 2D	Alrewas A and B Cambridge x 1 Carnforth A and B Chelmsford x 1 Diss x 1 King's Lynn A and B Kirriemuir A, B and C Peterborough C St Fergus 1A, 1B, 1C and 1D Wisbech B Wormington A and B

1.8 Our Environmental Regulators expect us to use derogated units for the absolute minimum time, within the limited hours, to meet our operational requirements. For investments due to be delivered beyond RIIO-2, we are reviewing the correct blend of decommissioning and derogations due to marginal cost benefit analysis outputs for some compressors and the future uncertainty in gas flow patterns on the network. Given the potential impacts on network capability, we will work with stakeholders in the development of our RIIO-3 plans to reach the optimum conclusion.

1.9 Delivery of these RIIO-2 proposals will be measured through a number of compressor emissions price control deliverables as part of the RIIO-2 price control, and our proposals for this are set out in our business plan annex A3.01. Our proposals at King's Lynn, Peterborough and St Fergus will be subject to an uncertainty mechanism, please see annex A3.02.

1.10 This document is accompanied by four Justification Papers which set out the scope, costs and benefits of each of our RIIO-2 compressor, emissions-related investment proposals. Alongside these Justification Papers are four Cost Benefit Analysis (CBA) documents providing a

[3] There are additional units being decommissioned due to other drivers. See Appendix A16.08.
[4] See footnote 3

quantitative assessment of the main options under consideration, demonstrating the value each option brings. These documents relate to the Wormington, King's Lynn, St Fergus, Peterborough and Huntingdon sites and can be found in annexes A16.10 – A16.17 of the business plan.

1.11 Our investment proposals for RIIO-2 are based on the four 2018 Future Energy Scenarios (FES). Following the government announcement on net-zero in the summer of 2019, the FES 2019 report was expanded to include a standalone sensitivity analysis on achieving net zero. This net-zero sensitivity falls within the range of the four FES 2018 scenarios and therefore is inherent in our proposals. All four FES scenarios show a long-term future for gas usage.

1.12 This topic also has several interactions with other aspects of our business plan. In particular, our asset health proposals which have been developed alongside the emissions compliance work proposed in this document. The related investments proposed in the Asset Health Justification Papers must be fully funded to enable these works. Should this not be the case, other compression on the network will not be as resilient as needed to support the delivery and ongoing maintenance of these investments. For more information, see section 12 Interactions.

1.13 This plan has also been reviewed as part of the overall costs associated with our compressor fleet to ensure that all costs are justified. For more information, refer to Compressor Supporting Information in Appendix A12.04.

2 Context

2.1 The following section introduces the relevant emissions legislation, how it affects our assets and how those assets are used.

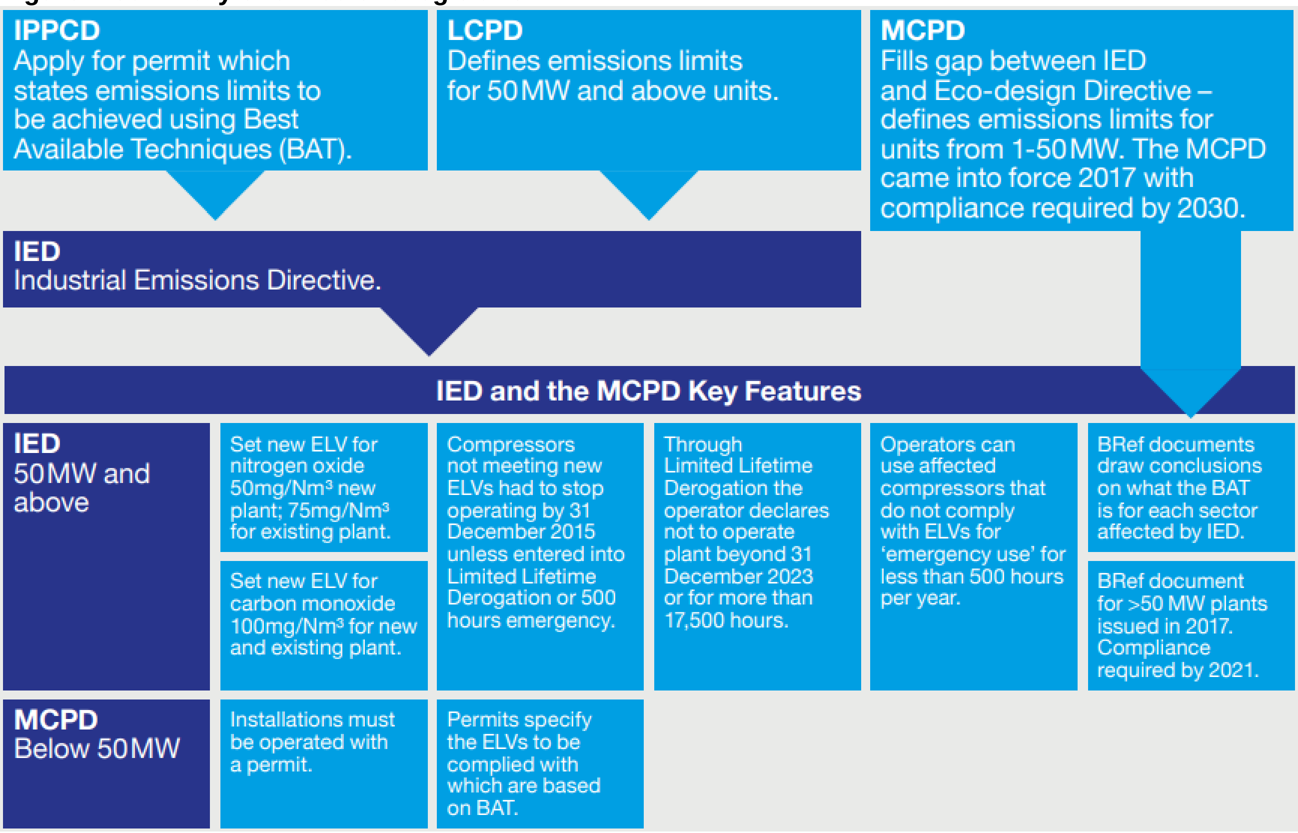
The legislation and how it affects us

2.2 Environmental legislation has been developed over time, introducing new standards to minimise the impact of industrial activities on the environment and human health. The legislation aims to reduce the pollutants discharged to air, water and land. National Grid's gas turbine driven compressors, and several smaller assets, are impacted by the legislation due to limits on emissions of sulphur dioxides (SO2), nitrogen oxide (NOx) and carbon monoxide (CO) to the environment from the combustion of natural gas.

2.3 It is mandatory for all EU countries to comply with the minimum standards set out in the legislation described in this section. This legislation has been transposed into UK law, so will remain mandatory post-Brexit, and applies to the assets in operation on the gas National Transmission System (NTS).

2.4 This section introduces all emissions legislation that affects our assets, summarised in Figure 1.

Figure 1 Summary of emissions legislation[5]



[5] *BRef documents are BAT Reference documents*

Large Combustion Plant Directive (LCPD) 2001 (Directive 2001/80/EC)

2.5 The LCPD applies to all combustion plants with a thermal input of 50 MW or more. Such combustion plants must not exceed the Emission Limit Values (ELVs) as defined in the directive. An ELV is the maximum permissible rate at which a pollutant can be released by an installation. The ELVs set out in this directive can be met in one of two ways which are summarised below:

1. All equipment is fully compliant with the specified Emission Limit Values and can be operated without restriction
2. Choose to restrict the operation of non-compliant equipment by entering it into one of the two available derogations under the IED, either the Limited Lifetime Derogation (LLD) or the Emergency Use Derogation (EUD).

2.6 Any non-compliant plant and equipment not operating under derogation cannot be used after 31 December 2023.

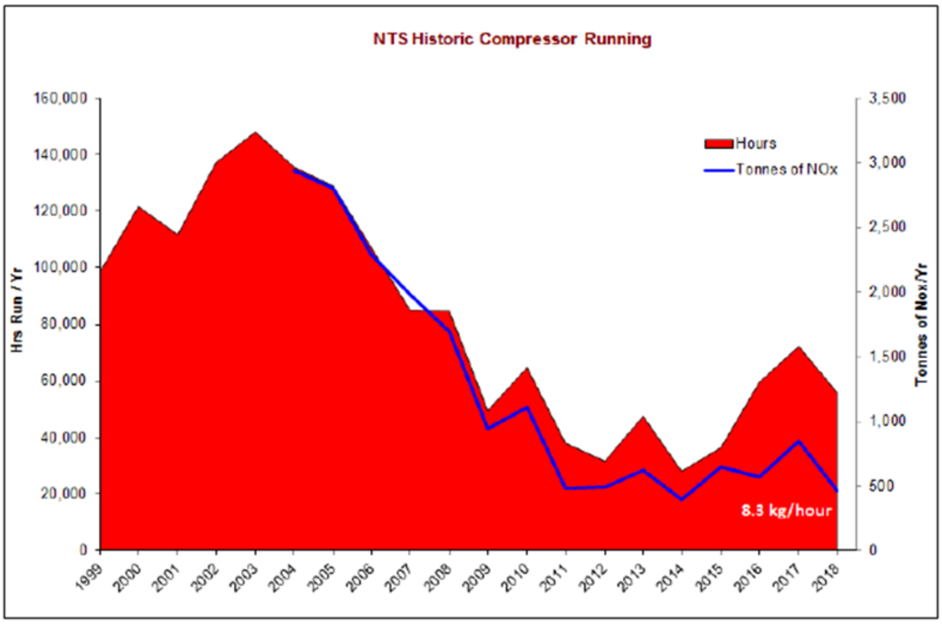
Integrated Pollution Prevention and Control Directive (IPPC) 2008 (Directive 2008/1/EC)

2.7 Under the IPPC, any installation with a high pollution potential is required to have a permit. One of the pre-requisites for this permit is that Best Available Techniques (BAT) are used to prevent or reduce the emission of pollutants. BAT assessments are required when developing a solution to avoid or reduce emissions from industrial installations and hence the impact on the environment. BAT assessments take account of the balance between costs and environmental benefits over the full lifecycle of the installation.

2.8 The impact of IPPC means that all our compressor units have a permit which specifies the maximum ELVs to air for that unit. We have an overarching IPPC strategy as agreed with the Environment Agency (EA), Scottish Environmental Protection Agency (SEPA) and Natural Resources Wales (NRW) which requires us to review our compressors as a fleet on an annual basis, targeting those sites that emit high levels of NOx to maximise the environmental return. This process is called the Network Review.

2.9 Between 2008 and 2018, NGGT has delivered several projects decreasing overall NOx emissions by two-thirds across the compressor fleet, whilst maintaining a similar number of operating hours, see Figure 2. The projects include installation of low-NOx technologies, limiting operating hours for sites with older unabated gas turbines and installation of electric drives.

Figure 2 Compressor running hours vs NOx emissions



The Industrial Emissions Directive (Directive 2010/75/EU)

2.10 The IED brings together existing pieces of European environmental legislation, including LCP and IPPC. The LCP directive is replaced by Chapter III (with Annex V) of the IED. Addressing IED units first has meant that our most polluting compressors have been or are already in the process of being addressed.

2.11 The major provisions of the IED which impact National Grid and our compressor units are as follows.

<u>The use of permits for installations</u>

2.12 The IED specifies that all installations must be operated with a permit. These permits specify the ELVs for polluting substances likely to be emitted from the installation concerned and also determine the environmental risk of that installation. This mirrors the specifications set out in the IPPC whereby installations must comply with the ELVs set out in their permit, which are based on BAT (see **Best Available Techniques Process**).

<u>Establishment of BAT Reference documents</u>

2.13 The IED also introduces an increased emphasis on the status of the BAT Reference (BREF) documents. These BREF documents draw conclusions on what the BAT is for each sector to comply with the requirements of IED. This then forms the reference for setting the permit conditions mentioned above.

<u>The updating of ELVs for installations above 50 MW</u>

2.14 The IED states that for installations with a thermal input over 50 MW it is mandatory to comply with the following ELVs;

- Carbon Monoxide (CO) – 100mg/m^3
- Nitrogen Oxide (NOx) – 75mg/m^3 for existing installations
- Nitrogen Oxide (NOx) – 50mg/m^3 for new installations.

Limited Lifetime Derogation

2.15 The requirements for a Limited Lifetime Derogation state that from 1 January 2016 to 31 December 2023 combustion plant may be exempted from compliance with the ELVs for installations above 50 MW provided certain conditions are fulfilled:

(a) The operator makes a declaration before 1 January 2014 not to operate the plant for more than 17,500 operating hours within the derogation period, which started on the 1 January 2016 and ends on the 31 December 2023;

(b) The operator submits each year a record of the number of operating hours since 1 January 2016.

2.16 National Grid has duly made the required declaration and entered six high usage compressors into this derogation. Based on current forecasts of unit running hours, the only unit likely to near the 17,500 hour limit by 31 December 2023 is Hatton B.

Table 2 Compressors on LLD with historic annual running hours (Jan-Dec)

Compressor Station	Berth / Unit	2016 (hrs)	2017 (hrs)	2018 (hrs)	Total (hrs)
Carnforth[6]	A	0.0	0.0	0.0	**0**
Hatton	B	2535.0	3453.8	841.8	**6830.6**
	C	1455.0	1970.5	657.4	**4082.9**
Kirriemuir[7]	D	712.4	0.0	0.0	**712.4**
St Fergus	2A	755.7	2441.4	1730.1	**4927.2**
	2D	191.0	54.0	564.9	**809.9**

Emergency Use Derogation

2.17 The IED allows an enduring derogation from the requirement to meet the specified ELVs for equipment used in emergencies and less than 500 hours per year. As with the Limited Lifetime Derogation, this derogation has been applicable from 1 January 2016 and a number of our operating units have been entered into this derogation.

Table 3 Compressors on EUD with historic annual running hours (Jan-Dec)

Compressor Station	Berth / Unit	2016 (hrs)	2017 (hrs)	2018 (hrs)	Total (hrs)
Carnforth	B	7.2	1.3	22.9	**31.4**
Hatton	A	78.3	196.5	233.4	**508.2**
Moffat	A	85.7	6.2	83.7	**175.6**
	B	174.6	97.5	238.4	**510.5**
Warrington	A	8.6	65.3	68.8	**142.7**
	B	9.4	13.7	70.3	**93.4**
Wisbech	A	11.0	6.8	15.3	**33.1**

[6] Carnforth is disconnected from the NTS
[7] Kirriemuir Unit D has now been disconnected from the NTS

Medium Combustion Plant Directive (MCPD) (Directive (EU) 2015/2193)

2.18 Following assessment of network capability requirements, the MCPD is the major driver behind our RIIO-2 emissions investment proposals. MCPD regulates pollutant emissions from the combustion of fuels in plants with a rated thermal input equal to or greater than 1 Megawatt thermal (MWth) and less than 50 MWth. The affected assets are referred to as Medium Combustion Plants (MCPs).

2.19 The MCPD regulates emissions of Sulphur Dioxides and Nitrogen Oxides to air through ELVs and requires monitoring of Carbon Monoxide emissions. ELVs are differentiated according to the plant's age, capacity and type of installation. This legislation was initially set with a deadline for compliance of 2025 for all polluting plant. In 2015 we successfully influenced European legislation to extend the compliance date to 1 January 2030 for gas compressors to ensure the safety and security of a national gas transmission system. Our plant impacted includes gas turbines compressors and a small number of water bath heaters, boilers and standby gas generators. Units can also be derogated - restricted to 500 operating hours per year, based on a 5 year rolling average.

2.20 The majority of water bath heaters, boilers and standby gas generators are in the process of being replaced due to their condition under our asset health work programme. There is currently no work planned in RIIO-2 for non-compressor assets. However, there are two water bath heaters which are likely to need addressing in RIIO-3.

Best Available Techniques

2.21 National Grid is legally bound under the IED, implemented through its site Environmental Permit Regulations (EPR) permit (in England and Wales) or a Pollution Prevention and Control (PPC) permit (in Scotland), to comply with the requirements of BAT in respect of its compressor operations.

Table 4 Best Available Techniques summary

Definition of Best Available Techniques

BAT can be defined as follows:

- *Best* — The most effective techniques for achieving a high general level of protection for the environment as a whole.
- *Available* — Techniques developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions taking into consideration the cost and advantages, whether or not the techniques are used or produced in the United Kingdom as long as they are reasonably accessible to the operator.
- *Techniques* — Includes both technology and the way the installation is designed, built, maintained, operated and decommissioned.

2.22 NGGT is required to use BAT as the primary selection mechanism for all new and substantially modified compressor machinery trains. This means that when we are looking at solutions for achieving compressor emissions compliance, BAT determines the chosen option for build solutions.

Timeline

2.23 The combustion emissions legislation timescales applicable to NGGT are summarised in Table 5 as provided in Appendix 1 of the Compressor Emissions Compliance Strategy Guidance document from Ofgem[8].

Table 5 Combustion emissions legislation timescales applicable to NGGT

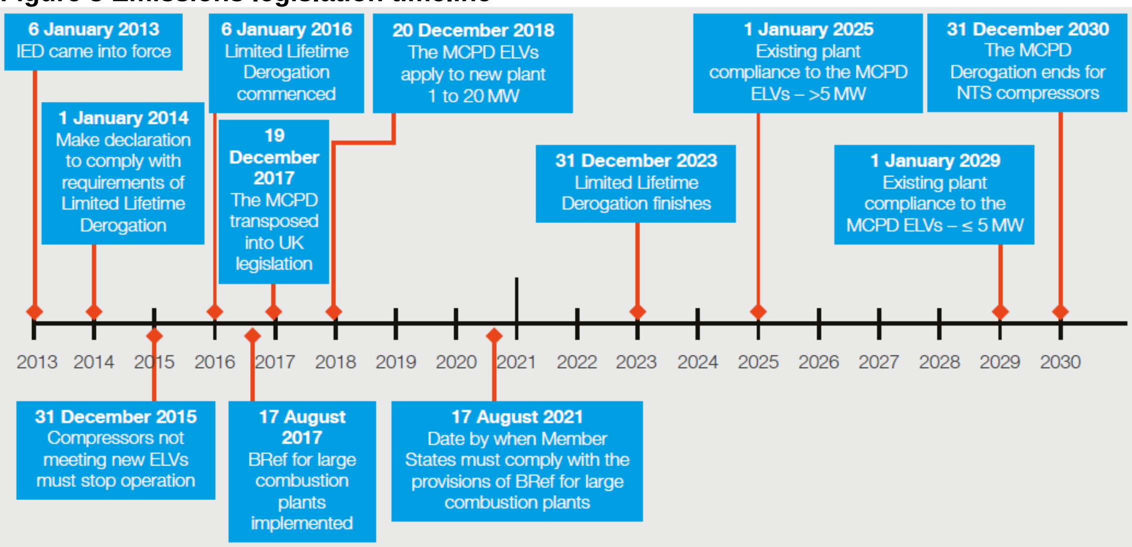
Date	Legislation	Requirement
31 July 2021	IED Chapter II	Existing LCP that are not subject to IED's Chapter III Limited Life or Emergency Use Derogations must meet the emissions requirements set out in the LCP BAT Conclusions.
31 December 2023	IED Chapter III LCP	Limited Life Derogation comes to end and plant on LLD will cease operation. Remaining plant will either have to operate under 500-hour emergency use derogation, meet Chapter III and LCP BAT Conclusions "New" plant emissions requirements or cease operations.
1 January 2030	MCPD	Derogation for gas compression plants and other assets operating on a national transmission system ceases and all MCPD scale (1-50MW) plant must meet the emission limits as set out in the MCPD, operate under a 500-hour operating hour derogation or cease operations.

2.24 The key dates summarised in Table 5 are the minimum legal requirements that NGGT must meet. However, the overarching requirement for a Chapter II IED activity to operate to BAT could result in a smaller MCPD scale plant being upgraded before these deadlines. This could apply in situations where an MCPD unit on a high usage site is identified for replacement under IPPC during the network review, as is the case for Peterborough and Huntingdon.

2.25 The MCPD units are also planned to be delivered ahead of the legislative deadline to minimise risk to gas supplies and enable drive efficient delivery of an overall programme of work.

2.26 An overview of the legislative timeline is shown in Figure 3.

Figure 3 Emissions legislation timeline



[8] https://www.ofgem.gov.uk/system/files/docs/2019/06/compressor_emissions_compliance_guidance.pdf

Impact on NGGT's Compressor Fleet

2.27 In the last 20 years, there has been a significant shift in the way the gas transmission network is utilised. Historically, the NTS has operated on a North to South flow pattern with compression used to pull and push the gas from the main entry point at St Fergus to the high demand areas in England. However, with the development of new Liquefied Natural Gas (LNG) import terminals and interconnectors, there are now more entry points onto the system and these are distributed around the country. The UK Continental Shelf (UKCS) supplies have declined, our dependence on gas for power has increased and in 2004 the UK became a net importer of gas on an annual basis.

2.28 The main reasons we use compressors are:

- to transport gas from the supply points to the demand centres;
- to provide and maintain pressures within network design safety parameters;
- to meet contractual capacity and exit pressure commitments;
- to provide system flexibility to meet rapidly changing use and conditions;
- to provide network resilience against supply losses or very high demand; and
- occasional use to facilitate maintenance.

2.29 This supports our ability to enable stakeholders to move gas on and off the transmission system where and when they want.

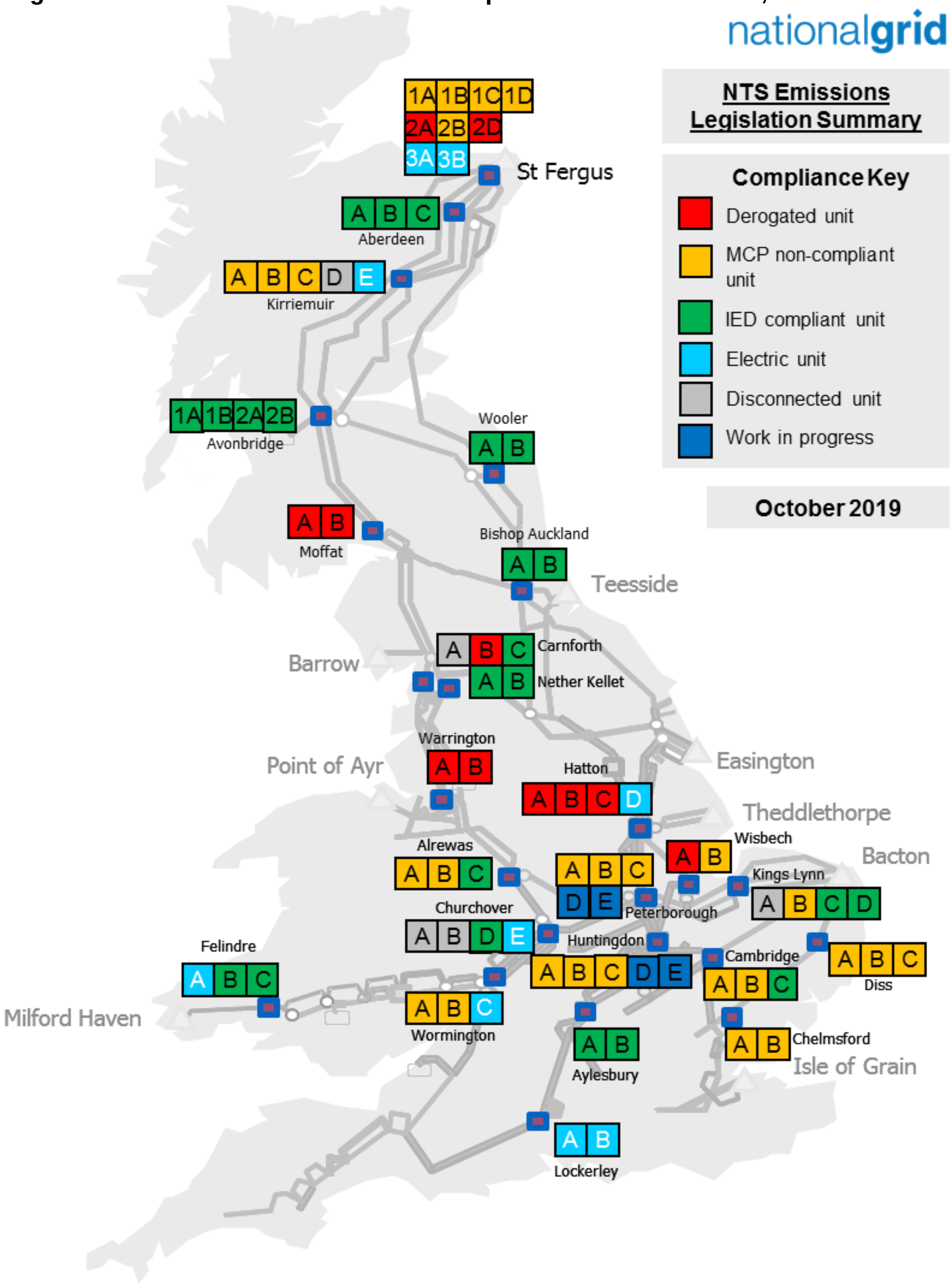
2.30 Our compressors have an impact across the whole energy system. For example, as well as controlling the pressure of gas to the distribution networks, compressors are used to facilitate maintenance on distribution networks. Gas is also supplied to power stations to generate power for the UK. These flows are increasingly volatile due to the increasing amounts of intermittent renewable generation. Our compressors provide the flexibility to respond to this volatility, especially important where power stations are located at the extremities of the network.

2.31 The current compressor fleet on the NTS comprises seventy-one[9,10] operational units and four disconnected units, including units that are compliant with emissions legislation (gas and electric drives) and units impacted by the IED and MCPD, see Figure 4. There are twenty-eight gas turbine-driven compressors units on the NTS that are non-compliant with MCPD[10].

9 Does not include new units being built at Peterborough and Huntingdon,

10 Includes King's Lynn Unit A, an Avon unit that was disconnected in 2018. It is shown as operational due to the timing of our business plan creation.

Figure 4 Current state of emissions compliance across the NTS, October 2019



2.32 These twenty-eight units are located across eleven compressor sites, see Table 6. Most stations have multiple affected units.

Table 6 Number of units affected by MCPD at each compressor station

Compressor Station	No. of MCPD non-compliant units
St Fergus	5
Kirriemuir	3
Wisbech	1
Alrewas	2
Peterborough	3
King's Lynn	2
Huntingdon	3
Wormington	2
Cambridge	2
Diss	3
Chelmsford	2
Total	**28**

Types of Gas Compressors affected by MCPD

2.33 There are currently three types of gas generator in service across the NTS which would fall within the range of the MCPD: the Siemens SGT400 (previously designated as the Cyclone); the Solar Titan; and the Rolls Royce (now Siemens) Avon1533.

2.34 The SGT400 and Solar Titan engines employ Dry Low Emissions (DLE) technology; these have emissions falling within the ELVs specified by the MCPD and represent BAT. The Avon gas generators within our fleet are not compliant with the ELVs specified by the MCPD.

2.35 All twenty-eight units affected by MCPD are Avons.

2.36 Table 7 lists all compressor sites containing Avons. Where Avons are currently lead units on their site, they are highlighted. At Peterborough and Huntingdon, the Avons will no longer be lead units once the current works are completed to install DLE units.

Table 7 NGGT's compressor sites affected by emissions legislation.

Site	Total no. of units	No. of Avon units	Primary Unit(s)	Backup Unit(s)	Works in Progress	Primary mode of Avon operation
Alrewas	3	2	1 x DLE	2 x Avons		Single Unit
Cambridge	3	2	1 x DLE	2 x Avons		Single Unit
Chelmsford	2	2	2 x Avons			Single Unit
Diss	3	3	3 x Avons			Single Unit / Series
Huntingdon	3	3	3 x Avons[13]		2 x DLEs (IPPC funding)	Parallel
King's Lynn	4[11]	2[11]	2 x DLE	2 x Avon[11]		Parallel
Kirriemuir	4	3	1 x VSD[12]	3 x Avons		Parallel
Peterborough	3	3	3 x Avons[13]		2 x DLEs (IPPC funding)	Parallel
Wisbech	2	1	1 x Avon	1 x RB211 derogated		Single Unit
Wormington	3	2	1 x VSD	2 x Avons		Single Unit / Parallel
St Fergus	9	5	2 x VSD	5 x Avons, 2 x RB211s		Parallel
Total	**39**	**28**	**20**	**19**	**4**	

Key

(blue)	Avon is lead unit on site
(grey)	Avon is backup unit

[11] Including King's Lynn Unit A, an Avon unit that was disconnected in 2018. It is shown as operational due to the timing of our business plan creation.
[12] Variable Speed Drive (VSD)
[13] Two units at Peterborough and two units at Huntingdon are being replaced under IPPC in the May 2018 reopener.

Compressor Compliance

2.37 Emissions testing is carried out at intervals as specified in the permit, dependent on running hours. The standard interval is to test once per year. We use a Predictive Emissions Measurement System (PEMS) which means that, if a compressor runs for less than 2200 hours in a year, the testing can be deferred to the following year to give a two year interval. In all cases, we have to carry out emissions testing every 4380 hours of running, even if this is in less than 12 months. These numbers are equivalent to six months of running (4380) and three months of running (2200). An additional test is done if any work is carried out that would cause a change in the emissions profile of the unit, e.g. changing the gas generator or replacement of certain ancillary equipment. The PEMS reads data from the control systems to determine the operating point within the model. Following each emissions test, the PEMS model is updated to maintain its accuracy.

2.38

Table 8 summarises the emissions of the Avon compressor units during testing and operational running over the last seven years. Highlighted in red are results above the 150g/m^3 limit and highlighted in orange are results above 135mg/m^3. Where the results are amber, we will progress investigations into control system restricted performance for RIIO-3.

2.39 It can be seen that there are a few units which have not breached the NO_x limit during an emissions test and/or during operational running however these units are capable of breaching the limit and as requirements change in the future they might do so.

2.40 Addressing emissions compliance of the units with emissions currently below the thresholds is planned for RIIO-3. This will give us time to investigate whether the emissions are expected to continue at these levels, and they are in effect compliant units, or whether other minor modifications are possible to ensure they remain compliant units.

Table 8 Emissions testing results of Avon compressor units[14]

Site	Unit	Highest recorded NOx in an emissions test	Highest level of Nox during operational running in last 7 years	Number of operational running hours above 150 in last 7 years
Alrewas	A	138	135	0
Alrewas	B	147.9	152	7
Cambridge	A	145	138	0
Cambridge	B	146.4	162	4
Chelmsford	A	133.4	117	0
Chelmsford	B	141.9	130	0
Diss	A	128.6	130	0
Diss	B	140.8	140	0
Diss	C	141.9	139	0
Huntingdon	A	153.4	159	266
Huntingdon	B	154.1	156	377
Huntingdon	C	154.1	153	165
Kings Lynn	A	152.1	127	0
Kings Lynn	B	152.2	154	59
Kirriemuir	A	153.2	159	216
Kirriemuir	B	151.4	154	37
Kirriemuir	C	149	150	3
Peterborough	A	153.8	164	1321
Peterborough	B	148.8	165	900
Peterborough	C	151.8	150	4
St Fergus	1A	150.6	157	82
St Fergus	1B	163.5	145	0
St Fergus	1C	157.8	163	1
St Fergus	1D	142.4	177	35
St Fergus	2B	151.2	160	133
Wisbech	B	147	147	0
Wormington	A	151.9	153	2
Wormington	B	160	160	14

[14] King's Lynn Unit A is an Avon unit that was disconnected in 2018 which is why the operational results are significantly lower. It is shown as operational due to the timing of our business plan creation.

3 Pathway to Compliance

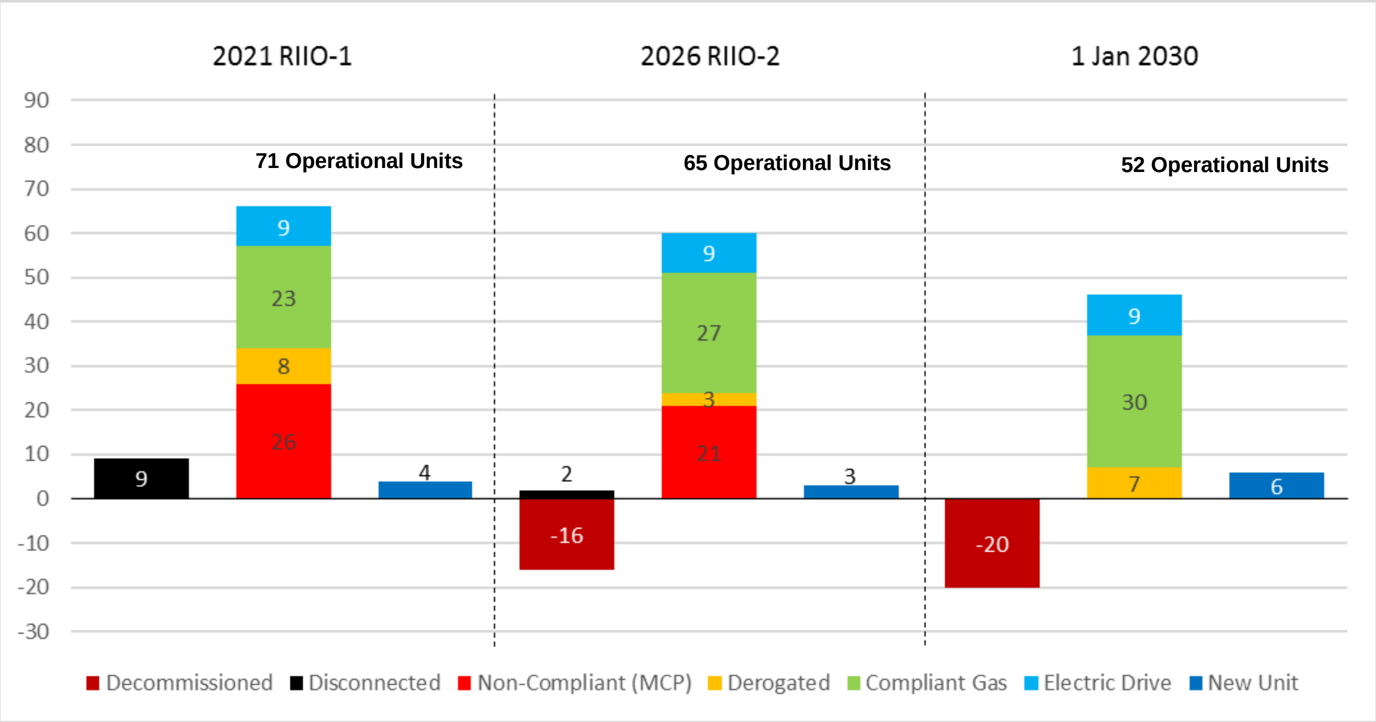
3.1 The following section summarises the expected state of emissions compliance across the NTS at the end of RIIO-1, at the end of RIIO-2 and by the compliance date of 1 January 2030.

3.2 We propose installing thirteen new compliant units by 1 January 2030.

3.3 In total, we are currently proposing to decommission thirty-six[15] compressor units and seven units will be operating under derogations by 1 January 2030. This will reduce the capability of the network. The end of RIIO-3 position reflects our current best view on future RIIO-3 derogations or decommissioning decisions. These may change as part of our ongoing assessment of network capability.

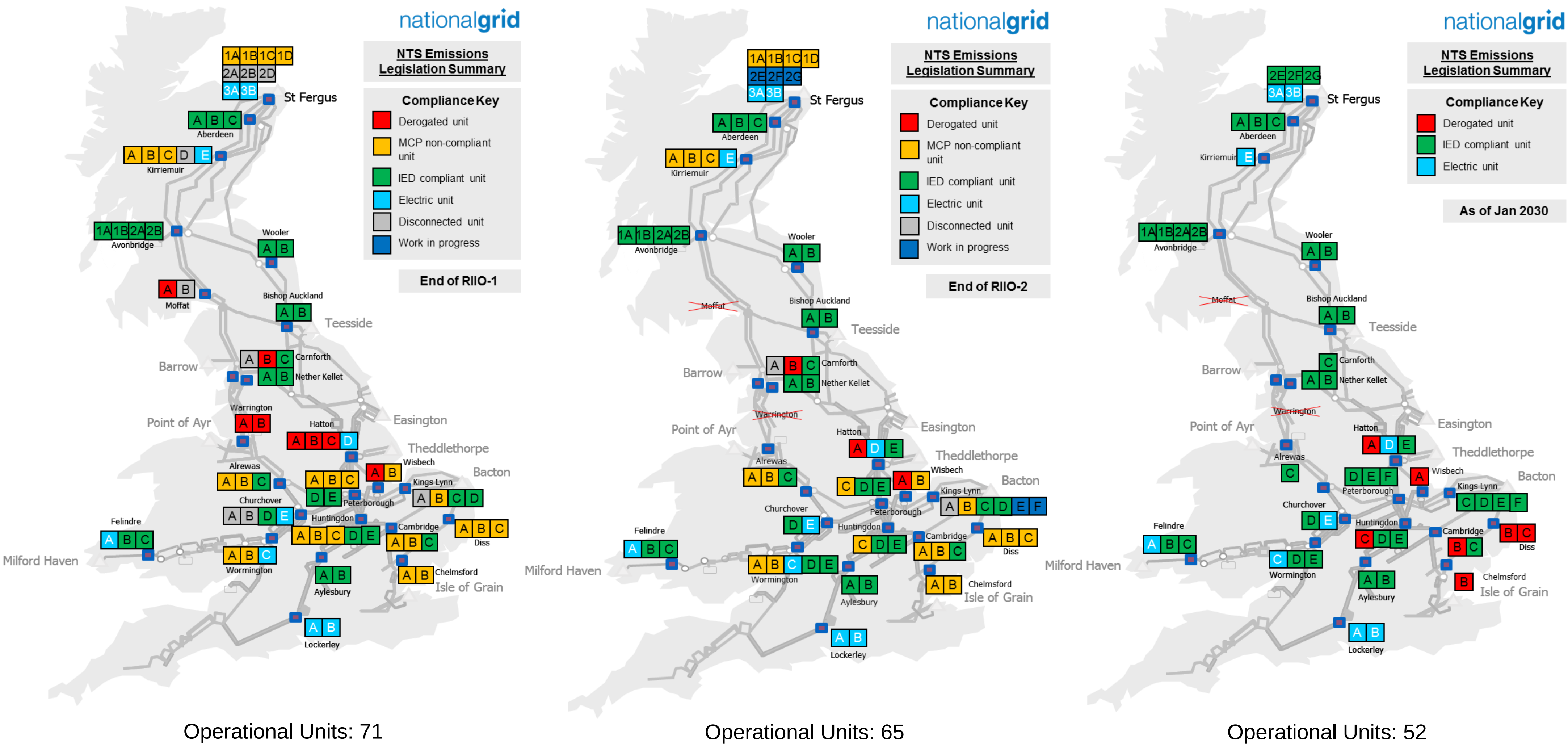
3.4 Figure 5 summarises the number of units on the NTS at the end of RIIO-1, RIIO-2 and by 1 January 2030, including the state of emissions compliance. Figure 6 shows site by site which compressor units are compliant with emissions legislation, those that are non-compliant (and with which set of regulations), those that are under derogation and units proposed to be decommissioned.[16]

Figure 5 State of emissions compliance from RIIO-1 through RIIO-2 and the MCPD compliance date of 1 January 2030



[15] *Includes two units at Moffat and two units at Warrington subject to employee and trade union consultation.*
[16] *Operational totals include King's Lynn Unit A, an Avon unit disconnected in 2018. It is shown as operational due to the timing of our business plan creation.*

Figure 6 State of emissions compliance across the NTS at the end of RIIO-1, RIIO-2 and the MCPD compliance date 1 January 2030



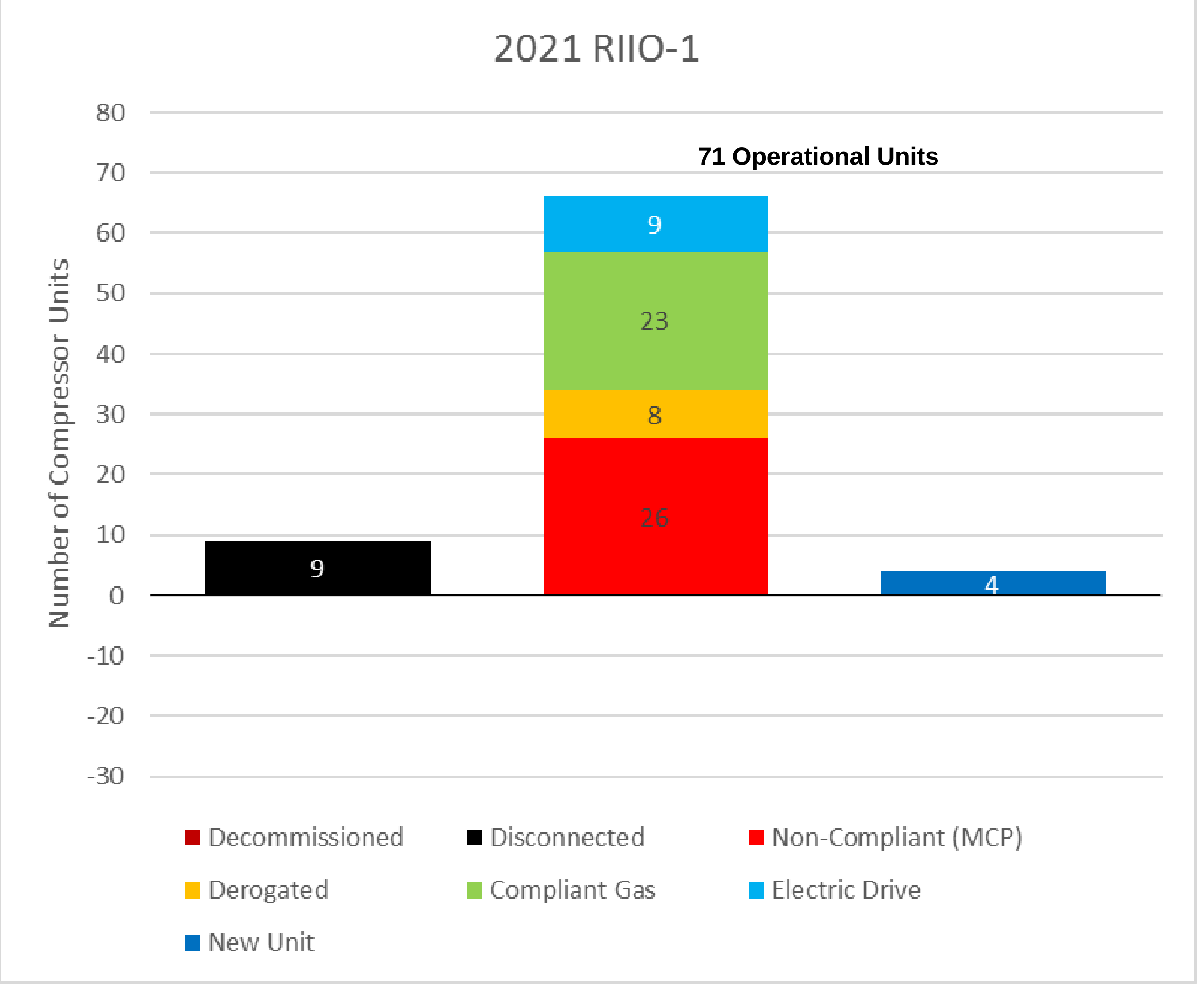
State of Compliance at the end of RIIO-1

3.5 Figure 7 shows that at the end of RIIO-1, there will be seventy-one operational compressor units and nine disconnected units.

3.6 Four new units will be connected to the NTS: two at Peterborough and two at Huntingdon. These are units affected by IPPC under the IED and were funded in RIIO-1.

3.7 There will be eight units operating under LCP derogations.

Figure 7 State of emissions compliance at the end of RIIO-1



State of Compliance at the end of RIIO-2

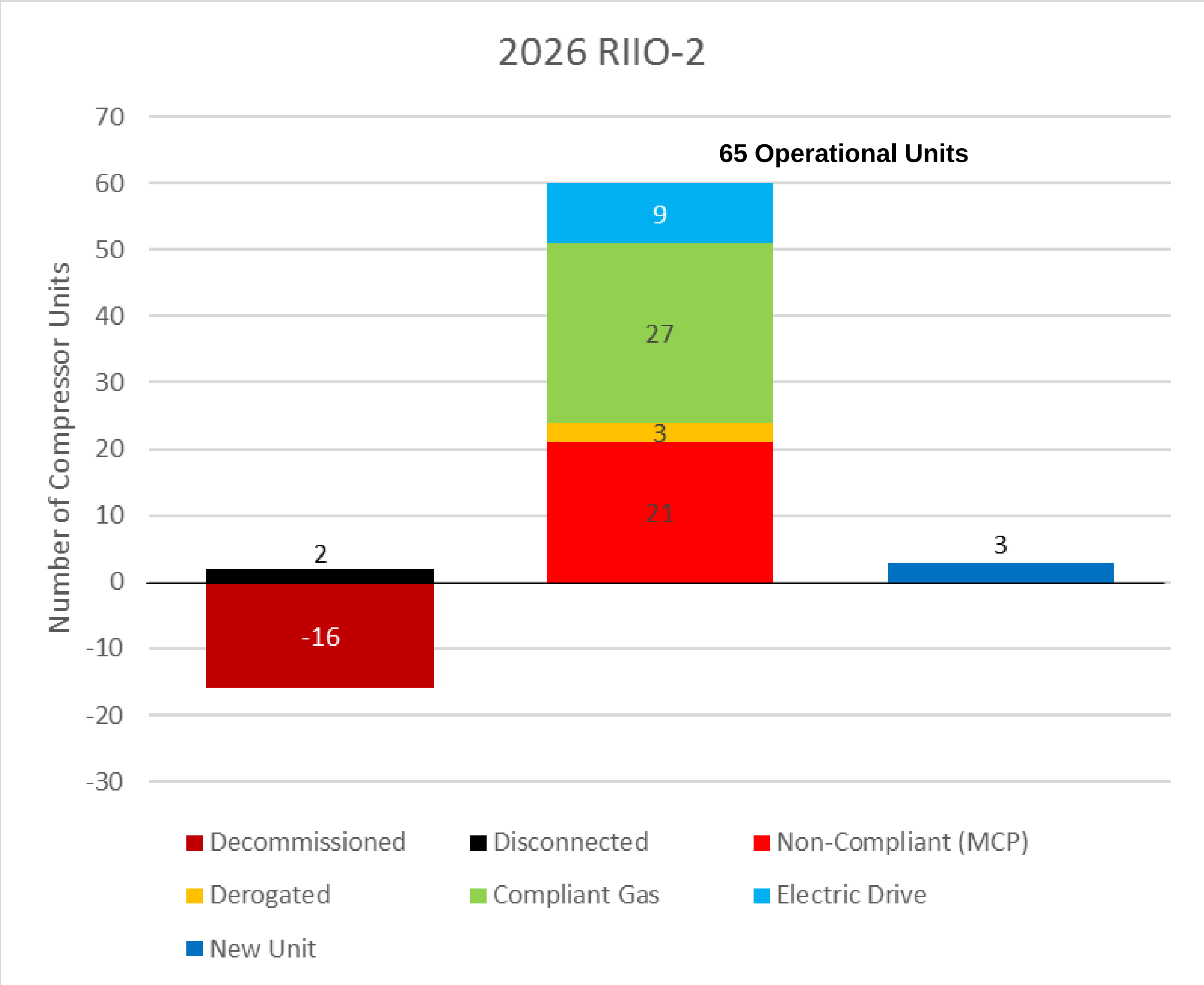
3.8 Figure 8 shows that at the end of RIIO-2, there will be sixty-five operational compressor units and two disconnected units.

3.9 During RIIO-2 three new units will be installed. There will be one new LCP/IPPC unit connected to the NTS at Hatton and two new MCPD units at Wormington. Two new units at King’s Lynn will be being built in RIIO-2 but will not be operational until 2027. Work will also have started on three new units at St Fergus during RIIO-2.

3.10 There will be three units operating under LCP derogations.

3.11 Decommissioning of sixteen units will take place in RIIO-2, including nine being replaced by new units. The other seven units are included in the annex A16.08 Redundant Assets Justification Paper (two at Warrington, two at Moffat and three already disconnected from the network in RIIO-1).

Figure 8 State of emissions compliance at the end of RIIO-2



State of Compliance at 1 January 2030

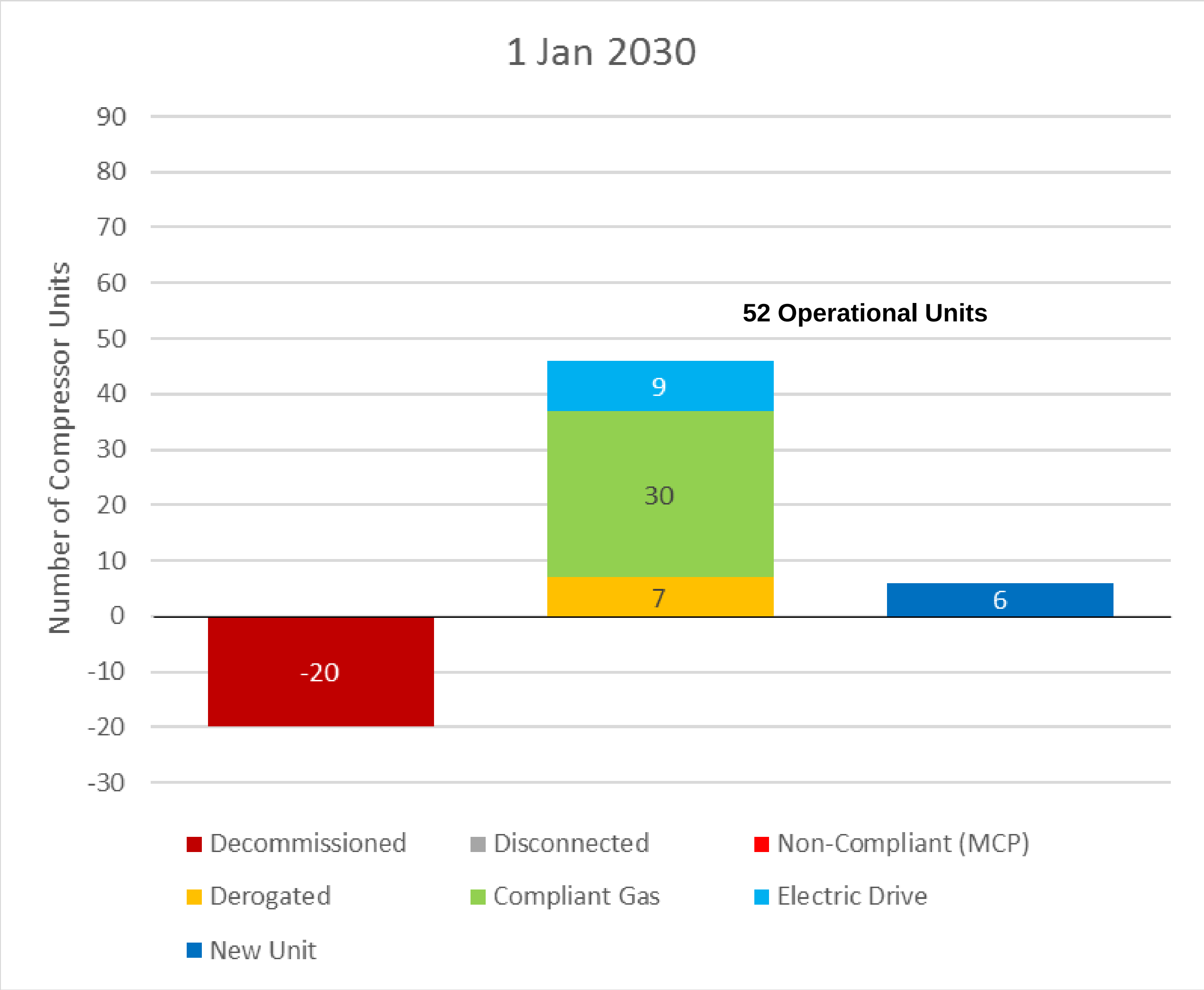
3.12 Figure 9 shows that at the MCPD compliance date of 1 January 2030, there will be fifty-two operational compressor units.

3.13 Between the end of RIIO-2 and 1 January 2030, there will be six new units connected to the NTS: two at King's Lynn, one at Peterborough and three at St Fergus.

3.14 Under current thinking, which is subject to further work to refine which units will be decommissioned and derogated, there will be seven units operating under derogations (two under the LCP and five under the MCPD).

3.15 In this same period, a further 20 units would be decommissioned under current proposals.

Figure 9 State of emissions compliance at MCPD date of 1 January 2030



4 RIIO-1 Reflections

4.1 This section discusses the funding arrangements for emissions compliance in RIIO-1 and our innovation projects that have resulted in significant benefits in this area.

RIIO 1 Framework: baseline funding and reopeners

4.2 Within Transmission Price Control Review 4 (TPCR4) we undertook work on our most utilised and polluting gas compressor sites to meet requirements for IPPC phase 1 and 2. We invested in electric drive compressors at St Fergus, Kirriemuir and Hatton.

4.3 As we developed our RIIO-1 business plan, we assessed the options available and at that time our legal guidance was that the emergency use derogation for 500hrs could not be used on our compressor fleet. As such our business plan was reflective of total compliance based on all units being fully replaced.

4.4 Ofgem's final proposals split the funding between baseline funding of £142.7m[17] at three sites (related to work at IPPC phase 3 work at Peterborough, Huntingdon and LCP works at Aylesbury). In addition, an allowance of £9m was provided to produce an integrated plan to carry out future works. Finally, an uncertainty allowance of £269m was also included. This funding was subject to a reopener mechanism for IPPC Phase 4 and IED Phase 2 projects and subsequently reduced to £0.5m.

Table 9 Summary of allowances throughout RIIO-1

Project scheme	Output	Start date	Delivery date	Cost (£m, 9/10 base)	2015 Reopener request change (£m, 9/10 base)	2018 Reopener request change (£m, 9/10 base)	Reopener Decision (£m, 9/10 base)
IPPCD Phase 3 and IED Phase 1	Peterborough	2013	2020	142.7			
	Huntingdon						
	Aylesbury						
Emissions abatement Optioneering	Development of emissions abatement integrated plan	2013	2015	9			
IPPCD Phase 4 and IED Phase 2	Integrated plan to set outputs	2015		269.3 subject to reopener	+40m	-157m	0.5

17 2009/10 price base

4.5 Our plans for the fleet evolved significantly over the RIIO-1 period. Gas DLE technology was demonstrated to be BAT on several sites with a lower cost than equivalent electric drive units. This will be covered in further detail in 7 Options Analysis.

4.6 Certainty of legislation meant that less work was required in RIIO-1 than initially expected in our RIIO-1 business plan submission.

4.7 Whilst our 2015 reopener was underpinned by stakeholder support Ofgem rejected the proposals based on a lack of cost benefit analysis. In our 2018 reopener, Ofgem's view was that solutions to decommission or undertake asset health works on units operating under derogations was not within the scope of the reopener. They also proposed IPPC works of second units at Peterborough and Huntingdon should be funded through the baseline funding. For St Fergus and Hatton, the final two of the sites within our reopener request, Ofgem considered that there was a case for investment, but due to the uncertainty of the solutions at both sites decided not to provide ex-ante funding. It was acknowledged that we may need to incur expenditure at St Fergus and Hatton during the RIIO-1 period and we are continuing to work with Ofgem on our proposed solutions for these sites. We are unlikely to progress these projects without clarity on funding. An Ofgem consultation on these projects closed in late September 2019.

4.8 For the Peterborough, Huntingdon and Aylesbury sites we are delivering the outputs in line with the allowance and our solution at Aylesbury has offset additional scope costs at Peterborough and Huntingdon.

RIIO-1 Innovation

4.9 Within RIIO-1 our innovation projects have resulted in some significant benefits by reducing emissions.

Aylesbury Compressor Site Emissions Reduction

4.10 We have continued to invest in business improvement to drive efficiencies in our business, an example of this is Aylesbury Compressor Site Emissions Reduction. As part of our RIIO-1 work programme, we looked at Aylesbury first, an important site for our business, providing critical back-up for regions in the South and South West of England which fell under the scope of IED.

4.11 Aylesbury has unique compressors installed, which were only non-compliant with the NOx aspects of the legislation. The two Aylesbury units are prototype Dry Low Emissions (DLE) engine units, installed in 1999. These features enabled us to apply an innovative technology called static catalyst abatement which abates NOx emissions.

4.12 Rather than replacing the full compressor unit, both exhaust stacks could be removed, with new stacks installed in their place with static catalysts built into them. After thorough analysis, we established that the solution could cost nearly 5.5 times less than replacing the entire units, reducing the materials used, construction costs and the length of the project dramatically. We also contracted to ensure 20 years' worth of spares for these unique compressors. Commissioning and performance tests showed that we were outperforming the IED targets. While the objective of this project was to abate NOx, we also anticipate an overall reduction in CO of approximately 2,000 tonnes over the 20-year design life of the new system depending on run hours.

Figure 10 Exhaust stack and catalyst abatement system at Aylesbury compressor station

4.13 These first IED-compliant units are now a vital part of our compressor fleet and have been delivered with savings in the region of £68m against our Ofgem allowance for entire new units. Unfortunately, the unique nature of Aylesbury compressors means this approach is not applicable to the rest of our compressor fleet.

Selective Catalytic Reduction

4.14 During RIIO-1, we developed an innovation project to assess Selective Catalytic Reduction (SCR) as a possible solution for emissions compliance. The project ran from February 2016 to February 2017 initially looking to understand the potential technical challenges associated with implementing an SCR project on a National Grid compressor station, and solutions to these challenges.

4.15 The project outlined a conceptual design suitable for roll-out on National Grid compressor stations and looked to define and resolve integration issues associated with introducing the technology onto site. This work enabled SCR to be included as an option for investment in the May 2018 reopener, and as part of our MCPD proposal in the RIIO-2 business plan. However, we were unsuccessful in getting any tenderers to supply SCR solutions at St Fergus due to the age and condition of the compressor units, indicating there may be limited sites where this is a viable alternative.

Variable Envelope Compressors

4.16 We also undertook an innovation study on Variable Envelope Compressors, looking at technology which would enable us to flexibly adjust the operating envelope of a unit under different flow conditions. This technology could have avoided the cost of 're-wheeling' units. Re-wheels are necessary whereby the operating envelope of the unit no longer matches the gas flow through the station.

4.17 The project provided a robust techno economic case for the use of variable guide vane technology on new compressors that may be installed to operate on the NTS. Unfortunately, the project did not demonstrate that variable vanes could be successfully used on NTS compressors at this time. The study recommended that a demonstration project be set up to establish the range, technical and economic feasibility of Variable Inlet Guide Vane (VIGV) +

Speed Control (SC) technology within the highly meshed NTS network. Such a project would incorporate additional features not addressed by existing variable compressor design, thus it remains a technology that is of interest potentially for innovation work for our RIIO-2 innovation programme.

5 Assumptions

5.1 The following section outlines the assumptions that have been made in the development of our Compressor Emissions Compliance Strategy.

Future Network Flows and Network Impact

5.2 NGGT needs to ensure that it manages the risks associated with medium to long-term uncertainty. The most significant uncertainty is the future network use in a range of possible energy futures.

5.3 The FES 2018 report shows both annual gas demand and 1-in-20 peak day demand decreasing from their current levels in all four scenarios, however they all show a long-term future for gas usage. The volume of gas supplied from the current UKCS and Norwegian entry points is also forecast to change over time with alternative and geographically diverse sources like LNG, shale gas or green gas likely to play a far greater role in the UK's future gas supply.

5.4 The UK government has set a target of net-zero greenhouse gas emissions by 2050. The changes required to meet this target are significant but for gas they fall within the envelope of the current FES planning scenarios.

5.5 Based on an expected fall in total gas flows, along with the likely changes to where gas enters the transmission system, there is uncertainty around the long-term requirements for certain elements of the NTS. There is a risk that compression capacity that is impacted by environmental legislation and is replaced may no longer be needed in the long term with a risk of asset stranding. Conversely, there is a risk that decisions to remove assets from the network too early, or to limit their operation, may mean that the capability of the network is below the future realised capability requirement, adversely affecting our ability to supply gas. We consider these risks and potential consequences when selecting the most appropriate option to meet stakeholder needs. Please see the network capability chapter 11 of the business plan.

5.6 To help us manage uncertainty, developing the network capability approach we have applied principles that form the basis of our compressor asset management strategy; these compliment the outputs of the CBA, and provide a more holistic decision-making framework. The combination of these two views has allowed us to make more informed, justified decisions in uncertainty, especially in the case where there is little difference in the Net Present Value (NPV) of credible options.

Managing Uncertainty - Principles of the compressor emissions plan

5.7 The underlying principles of the emissions plan are to ensure we comply with new and existing legislation while providing the required levels of service to our customers and consumers. To do this, the following basic principles have been applied:

1. We have looked at levels of network capability that may be required to meet the needs of stakeholders to take gas on and off the system as and when they want using a range of scenarios.

2. All investment decisions will be informed by a robust CBA and consideration of non-monetised risks and benefits.

3. In building our business plan we have used the Steady Progression Scenario from FES 2018. This scenario was the initial basis of the Energy Network Association's (ENA's) Common RIIO-2 Scenario. Our compressor plans will be based on FES 2018, and appropriate sensitivities, which look at a range of energy futures.

4. Where we propose to reduce the number of existing compressor units, this assumes sufficient reliability of the remaining compression units on our network as overall demand drops into the future. Maximising availability of units will mean investing more heavily in the retained units to make sure they have the levels of capability and reliability required.

5. We will consider the age and condition of the existing units and the associated implications in our decision-making, such as reliability and availability (factored in to the CBA); obsolescence; the willingness and ability of Original Equipment Manufacturers (OEMs) to provide continued support to older machines; and the ability to replace the skills of an ageing workforce to continue to service the equipment.

6. Where there is significant uncertainty around the need for a compressor due to either decreasing flows or other changes in flows, we will consider no/low-regret investment options (for example, derogation of units where possible, or market-based solutions to meet capacity needs, if appropriate).

7. While we are currently unaware of further emissions legislation coming into force, we will ensure that our solutions represent BAT to reduce the likelihood of further investment due to more stringent emissions limits.

8. Where we will propose to build new units to achieve compliance and there is significant uncertainty in flows or a broad range of flows expected through a compressor station, we will be guided by the BAT assessment and are likely to invest in multiple smaller compressor units, rather than a single large unit, to ensure flexibility and future-proofing.

9. Where our analysis indicates we no longer need a compressor unit / station, we will assess the options of continuing to operate until the MCPD compliance date of 1 January 2030 versus decommissioning as soon as possible, looking at stakeholder network capability needs. The timing of any decommissioning will be driven by FES forecasts of declining flows, ongoing feedback from our customers and the requirement for the unit to support the overall deliverability of investment and maintenance work on the network.

10. Where units are derogated under MCPD legislation due to expected low running hours, there will be an ongoing review of the need for those units. We expect this

to allow us to decommission additional units post 2030 as units require significant health spend and running hours decrease.

11. Where the CBA output indicates that derogation of a unit is the preferred option but the expected run hours are close to the derogation limit of 500 hours per year over five years, the criticality of the compressor unit for operation of the network will be assessed. This may lead to a recommendation for a new unit to mitigate the risk due to future uncertainties in flow.

12. As flow patterns change so does the criticality of our compressors; therefore, we will respond accordingly by reprioritising the focus of compressor investment.

13. Where units are theoretically non-compliant but appear to operate within the ELVs, this will be assessed in preparation for RIIO-3 and alternative solutions such as control system restricted performance will be investigated.

Assumptions

5.8 The following assumptions underpin our analysis for our compressor emissions investments. Any changes to these could require a change to our plans. Assumptions specific to cost benefit analysis can be found in **Cost Benefit Analysis**.

1. Investment will be required to complete Front End Engineering Design (FEED) studies in RIIO-2 for new units to be delivered post-RIIO-2. If this is not achievable we will be unable to build and commission new units by the MCPD deadline of 1 January 2030.

2. Supply and demand patterns have been considered in line with FES 2018 and relevant sensitivities. Future gas supply and demand may be different to that forecast due to changes in offshore or interconnector operating models, new discoveries or wider developments (such as an increase in shale gas or a move towards Hydrogen) not included in FES.

3. For operational purposes, BAT principles will apply to determine preferred running order of units on site. This will ensure we are always running the cleanest and most efficient units possible.

4. The related investments proposed in the Asset Health Justification Papers must be fully funded to enable these works as the analysis has been carried out on the assumption that the NTS is intact. If the Asset Health works are not fully funded then other compression on the network will not be as resilient as needed to support the delivery and ongoing maintenance of these investments.

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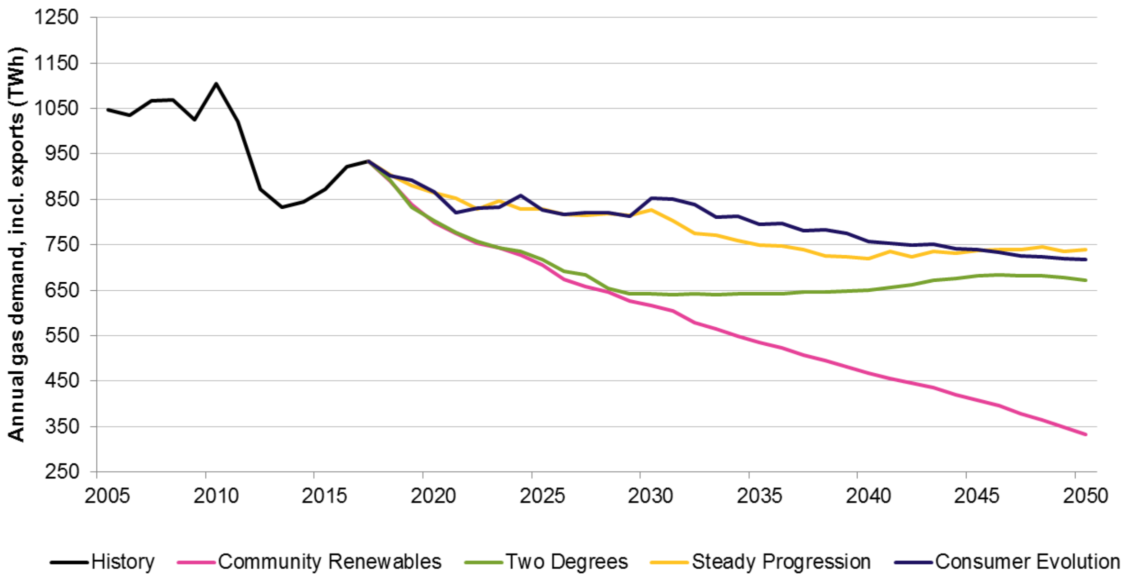
Supply and Demand Scenarios

5.9 We have selected the FES 2018 Steady Progression scenario as the central scenario for all the compressor business cases impacted by the MCPD. Using a consistent scenario for all the cases allows easier comparison between the merits of each individual investment and avoids selecting the most favourable scenario on a case by case basis.

5. 10 To ensure we test the full range of the scenarios we have assessed the other three scenarios, Community Renewables, Consumer Evolution and Two Degrees as sensitivities.

Figure 11 Average annual gas demand by FES 2018 scenario



5.11 Steady Progression was selected as it was the scenario most suitable as the central case. In terms of overall demand, it is the second highest demand scenario for much of the key period, 2030 – 2045, when the MCPD legislation takes effect. This overall demand is an indicator of the likely requirement for bulk running and any significant exit constraints.

5.12 For the compressors linked strongly to facilitating gas entry (such as King's Lynn, Wormington and St Fergus) Steady Progression was the mid case for the key entry sites for these compressors. The other scenarios alternated between being a high case or low case depending on the specific details of the scenario. High entry flows tended to produce the most significant constraint costs so selecting the mid-point for these was a key consideration of the scenario selection.

5.13 For peak demands, Steady Progression was the highest of the scenarios. Being able to meet 1-in-20 peak demands is a licence condition therefore using the highest scenario is appropriate. It is important we test that our network can meet this condition for all scenarios. Lower peak demands were assessed as part of the sensitivity analysis.

FES 2019

5.14 The plan is based on supply and demand in line with FES 2018 however, this section looks at the high-level impacts that FES 2019 could have.

5.15 Three of the four scenarios show an increase in yearly and peak gas demand and none have reduced. The demand of the fourth scenario, Community Renewables, is similar in FES 2019 to those from 2018. Figure 12 shows the changes in peak demand and Figure 13 the changes in yearly demand levels.

Figure 12 Changes in peak demand between FES 2018 and FES 2019

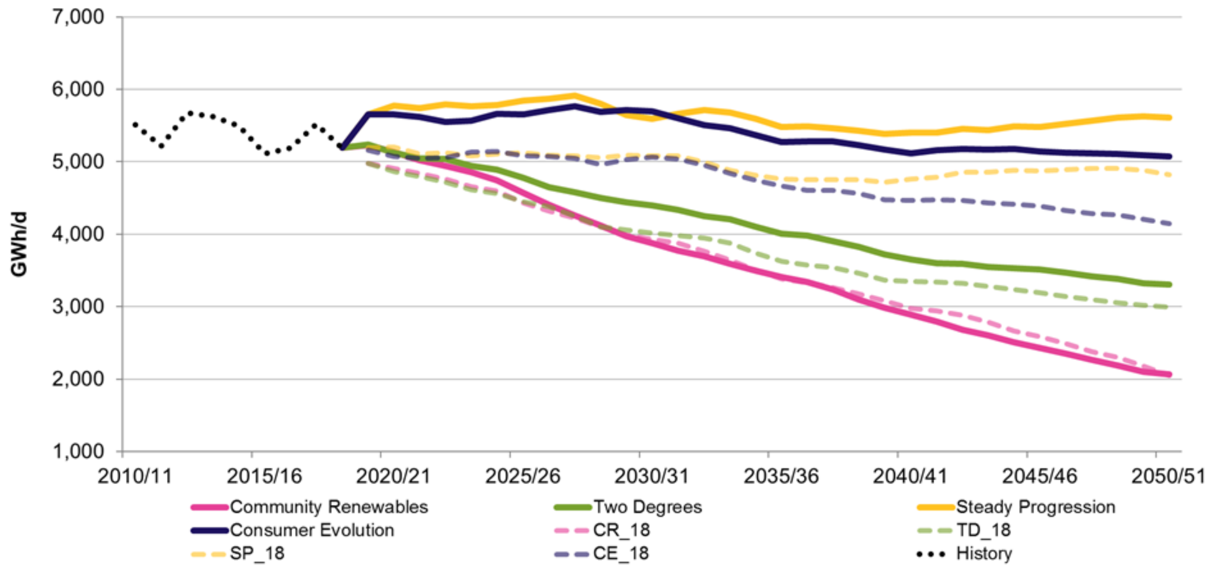
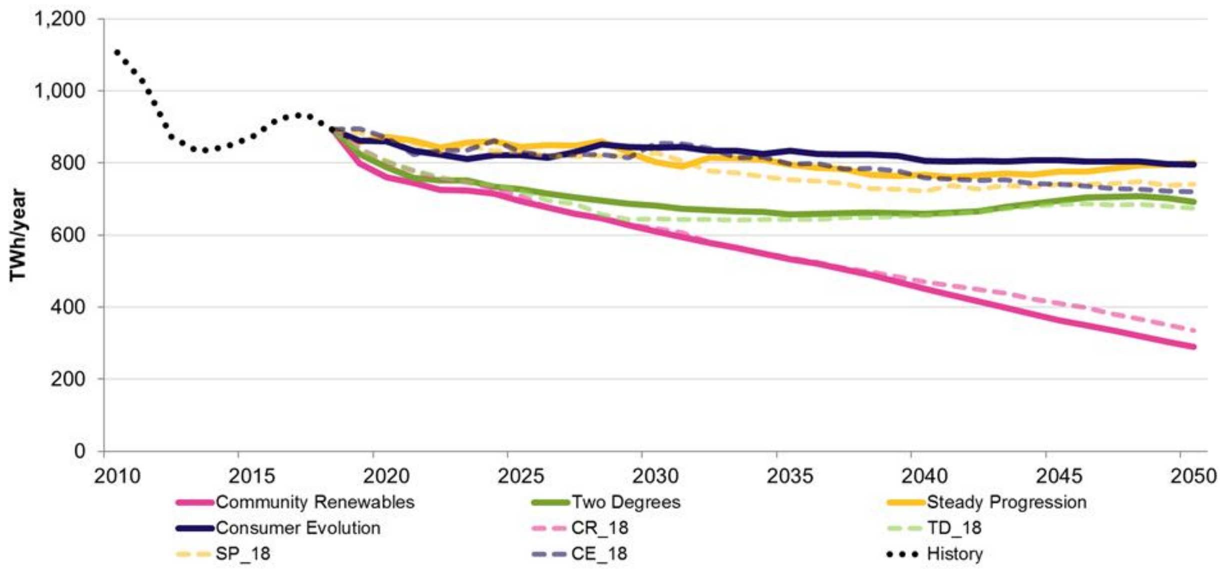


Figure 13 Changes in annual demand between FES 2018 and FES 2019



5.16 This increase in yearly and peak gas demand will put a greater requirement for compressors in the South of the country to support exit demands. The compressors at Cambridge, Diss and Chelmsford will still be required to support 1-in-20 demand conditions. And it remains critical that Hatton, Peterborough and Huntingdon have adequate back-up.

Availability and Reliability

5.17 Compressors are not always available when needed due to planned and unplanned outages. This can place greater reliance on other units on site or at other compressor stations on the network. To account for this in our investment plans, the CBA considers typical compressor availability in its calculations.

5.18 To calculate compressor availability, we have used average running and trip data for each compressor type on the network. This calculation uses the number of trips per 1,000 hours of running in the last five years. Actual repair data from St Fergus (VSD, RB211, Avons) and broader operational experience were used to calculate the likely severity of the trips and the time taken to repair; this allows us to estimate the expected outage duration for each trip. These are then multiplied by the number of hours running to give the average percentage of days available per year, see Table 10.

Table 10 Average annual compressor availability by unit type and operating hours

Unit	500 hours	>500 hours
AVON 1533	85%	73%
LM2500 DLE	91%	79%
SOLAR TITAN	94%	86%
SIEMENS SGT400	94%	86%
15MW ELECTRIC	96%	91%
24MW ELECTRIC	96%	91%
35MW ELECTRIC	96%	91%
**New Gas 15MW*	*97%*	*88%*
**New Gas 'Large*	*93%*	*82%*

5.19 For new gas units, we have used the highest availability data from comparable machines to give an estimate of performance under our operational conditions.

5.20 For electric drive units, availability is high as units are resilient and rarely fail however it should be noted that when we do see failures of electric drives they can be for significant lengths of time. This is due to the requirement to send the unit abroad for investigation and repair as well as not having spare units available due to their cost and bespoke nature.

5.21 We consider sensitivities on the availability level of compressors where this is a key factor in the outcome of the case. To do this we will look to increase the availability of compressors in the non-favoured options until they become the lead option to understand the sensitivity of the case to the assumptions on availability.

Risks

5.22 There are risks specific to certain sites which are included within the relevant Justification Paper. The overall risks which could apply to multiple sites are:

Technical solutions

- There could be future environmental legislation passed which tightens the limits for acceptable emissions. Where we are building new units, we will investigate technologies that meet current legislative requirements while endeavouring to future-proof against possible further restrictions on emissions. This will be supported by the BAT process and will be used to differentiate between different compliant options.
- The availability of new, future-proofed technology (for example, the development of compressor units which can be used with a blended mix of gases up to 100% Hydrogen) could change the BAT options available in future. This will be considered as part of the FEED.
- The CBA assumes an asset life of 45 years for new compressor units. There is a risk that due to the changing energy landscape the use of the NTS will change significantly in this time potentially stranding assets. We are only recommending building new compressors on sites where we are confident the site will be critical in the future. We are planning to defer decisions where we are not confident in the future requirements of the site.
- The costs in the current plan are for building compressors within current site boundaries. If this is established as not possible or cost-effective during the FEED the additional costs may change our recommended option.

Project delivery

- Building on existing sites is likely to require lengthy site outages due to working near to operational plant. Existing compressor units need to be kept operational during winter meaning project delivery can take twice as long compared to building on non-operational land.
- Delays in the completion of in-flight and proposed projects across the NTS could impact availability of outages and resources to complete these investments. We have created an achievable deliverability programme to mitigate this risk.
- If building outside of the existing site boundary then procurement of the land and planning permission could take longer than anticipated or be unsuccessful. We currently do not expect this to be required however until a full FEED is completed this remains a risk.
- The wider impact of MCPD across Europe puts pressure on the supply chain, leading to uncertainty over the availability of required asset solutions. For example, the lead time for a new compressor unit can be 12-18 months on average. National Grid is a very small part of the OEM's market and therefore has limited "buying power".
- Uncertainties around Brexit may have an impact upon currency as well as cost and availability of materials and contractors which is not currently reflected in our cost estimates.

6 Processes

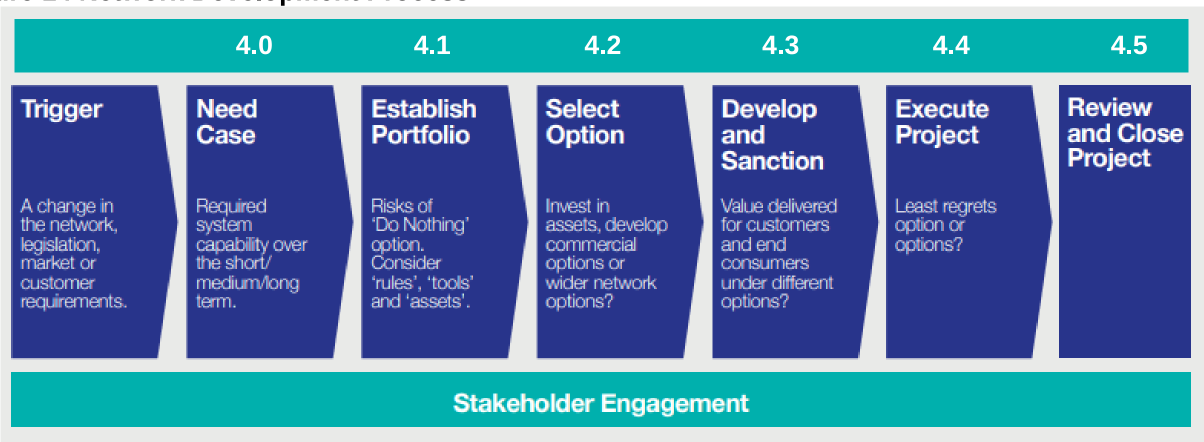
6.1 The following section outlines the processes that have been used in the development of our Compressor Emissions Compliance Strategy.

Network Development Process

6.2 The process we use for determining and managing investments is called the Network Development Process (NDP), see Figure 14. The purpose is to manage and define the project lifecycle from inception where we establish the needs case through to closure. The goal is to deliver projects that have the lowest whole-life cost, are fit for purpose and meet stakeholder and RIIO requirements.

6.3 There are six stages with a "gated" progress, which provides the means for financial approval and commits the investment to time, scope and cost parameters. All options included in this document are at the 'Establish Portfolio' stage. For further information, please refer to our Gas Ten Year Statement (GTYS)[18].

Figure 14 Network Development Process



Network Capability

6.4 The combination of compressors and other assets give a level of physical capability on the network that we can compare against stakeholder needs now and into the future. We have been carrying out stakeholder engagement to seek views on the appropriate level of network capability for the RIIO-2 business plan. This feedback has been a key input in defining our business plan proposal.

6.5 The risks around having too much or too little capability are as follows:

Excess capability
- Stranded or under-utilised assets resulting in higher network costs for consumers (associated with building, maintaining and operating assets).

Insufficient capability
- Inability to deliver the consumer priority of using energy as and when it is wanted because of disruption to customers' ability to take gas on and off the network.

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18 National Grid's Gas Ten Year Statement: https://www.nationalgridgas.com/insight-and-innovation/gas-ten-year-statement-gtys

- Entry constraints would impact where and when our customers are able to bring gas onto the network. This would prevent customers flowing cheaper sources of gas onto the system, increasing wholesale gas market prices.
- Exit constraints could impact all types of exit users, including potential disruption in supplying gas to domestic consumers.
- Independent analysis by EY19 suggests that constraints on the gas network under certain scenarios could increase gas and electricity costs by £42m-£246m per annum by 2025, and by £252m-£877m per annum by 2035[20]. Analysis undertaken in response to a question from the RIIO-2 Challenge Group supports the outcomes of this analysis[21]. The case study provided to the RIIO-2 Challenge Group explored the impact of a trip at the Lockerley compressor station during high levels of demand. It showed that if the compressor could not be restarted quickly, the trip could result in low gas pressures in the south west, creating a need to curtail gas flows to power generation in the south west and potentially other gas consumers. We would expect that the costs associated with these constraints would be passed onto gas and electricity consumers.
- Potential inability to respond to the most effective future energy pathway by closing options down early. This includes limiting options to repurpose pipelines for transporting hydrogen or carbon dioxide as part of a carbon capture scheme.

6.6 We have undertaken some work focusing on demonstrating the link between our proposals and its impact on network capability. These have produced sets of network capability metrics which have been used within the relevant Justification Paper for each compressor to articulate some of the impacts that different proposed options have on network capability.

6.7 More information on the network capability work can be found in chapter 12 of the business plan and its supporting annexes.

[19] *Please see annex A12.01.*

[20] *We will continue to develop our approach to CBAs to better consider these types of 3rd party impacts*

[21] *Letter from Chris Bennett, 1st October to Roger Whitcomb (Chair, RIIO-2 Challenge Group)*

Option Assessment Criteria

6.8 Table 11 summarises the five criteria against which each site option is reviewed. Each criterion is accompanied by a range of descriptions from an undesirable result to positive ones.

Table 11 Option Assessment Criteria

Criteria	Description				
Can we meet FES predicted Entry levels?	Cannot meet FES Entry levels.	Meets FES Entry levels in less than 50% of the scenarios.	Meets FES Entry levels in 50% or more of the scenarios.	Meets FES Entry levels in all scenarios.	Increased Entry levels above predicted FES levels.
Can we meet FES predicted Exit levels?	Cannot meet FES Exit levels in all scenarios.	Meets FES Exit levels in less than 50% of the scenarios.	Meets FES Exit levels in 50% or more of the scenarios.	Meets FES Exit levels in all scenarios.	Increased Exit levels above predicted FES levels.
Does this option represent an appropriate level of resilience on the network?	Does not provide resilience for the loss of largest credible unit(s) at the station.	Reduces resilience considering the loss of units at interacting stations, where the affected units are currently next in line.	Reduces resilience for the loss of units at interacting stations, where the affected units are not currently first in line.	Provides similar level of resilience as the existing situation.	Increases the resilience of the network.
Does this option allow National Grid to retain current capability?	Will reduce capability and impact how the NTS is currently used.	Capability reduced to a level insufficient to meet sold capacity and/or FES levels.	Capability reduced to potentially be insufficient to meet sold capacity and/or FES levels.	Sufficient capability to meet sold capacity and/or FES levels.	Increased capability to meet sold capacity and/or FES levels.
Does this option allow the network to be operated in sensitivities beyond FES?	FES cannot be met.	Significantly reduces capability to exceed FES.	Reduces capability to exceed FES.	Provides similar capability as the existing situation to exceed FES.	Enhances the ability over the existing situation to exceed FES.

6.9 The statement which is most closely matched by the option under consideration is selected. Once this has been done for all five criteria and all the options, a summary chart such as that shown in Table 12 can be used to qualitatively compare options and potentially discount those which are not viable as well as highlighting options with additional benefits (dark green descriptions).

Table 12 Example option assessment summary

Options	**Can we meet FES predicted Entry levels?**	**Can we meet FES predicted Exit levels?**	**Does this option represent an appropriate level of resilience on the network?**	**Does this option allow National Grid to retain current capability?**	**Does this option allow the network to be operated in sensitivities beyond FES?**
1					
2					
3					
4					

Cost Benefit Analysis

6.10 We have used our CBA to quantitatively assess and compare a range of options to inform the optimal solution. The CBA was developed following feedback from the 2015 re-openers, an independent review was completed by Pöyry in 2017 and our methods have been subsequently developed to account for feedback received since our 2018 submission.

6.11 The assessment includes costs of maintaining and replacing assets, fuel usage, emissions costs, site operating costs, the costs of managing constraints and where relevant, the cost of commercial options along with market impacts. Figure 15 and Table 13 show the data flow of the CBA model and assumptions used.

Figure 15 Overview of the CBA tool assessment

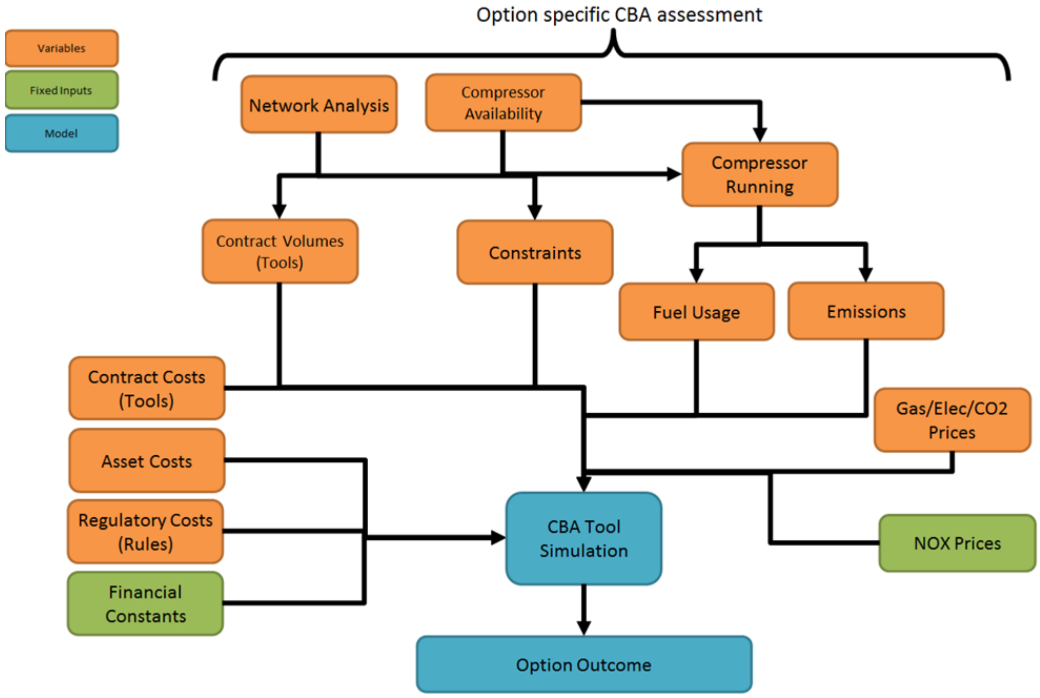

Table 13 Assumptions used in the CBA model

Element	Value
WACC	2.90%
STPR	3.5% (Years 0 – 30) / 3.0 % (30+)
Regulated Asset Life	45 Years
Assessment Period	25 Years
Depreciation method	Straight Line
Capitalisation (see 6.18)	73.5%

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6.12 The assessment of the asset is carried out over a 25-year period. This is consistent with our assumption on the lifetime of the asset. Asset Health, constraint costs, fuel usage and emissions are calculated for 25 years after the installation of the asset.

6.13 All investment costs and any applicable operating costs are recovered through our Regulated Asset Value (RAV) over 45 years, based on the regulated asset life defined in RIIO-2. This reflects the cost to the consumer of these elements, as this is how these costs would be recovered. Constraints, fuel usage, emissions and any contract costs are all recovered in the year they are accrued. To allow for comparison between costs occurring over different time periods, future values are discounted using rates from the government's Green Book.

6.14 The cost of constraints is calculated based on the capability of the network, the distribution of supply/demand patterns along with cost assumptions for constraint management. The network modelling that underpins our capability assessment is generated through our network modelling tool Simone. The required capability, expected flow patterns and availability of compressors determines our running expectations. These contribute both to expected fuel costs and emissions performance. Entry constraints are assumed to be resolved through a mixture of locational actions (50%) and buy backs (50%) this is consistent with our constraint risk forecasting and reflects the different tools we could use to resolve these constraints. To test the impact of this assumption we apply a sensitivity of 75% locational actions and 25% buy backs. Exit constraints are resolved through a locational buy and sell. Locational buys and buy backs are costed based on the forecast price, locational sells are priced at zero cost.

6.15 For scenarios and options where we do not have sufficient physical capability to meet our peak demand obligations we have included commercial solutions to ensure these are met. These are typically contracts to either turn-up supply or turn-down demand. The cost of the contracts is dependent on the volumes required along with the potential providers. The initial basis for these costs are bids received as part of the Operating Margins (OM) tender process, where required expert judgement is used to adjust these if the volumes required are significantly greater than those tendered.

6.16 The tool generates a Net Present Value (NPV) of the options for each FES scenario. The quoted NPV is based on 2065, 45 years after the start of the spend. The CBA tool uses a range of supply and demand scenarios and Monte-Carlo analysis to account for uncertainties in the input data to create a range around the NPV for all options. We are providing simplified CBA templates to allow Ofgem and the RIIO-2 Challenge Group to review the outputs and the needs case.

6.17 Our CBA contains assumptions around delivery of various activities which are translated into timing profiles of expenditure. These are based on historical work programmes where possible, or otherwise advice from external experts or contractors.

6.18 We have assumed a capitalisation rate of 73.5% in our CBA templates. This may have an impact on calculated NPVs shown throughout our justification papers, although not on the final proposed options. The impact of the updated capitalisation rate has been reflected in the associated CBAs for each accompanying justification paper.

Non-monetised risks and benefits

6.19 Our decision-making process is informed by the outputs of the CBA, but recognises that not all risks and benefits can be accurately quantified within the CBA. To ensure we can demonstrate the best value for the customer, we will consider these qualitative, non-monetised benefits in our final proposals. Examples of non-monetised factors which will also contribute to the final decision are:

a) Evidence of stakeholder support for one option over another.

b) Operational considerations such as handling within-day changes in supply or demand.

c) The possibility that our forecasts of the future may change.

d) Assumptions about the availability of existing assets may change.

e) Impact on consumer, whole sale energy prices from a constraint on the gas transmission network.

Best Available Techniques Process

6.20 All National Grid's gas turbine driven compressor stations are subject to regulation under the Environmental Permitting (England and Wales) and Pollution Prevention and Control (Scotland) Regulations. These Regulations place obligations on operators of permitted processes to apply BAT to the way in which an installation is designed, built, maintained, operated and decommissioned.

6.21 BAT assessment is the primary selection mechanism for all new and substantially modified or retrofitted compressor machinery trains. A detailed justification of any investment decision and how it meets the requirements of BAT is required to support an application to the relevant environmental regulator to operate a new or vary an existing facility. Following a successful determination of the application, a legally binding permit will be issued.

6.22 National Grid developed a BAT evaluation approach which supports the Compressor Machinery Train selection process for new compressor investment projects, and ensures that the relevant considerations relating to potential environmental impact, whole life costs and operating efficiency are taken into account. It also ensures that the selection is consistent with National Grid's corporate objective of ensuring that every project delivers Whole Life Value (WLV).

6.23 This process takes place during the project Feasibility Phase. The approach, which is supported by a BAT Evaluation Toolkit, utilises comparative performance and design information on candidate Compressor Machinery Train packages supplied by the OEMs.

- 6.24 The UK environmental regulators have set out an outline stepwise approach for the assessment of BAT. This requires that an operator should:
  - Review the market to identify possible technical options that are available (candidate BAT techniques).
  - Consider the potential environmental impacts of these options to determine which represents the Best Environmental Option (BEO).
  - If the BEO is not acceptable on cost grounds, the environmental performance and costs of the other options should be compared.

6.25 Given the unique nature of the gas NTS, this approach has been refined to ensure that the operational requirements are considered, including safety, availability, reliability and flexibility and that the selection can be conducted within the constraints of a tendering exercise subject to legally binding EU procurement rules.

Preliminary BAT Assessment

6.26 An external company, Project Environmental Solutions Ltd (PESL), has carried out a preliminary BAT assessment on Wormington and are in the process of completing assessments for King's Lynn, Peterborough and Huntingdon. Preliminary BAT assesses compliance options without going out to OEM tender.

6.27 The Preliminary BAT assessment was undertaken using a stepwise assessment process underpinned by an environmental cost-benefit analysis methodology, drawing together environmental and operational priorities to support decision making. The assessment was undertaken independently from the CBA Tool analysis using a different methodological approach. However, it incorporated common assumptions on cost, investment cases and future gas supply predictions. The preliminary BAT assessment included consideration of constraint costs. The addition of constraint costs illustrates the future significance of Wormington to the NTS and leads the assessment to indicate that the preliminary BAT solution would be two new DLE units, tying-in with the CBA outputs.

6.28 The key steps of the Preliminary BAT assessment are summarised in Figure 16. These steps include: historical data analysis, identifying current and future usage Process Duty Specification (PDS) points, identifying primary sensitivities (including de-rating), identifying candidate options from known market-based solutions, mapping load-splitting between units and combining options in a preliminary BAT assessment tool.

Figure 16 Wormington Preliminary BAT assessment method overview

6.29 The modelled period is 20 years, over which total emissions and whole life operating costs (including fuel) are calculated. Options are qualitatively evaluated for the following technical and environmental criteria:

- Compressor envelope versatility
- Emissions future proofing
- Ownership
- Constructability
- Environmental hazards
- Noise

6.30 The specific results of the Wormington assessment will be included in Appendix A16.10.

7 Options Analysis

7.1 Without action, the existing fleet of Rolls-Royce (now Siemens) Avon gas turbine driven compressors will become non-compliant with the environmental legislation. All Avon units are captured under the MCPD and will either need to cease operation before 1 January 2030 or operate under derogation. Where these options are not suitable, then alternative options to meet network needs will be required. This section describes the options that have been considered across the network for MCPD compliance.

Counterfactual

7.2 The 'Counterfactual' is defined to act as a starting point for decision-making. It allows us to demonstrate the impact on the current network with minimum interventions to meet the legislative requirements. The output of the CBA identifies the option or options which have the most favourable NPV. These are presented relative to the Counterfactual.

7.3 Counterfactuals are defined in each of the individual Justification Papers as the case where no action is taken to make the affected compressor compliant, and instead run compressors on derogations. This would limit the Avon units to 500 hours per year over a five-year rolling average. We assume in this case that we keep all existing compressor units, unless we have already committed to decommission them, or network capability requirements indicate they are no longer needed to meet stakeholder needs.

7.4 It is not feasible to derogate all Avon units on the network and meet our requirements for moving gas around the network to provide the flows and pressures required by our customers. We would be at risk of breaching the operating hour restrictions under the derogations, and therefore incurring financial penalties and potentially losing permits to operate which could ultimately mean customer needs and our obligations are not met.

7.5 When assessing the feasibility of derogating units, we will consider other operational factors such as the ability to take outages elsewhere while relying more heavily on derogated units.

Options description

7.6 The high-level options considered for compliance with the MCPD are shown in Table 14. Further detail on these options is provided below.

Table 14 High-level options for compliance with the MCPD

Decommission	Decommissioning is the option of permanently removing assets from service. This will reduce network capability.
Derogate	Existing non-compliant Medium Combustion Plant will be unable to operate for more than 500 hours per year on a rolling five-year average after 1 January 2030. These assets will not need to comply with MCPD Emission Limit Values. Having limited available hours, these derogated units will impact the ability to meet stakeholder network capability requirements.
Make Compliant	Three high-level options for achieving compliance: 1. Install a new, MCPD-compliant compressor machinery train. 2. Install abatement technology to achieve the specified ELVs. 3. Limit the power in the control system to reduce emissions from the unit.
Commercial options	Options such as turn-up or turn-down contracts with terminals/storage operators for constraint management.

Decommission

7.7 Decommissioning is the option of permanently removing assets from service. If changing gas flow patterns indicate any units would no longer be required in the long term, units could continue operation until 31 December 2029 if required to meet stakeholder needs. These units could support network requirements whilst the programme of construction works to deliver the new units is ongoing. Until then, normal asset health investment would be required and the ongoing costs of maintaining the unit until that point would be covered by our asset health plans. Where we are replacing a unit, decommissioning of the old unit is planned to align with the build timescales. Where we are decommissioning a unit without building a replacement, costs are therefore planned in for RIIO-3 to ensure network resilience while delivering our RIIO-2 plan.

7.8 Where an option refers to unit decommissioning this includes dismantling and disposal of the compressor train, removal of all associated balance of plant equipment and systems and demolition of the compressor cab. For complete sites, we are likely to have to undertake work on all the above ground installation to isolate the site from network feeders and fully remove all equipment, above and below ground, and return to greenfield state.

7.9 Decommissioning units impacts network capability and has implications for the flexibility of service that we can offer to our customers and our ability to respond to a wide range of supply and demand scenarios. However, it will reduce asset health investment and maintenance spend.

Derogate

7.10 MCPD offers a derogation where plant which operates for no more than 500 hours on a rolling five-year average does not need to comply with ELVs. Having limited available hours, these derogated units will impact the level of network capability we can deliver. Although derogated, our Environmental Regulators expect us to use these units for the absolute minimum time to meet the principles of the UK legislation and associated permitting regime. No emission related capital investment would be required in the business plan, however ongoing asset health investment would be required and is likely to increase as the asset ages.

7.11 Where there is an on-going need for a unit on the network, but running hours are expected to be below 500, derogating a unit is a viable option. The derogation costs in the CBA include full re-life costs, to make sure the unit is maintained to a suitable level for running past 2030.

7.12 If the longer-term future of a unit is especially uncertain past 2030, derogation is recommended as an interim solution – effectively deferring the decision on a longer-term solution. This allows us to minimise the risk of spending on a unit unnecessarily. Where this is recommended, asset heath investments will be minimised, therefore reducing the potential cost.

New Units

7.13 Installation of a new, emissions compliant compressor machinery train is another option available to us. When considering the installation of new plant, there are two sub-options: gas or electric drive compression.

7.14 Analysis of the costs of construction (including electrical High Voltage (HV) connection) and operation of electric drive compressors has shown that they are only cost effective when operated in excess of 5,200 hours per year. The units impacted by the MCPD are either required for backups to electric drives or would not see this level of usage and so it is likely that gas generators based on DLE technology to control emissions to atmosphere would be the chosen option. Further information on why electric drives units have been discounted at the priority sites is included in **Discounted Options** on page 52.

7.15 For the CBA, typical units of either 15MW (Avon-equivalent size) or 30MW units (RB211 or large VSD-equivalent size) are assumed. The final BAT assessment will refine this to recommend the actual number of units and sizes required, accounting for units that are commercially available. We will also consider compressor solutions that are Hydrogen compatible as they become commercially available.

Emissions Abatement

7.16 In the CBA, Selective Catalytic Reduction (SCR) was assessed as an option for Avon units. It proved not to be the most economic option at sites with higher run hours (e.g. Wormington).

7.17 On sites where SCR may be an economic solution, it is being taken forward to the preliminary BAT assessment. As part of the BAT assessment we will work with the Environmental Regulators to establish whether SCR is a viable solution.

7.18 Under this option, we would use emissions abatement technology to achieve the specified ELV. There are two abatement options currently under consideration: water or steam injection technology or SCR technology to treat the exhaust gases.

7.19 In addition to the investment required in the emissions abatement technology, extensive asset health expenditure will be required to extend the operational life of the assets (including the cab structure) and to replace all obsolete and unsupported technology. Within the past year, in exploring options for SCR at St Fergus, Siemens said they would not tender a refurbishment and SCR solution based on the age of the assets and historic Intellectual Property Rights. The wording in their response is given below.

> “This equipment was installed in the 1970s and was installed based on the emission and noise regulations that applied during that time. The compression train was packaged by GEC with a Gas Generator, Power Turbine and a GE Compressor. Due to the age and with Siemens not being the OEM[22] we had little operating data and literature available which causes difficulty in assessing how to repackage the equipment.”

7.20 The installation of emissions abatement technologies and combined Avon re-life requires a two-year construction outage of the unit to complete. During this time, that compression capability would be unavailable whereas building new units in parallel allows the continued use of the current Avons to support winter gas demand until the new unit is available to take over. This increases risk to security of supply, particularly during high demand winter months.

7.21 Additional considerations include: the limit to the longevity of SCR technology; higher fuel consumption of a machine fitted with SCR; and ongoing ammonia bed replacements, specialist maintenance and disposal activities.

22 OEM is Original Equipment Manufacturer

Control System Restricted Performance

7.22 Where units are deemed to be low-use in the future, there is an opportunity to consider Control System Restricted Performance. Where an Avon operating at full power emits a NOx level close to the 150mg/m^3 legislative limit, it may be possible to permanently de-rate the Avon to limit the power in the control system and reduce emissions from the unit.

7.23 As part of the Preliminary BAT assessment carried out for Wormington, PESL concluded that whilst de-rating the Avons could potentially be technically achievable, it could increase CO emissions, and there is a risk that this approach may not provide a reliable option in the medium to long term.

7.24 Although this could be a less expensive solution, implementing this technique will result in a change to the operating envelope of a unit. As part of the Preliminary BAT assessment for Wormington, software models were used to predict performance of Avon units if they were restricted and used to supply site duty. The result of this analysis is shown in Figure 17. This shows that, on face value, a potentially significant amount of single engine useable compressor envelope may be lost (red area).

Figure 17 Map of the impact Wormington compressor envelope

7.25 The impact of this option will need to be assessed against operational requirements at each site if taken forward. It could also result in more significant usage of these older units which could increase the required asset health expenditure.

7.26 A study is currently underway to investigate the feasibility of this option at sites with lower anticipated running hours. Discussions are also scheduled with National Grid's network team, legal advisors and with the environmental regulators to confirm the viability of this approach.

Commercial Options

7.27 Commercial options are an important consideration when assessing how to meet the network needs. These solutions potentially avoid the physical use of compressors, and consequently reduce the emissions impact of the fleet overall. Typically, the commercial and regulatory options are suited to short term scenarios, meeting a peak demand and supply pattern linked to a single, entry point, rather than a complete alternative option to investment in the compressor fleet. It is also important to note that commercial solutions to meet emissions requirements will have corresponding physical requirements in other areas (for example, if a commercial solution is chosen instead of a new unit option, decommissioning would still have to be undertaken on the existing unit).

7.28 Bi-lateral contract arrangements at either entry or exit points can be used to manage network flows. For example, to help meet the required pressure level at a distribution network offtake, a turn-up contract could be negotiated with the relevant gas shippers at a particular entry point. Flows through that entry point are then increased on request by National Grid, boosting local pressures. A turn-down contract at a power station can be used in a similar way. As an alternative to asset investment, contracts of this type are likely to be the most effective options when linked to single entry points over the short term, and where there is sufficient notice to put these in place.

7.29 As an example, we used a turn-down contract to support a heightened constraint risk from May – September 2019 in the Milford Haven area. High LNG flows had been seen through the Winter period, and unexpectedly continued to rise throughout April, and into May. Our modelling at the time showed that, alongside the critical Asset Health works due to start in the area end-May, there could be insufficient capability to support continued high flows. An increased risk of entry capacity constraints was therefore likely, until September when the work would complete. Given this was an imminent and time-bound requirement, physical reinforcements to the network were not viable. It was concluded that a turn-down contract with a power station in the area provided the most cost-efficient means to manage the risk of high LNG flows over the period of reduced capability.

7.30 The turn-down contract was considered a more cost-effective constraint management solution than using on-the-day commercial tools, such as Buy Back of Firm Entry Capacity (already sold to Shippers in long and short-term auctions). In the exploration of contractual options, a number of stakeholders were consulted, and offers were received for both turn-up and turn-down contracts in the area. All offers at the time contained exclusions and/or limitations in certain scenarios, that left a varying degree of residual risk to potentially still be managed on the day. In addition, the range of prices offered was broad. For any commercial option, the associated costs would be specific to that circumstance (reflecting the perceived risk to the counterparty) and would carry a high degree of uncertainty until the final stages of negotiation.

Options Costs

7.31 Costs have been compiled internally by eHub, National Grid's Estimating and Cost team, and by our Compressor team in combination with available tenders and past experience.

7.32 National Grid operational expenditure (OPEX) and asset health, including ongoing abatement spend, is calculated on a site-specific basis from historic data.

7.33 Cost estimates used in the CBA include a sensitivity range around P50.

Decommissioning

7.34 The cost of decommissioning, is [redacted] (2018/19 price base) per unit. Delivery of decommissioning is assumed to take place over two years, phased using the following profile.

Table 15 Two-year phasing assumption

y-1 (Design)	y (Decommission)
30%	70%

7.35 These unit costs are consistent with those that have been used in RIIO-1 reopeners. The costs are based on work done by Amec Foster Wheeler assessing decommissioning cost for a single unit.

Derogate

7.36 Subject matter experts were consulted to create a unit-specific overhaul programme and estimate the associated costs to enable the unit to run for up to 500 hours per year from 2030. This re-life cost reflects the age and condition of the Avons, which are between 20 and 48 years old. Substantial work is required to ensure they are available when called upon for the <500 hours.

7.37 Reported Plant Status Issues (PSI) were used as starting point for calculating site and unit asset health costs with subsequent asset health intervention driven by technical "Asset Life". Source data for pricing assumptions was derived from a combination of internal and external sources:

- Historic sanctioned projects with full project costs (i.e. labour, materials, delivery and indirect costs).
- Project costs and delivery estimates from OEM.

New Units

7.38 To deliver the programme of works required, existing Avons will be retained until the replacement has been installed. Therefore, the proposed new units in this document will be built within the National Grid land boundary but most likely outside the current operational fence line. This assumption is in place to minimise the length of outages on operational sites - reducing operational capability and potentially leading to constraints across the network. If any of the FEED studies show that building on brownfield land is possible, that would be the preferred option as it would reduce the cost of that project.

7.39 Capital works costs were developed by the EHub team in our Capital Delivery department. Capital costs include labour (salaries and wages), materials, equipment and indirect costs (site mobilisation, quality control, security costs, and utilities) and are based on the time a project will take from its inception to the final project deliverable. The indicative cost per new unit used in the option analysis is taken from the most recent tender returns for the Hatton and St Fergus LCPD and IPPC FEED studies. These represent the most up-to-date industry costs for the delivery of new units.

7.40 Source data for pricing assumptions was derived from a combination of internal and external sources:

- Rates for general civil works have been taken from the Electricity cost book; this includes rates for drainage, footpaths, car parks, roads, offices, workshops etc.
- Rates for ISS fencing have been taken from the recently awarded ISS frameworks.
- An average of the tender submissions for Huntingdon and Peterborough Main Works, Huntingdon Early Works and EHub estimates.
- Actual quotes for "one off" type work such as degassing, Distribution Network Operator (DNO) supply, water bath heater, Pressure Reduction Area (PRA) skid.

7.41 The delivery element of the cost will change as work is done to develop the full scope of design and delivery for specific MCPD sites.

7.42 Delivery of new unit build is assumed to take place over six years, phased using the following profile. This is based on previous project experience whereby compression must be available for winter operations.

Table 16 Six-year phasing assumption

Year	1	2	3	4	5	6
% Cost	0.9%	3.5%	30.8%[23]	24.6%	29.4%	10.8%

Emissions Abatement

7.43 Subject matter experts were consulted to create a unit-specific overhaul programme and estimate the associated costs to re-life the units to an 'as new' condition. This re-life cost reflects the age and condition of the Avons. Substantial work is required to ensure they are reliable and in a fit state to accommodate the changes required to incorporate the emissions abatement technology. Subject matter experts were also consulted to estimate the costs of applying the emissions abatement technology.

7.44 The overall cost estimate includes the following elements:

- Common civils, local equipment room and pipework and valves
- Demolition of the existing compressor cab and compressor cab reinforcement
- Engineering, Procuring, Construction (EPC) works associated with SCR
- Project delivery, commissioning and training

7.45 The cost was estimated specifically for each Avon unit on the NTS. These costs range between [redacted] (in 2018/19 price base).

7.46 Delivery of emissions abatement is assumed to take place over six years, phased using the following profile provided by EHub. This is based on previous project experience.

[23] *For new gas turbines, the OEM works are forecast to be complete in year 3 and EPC works in years 4,5,6*

Table 17 Six-year phasing assumption

Year	1	2	3	4	5	6
% Cost	1.6%	29.5%[24]	5.8%	26.2%	29.5%	7.4%

Summary of Options Considered

7.47 Table 18 summarises which of the high-level options have and have not been considered for each of the high priority sites. Where an option has not been considered, an explanation is provided. These options are covered in detail in the site-specific Justification Papers.

Table 18 Summary of Avon options considered across high priority sites

Standard option for Avon	Site			
	Wormington	King's Lynn	Peterborough	Huntingdon
Disconnect and Decommission Avon prior to 2030[25]	✓	✓	✓	✓
500 hours' Derogation	✓	✓	✓	✓
Control system restricted performance	✓ Considered in Preliminary BAT study	To be picked up in FEED		
Emissions abatement (SCR) on Avon	✓	✓	✓	✓
Two new 15MW Gas Turbine Compressors. Decommission Avon once new unit is operational.	✓	✓	Only one unit is within scope	Only one unit is within scope
One new 15MW Gas Turbine Compressor. Decommission Avon once new unit is operational.	Parallel running of smaller 15MW units is required potentially for more than 500hrs.	✓	✓	✓

[24] This cost spike is because the OEM design and build for SCR is forecast to be complete in year 2. EPC works take place in years 4,5 and 6.
[25] Between 2024 and 2031 depending on site, unit and option

One new 30MW Gas Turbine Compressor, decommission Avon once new unit is operational.	✓	✓	A 15MW solution is sufficient to work in conjunction with the IPPC Units D and E.	A 15MW solution is sufficient to work in conjunction with the IPPC Units D and E.
Two new 15MW Electric Drive Compressors, decommission Avon once new unit is operational.	The lead unit at Wormington is an electric drive, therefore additional electric drive units are not considered.	King's Lynn does not have sufficiently high running hours to warrant a VSD with the associated local electricity network infrastructure cost.	IPPC unit BAT assessment concluded that GT units were preferable to electric alternatives due to availability of a connection.	IPPC unit BAT assessment concluded that GT units were preferable to electric alternatives due to availability of a connection.
One new 30MW Electric Drive Compressor, decommission Avon once new unit is operational.				
Commercial contracts to manage constraints and to ensure compliance with 1-in-20 obligations.	No 1-in-20 requirement, all constraints related to entry.	Not required to comply with 1 in 20 obligations. Insufficient demand at times of constraint for turn down contracts with UK demand. Contracts to reduce interconnector flows would require agreement with several shippers to achieve volumes required.	Not required to comply with 1-in-20 obligations as hours on derogated units would be preserved for 1-in-20 cover.	Not required to comply with 1-in-20 obligations as hours on derogated units would be preserved for 1-in-20 cover.

Discounted Options

7.48 Several options have been discounted from consideration. This section will explain what these options are and why they have not been included for further analysis.

Electric Drive Units

7.49 These units are effective at controlling local combustion emissions and have been considered but discounted at each of the priority sites for the following reasons.

7.50 At sites where Avons are providing back-up to an electric drive, it is not desirable to replace these with additional electric drives. This would increase the site's reliance on the electricity grid and should there be a sustained power outage, we may be unable to start compressors. This could impact the black start procedure, by meaning that gas could not be provided to power stations, leading to failures on both the gas and electricity networks.

7.51 A study completed by SKM showed that electric drives are only economic where a unit is expected to run more than 5,200 hours. This is partially due to the substantial cost of a new HV electricity connection for sites which do not already have electric drive units. This connection is, in many cases, prohibitively expensive and would add significantly to the length of time required to complete the project. Therefore, if fewer running hours are required, gas turbines are more financially beneficial.

7.52 Other disadvantages to be included when considering electric drive units are:

- the risk of electricity failure leading to inability to start compressors
- the potential for significant outages if there is a failure due to the requirement to send the unit abroad for investigation and repair as well as a lack of spares
- all current electric drive units on the network have been provided by a single OEM increasing our reliance on a single manufacturer.

Dry-Low Emissions – Lean Premix Combustion as upgrade for Avon Gas Turbines

7.53 There is no DLE upgrade path for the Avon gas turbine. Therefore, new build DLE is at present the only UK-proven, available technology for upgrading MCPD sized gas turbine units for NOx control.

7.54 The Avon DLE system fitted to the turbines at Aylesbury compressor station in 1999 was a pilot scheme, and the installed compressor units are the only two of their kind, never available on a commercial basis.

Wet Low Emissions

7.55 These units were discounted as they require approx. 140-320 litres of demineralised water/minute. The cost of storing and maintaining that water is prohibitive. Wet Low Emissions has therefore been discounted for Avon compliance.

Planned innovation projects

7.56 Our innovation strategy for RIIO-2 can be summarised by the interaction of three themes moving from present day to a position that the UK Gas Industry is completely decarbonised.

Figure 18 RIIO-2 Innovation Strategy

7.57 Within these themes there are several innovation themes planned for RIIO-2, which have the potential to increase or enhance the number of options available to meet MCPD requirements and contribute to lowering our environmental impact.

Fit for the Future

7.58 This theme focuses on safeguarding and preparing our assets for the challenges in operating for the next 50 years and towards a decarbonised future.

7.59 Within this category, the “Leak Detection and Emissions Monitoring” topic will look at early detection of leaks on the network and effective methods of monitoring emissions across the network including compressor sites.

7.60 This will include the current MorFE (Monitoring of real-time Fugitive Emissions) project which aims to develop a long-term measurement solution to detect and quantify fugitive emissions on the NTS. Fugitive emissions are leaks in components caused by loss of tightness of an item (e.g. seal, valve, plug) which is designed to be tight. Any leak is a concern from both a safety and environmental perspective. A prototype system has been developed which was successful at detecting venting and estimating mass emission and likely locations of fugitive emissions. However, to roll this system out across the NTS further work is needed to refine the prototype, reduce cost and increase the level of reliability and accuracy.

7.61 Proactively monitoring these emissions would allow faster and more targeted maintenance and asset health works to reduce emissions on site.

7.62 This category also includes the “Decarbonising Construction” and “Decommissioning” topics. The first aims to drive down carbon emissions during all stages of construction from design, through build to considering the operation and maintenance once completed. The second will look at innovative techniques for the safe, controlled and efficient decommissioning of redundant assets as well as potential use of decommissioned assets for innovation projects to aid in the understanding of the NTS and decision making for its future.

7.63 Although these two topics will not yield new BAT options for complying with emissions legislation, they have the potential to reduce our environmental impact across our construction, operation and/or decommissioning activities.

Ready for Decarbonisation

7.64 This theme will focus strongly on how the NTS will transport a blended mix of 'green' gases and future technology to better manage the assets we own. This will include the "Compressor Strategy" topic. As already discussed, the way the NTS is utilised is ever changing and innovative methods to utilise our existing compressor fleet are required to adjust to changing supply and demand patterns. There is also potential in the concept of mobile compression that can be called upon when needed to provide a temporary service whilst a compressor is being maintained or when short term compression is needed through a period of high demand. A successful innovation project in this area could provide additional resilience while new units are being built or provide additional back-up alongside derogated units.

7.65 Also in this area is work on "Carbon Capture and Storage"; the process of capturing waste carbon dioxide, transporting it to a storage location and safely locking it away to prevent the release to the atmosphere.

7.66 This topic will include the Captivate project which follows on from a techno-economic feasibility project completed in RIIO-1. The initial feasibility study investigated the potential to capture some of NGGT's compressor CO_2 emissions and a retrofit solution capable of storing the CO_2 as an inert, solid-state carbonate. Captivate will test the feasibility and effectiveness of a small-scale demonstrator at a single site and evaluate the feasibility of adopting the process at other gas transmission sites. If this technology is viable and cost-effective we can further reduce operational emissions.

Decarbonised Energy System

7.67 This final theme will be working predominantly on hydrogen: how hydrogen will interact with the NTS, how trading could be managed and whether direct offtakes for hydrogen can support the transport and commercial market.

7.68 The UK government has set a new target of net-zero greenhouse gas emissions by 2050. The FES 2019 report included a standalone sensitivity analysis on achieving net zero. It reached the conclusion that it is achievable, however requires immediate action across all key technologies and policy areas. In this scenario, hydrogen heating dominates the residential sector and the role of natural gas fundamentally changes, but it remains crucial to energy supply. It is used only with CCUS (Carbon Capture, Usage and Storage), as a key input to hydrogen production and industrial processes, and to generate electricity.

7.69 A full programme of works will be required in coming years to gather evidence to allow the NTS to transition from natural gas to hydrogen. We will consider new build versus reuse of the NTS. This work will support the development of the safety justification for the high pressure onshore transportation of hydrogen (or a mixture of hydrogen and natural gas) as required by UK safety legislation.

7.70 We will also work with OEMs to investigate hydrogen-compatible compressor technology as it becomes available. Siemens has already indicated that new DLE units would be compatible with up to 68% Hydrogen.

7.71 A few innovation projects have been completed or are underway which support this work. A feasibility study has been completed on the physical capabilities of the NTS with regards to its ability to transport hydrogen. This project reviewed the susceptibility to hydrogen degradation of the numerous materials present in the NTS. It concluded that re-purposing parts of the NTS pipelines and assets for future hydrogen service could be considered technically feasible from a materials perspective.

8 Compressor Utilisation and Emissions

8.1 The evolution of the network has resulted in changes to compressor utilisation. Some compressors are now required to support reverse flows: moving gas in the opposite direction from their original design; some compressors have become increasingly important across a large demand range; and some are only used during peak demand conditions or certain supply patterns to avoid significant constraints.

8.2 Compressor use varies significantly over time. Some of the key factors influencing compressor use, and therefore emissions, are listed below:

- Location of compressors on the UK NTS - particularly in areas where gas is placed on the network (e.g. entry points) or gas is taken off the transmission system (exit points). The entry of gas into the UK NTS is influenced by the price of gas from the UKCS, continental Europe via interconnectors and LNG input. This has meant that over the years the gas flows in different parts of the network have changed significantly.

- Changes in demand can affect compressor utilisation, where seasonality and/or adjustments in gas consumers can increase or decrease the need for supply. This influences the number of operating hours that a plant may utilise and in turn influences any decision to derogate or cease operation. For more information about how compressors are used to support within-day operations, see Gas Future Operability Planning[26] (GFOP).

- The type of compression plant utilised affects emissions. NGGT have made significant investment in placing low emission technologies (Electric VSD and low NOx gas turbines) at sites that have a high number of operating hours. The expectation of the Environmental Regulators is that these plants will be used in preference to the older unabated gas turbines.

- Plant or stations may be subject to outages for maintenance which could result in compression being provided by stations up or down stream of the affected facility. This will lead to higher emissions if an older unabated plant is utilised to cover such situations.

- Compressor use may vary to accommodate within-day operations – including maintenance on the NTS or distribution networks.

- Compressor use may also vary in order to provide gas to power stations used to support intermittent renewable generation. This results in compressors being used intermittently which adds to the wear and tear on units which are designed for continuous operation.

8.3 Forecast and, to some extent, historic compressor usage influences the compliance options open for a combustion plant. It may be possible for an existing unabated plant to continue to operate under a 500-hour derogation if forecast running hours are low enough. If a plant is anticipated to operate in excess of those hours then the unabated plant will need to be upgraded, as it cannot meet the emissions limits set out in the relevant legislation.

[26] *https://www.nationalgridgas.com/understanding-within-day-behaviour*

Historic compressor run hours

8.4 Historic run hours for each of the units tell part of the story for MCPD. Historic run hours vary significantly year on year and are dependent on: supply and demand patterns; outages at the site (and elsewhere on the network).

8.5 It is worth noting that the past use is not a suitable indication alone for future requirements. Over time, domestic demand is reducing but power station demand and volatility are increasing. On the supply side, LNG use is increasing while Theddlethorpe terminal and Rough storage have now closed. This changes the profile of compressor use over time. Looking at how much the use has varied between 2014 and 2018, there is clear indication that flexibility in the compressor fleet remains a key factor in operating the grid.

8.6 Historic unit run hours are shown in Table 19. This table highlights where units have been running for more than 500 hours. If these sites are non-compliant with emissions legislation and are forecast to continue to operate in this way, they will need to be upgraded.

8.7 Using FES, analysis has been completed on various future flow patterns, however it is impossible to determine exactly which future will transpire. It is therefore important that future compressor plans provide enough flexibly in operations that we would be able to facilitate a range of potential energy futures.

Table 19 Historic compressor unit run hours (2014-2018)

Unit	2014	2015	2016	2017	2018	Average (2014-2018)	Standard Deviation (2014-2018)
Alrewas A	20	51	36	22	1362	298	532
Alrewas B	25	7	9	9	59	22	20
Cambridge A	18	14	17	46	243	67	88
Cambridge B	8	41	38	108	75	54	34
Chelmsford A	8	22	12	67	961	214	374
Chelmsford B	105	89	22	813	112	228	294
Diss A	126	125	20	14	41	65	50
Diss B	0	15	15	763	1457	450	582
Diss C	15	6	11	344	560	187	227
Huntingdon A	1800	865	238	1635	1892	1286	637
Huntingdon B	1237	295	451	1381	1082	889	435
Huntingdon C	195	1116	376	33	9	346	407
King's Lynn A	2	4	0	13	N/A	N/A	5
King's Lynn B	21	7	3	12	747	158	295
Kirriemuir A	367	155	1234	599	1189	709	434
Kirriemuir B	11	11	783	823	392	404	354
Kirriemuir C	9	0	58	107	195	74	72
Peterborough A	2911	2370	522	30	2143	1595	1117
Peterborough B	2186	1443	1426	2451	3417	2184	737
Peterborough C	2077	1576	482	3221	1558	1783	888
St Fergus 1A	3263	2482	942	281	518	1497	1169
St Fergus 1B	175	25	632	339	447	323	211
St Fergus 1C	1497	2407	1214	1353	939	1482	498
St Fergus 1D	833	1371	776	1458	465	981	377
St Fergus 2B	60	253	1337	7	77	347	502
Wisbech A	94	21	47	11	9	36	32
Wisbech B	151	30	421	772	65	288	278
Wormington A	27	32	26	145	12	48	49
Wormington B	58	27	67	190	23	73	61

8.8 In addition to unit running hours, it is useful to consider the running hours at a site level to see which sites run most frequently. Historic site run hours for sites with MCPD units are shown in Table 20. This table highlights the highest running hours over the last five years.

8.9 Table 20 shows that running hours look very different in 2018. This is because 2018 had an unusual supply pattern, with lots of gas coming into the UK through Bacton in the South East. We had significant outages at some key sites across the network – Hatton, Kirriemuir and Churchover, for example. These events highlighted the importance of having multiple operating strategies available and maintaining resilience on the network. We were heavily reliant on different units to those we have historically used.

Table 20 Historic site run hours (2014-2018)

Site	2014	2015	2016	2017	2018	Average (2014 – 2018)	Standard Deviation (2014-2018)
Alrewas	152	106	129	55	1734	435	650
Cambridge	54	211	216	340	387	242	116
Chelmsford	113	111	34	880	1073	442	441
Diss	141	145	46	1120	2058	702	783
Huntingdon	3233	2276	1065	3049	2982	2521	797
Kings Lynn	304	35	28	186	1887	488	707
Kirriemuir	428	1688	5403	1532	1776	2165	1690
Peterborough	7174	5388	2430	5701	7118	5562	1725
St Fergus	10897	9424	10380	14166	14057	11785	1958
Wisbech	246	51	467	782	74	324	273
Wormington	1132	1441	1966	1303	2155	1599	394

8.10 Considering Wormington, for example, the unit run hours for the Avons are low, however, the site runs for around 1600 hours/year. The lead unit on site is an electric drive unit which is usually run on its own and has a limited flow range that it can operate within. The remaining two Avon units can be run in parallel to support higher flows. Wormington is used to support entry flows at Milford Haven, and a sustained outage at the site has the potential to cause significant disruption to UK gas supplies. Should the VSD have a sustained outage, as Hatton experienced in January 2017, then Wormington's run hours would fall to the back-up units, which with a 500-hour derogation would not be sufficient to support these flows.

9 RIIO-2 Priority Sites and Beyond RIIO-2

9.1 This section summarises our plans for:

- Compressor plant proposed for replacement or upgrade investment;
- Compressor plant expected to utilise available derogations within MCPD;
- Compressor plant expected to cease operation.

9.2 Table 21 summarises our compressor emissions compliance plan for MCPD. A request for allowances for the new units and the decommissioning of units in Table 21 is included in this paper. Where specific units are not named (e.g. Cambridge x 1), the unit is to be confirmed after condition assessment. We will review our decommissioning and derogation proposals beyond 2030 in our RIIO-3 business plan.

Table 21 Summary of MCPD compressor emissions compliance plan

	RIIO-2	RIIO-3 (1 January 2030 compliance date)
New Units	Wormington x 2	King's Lynn x 2 Peterborough x 1 St Fergus x 3
Derogations		Cambridge x 1 Chelmsford x 1 Diss x 2 Huntingdon C
Decommissioning	St Fergus 2A, 2B and 2D	Alrewas A and B Cambridge x 1 Chelmsford x 1 Diss x 1 King's Lynn A and B Kirriemuir A, B and C Peterborough C St Fergus 1A, 1B, 1C and 1D Wisbech B Wormington A and B

9.3 The seven units at Warrington (A and B), Churchover (A and B), Moffat (A and B) and Kirriemuir (D) are not listed here as they are included in the Annex A16.08 Redundant Assets Justification Paper.

9.4 In line with the agreed principle for the rebasing of our RIIO-1 Network Output Measure (NOM) target, we have specifically excluded risk additions/reductions arising from investments not funded via an Asset Health driver. We understand the same approach is being adopted for RIIO-2 Network Asset Resilience Metric (NARM) target setting.

9.5 In effect this means that "Asset Replacement funded under separate mechanisms", which includes our emissions investments will be excluded from our RIIO-2 asset health targets, both in terms of new and decommissioned assets. We would then anticipate that the asset changes will be incorporated as part of the RIIO-3 NARM's target setting process, or potentially as a material change following discussions with Ofgem.

Replacement or Upgrade Investment

9.6 Compressor units that are still required to operate the network beyond 2030 and have high forecast running hours are expected to be replaced with new, compliant compressor units. These replacement units may be of a different size and number compared to the original units depending on future operating requirements and the BAT recommendations.

9.7 The prioritisation of new builds is based on the criticality of sites for operation of the network and the ability to take outages. The prioritisation and timing of delivery of MCPD-driven replacements is discussed in Section 10, The Delivery Plan.

- **We plan to build five new units in total due to the MCPD between the start of RIIO-2 and 1 January 2030.**
- **Two MCPD compressor units will be built in RIIO-2, with work starting in RIIO-2 for the delivery of the three remaining new units by 1 January 2030.**
- **Two LCP compressor units will be replaced in RIIO-2.**

MCPD and LCP Derogations

9.8 Derogated units include all units that are still required for NTS operation but have low forecast run hours (typically below 500 hours per year).

9.9 Derogation of MCPD units will take place beyond RIIO-2. There will be three RB211 units on Emergency Use Derogations under the LCPD at the end of RIIO-2.

9.10 Beyond RIIO-2, we propose to derogate five MCPD compressor units from 1 January 2030. This leaves seven derogated units in total on the NTS. However, if there are any unforeseen, significant asset health issues then these plans would be re-assessed and decommissioning, disconnection or new build may take place.

9.11 We are considering additional derogated units to cover for future uncertainties in flow. We will continue to engage with stakeholders to finalise our proposals in this area for RIIO-3.

- **MCPD derogations fall outside of the RIIO-2 period.**
- **We plan to derogate five MCPD units by 1 January 2030.**
- **There will be three derogated units under LCP (Emergency Use Derogations) on the NTS at the end of RIIO-2.**
- **There will be two derogated units under LCP (Emergency Use Derogations) on the NTS by 1 January 2030.**

Decommissioning

9.12 Compressor units to be decommissioned include all compressors non-compliant with LCP, IPPC and MCPD emissions legislation which are no longer required. These units are either being replaced with new, compliant units or are no longer required for operation of the network in future.

9.13 We do not plan to decommission any MCPD compressor units in RIIO-2. Decommissioning of MCPD units will take place close to the MCPD compliance deadline of 31 December 2029. This will enable us to deliver our outage plan in the most effective way, minimising the risk of customer disruption.

9.14 There are six LCP/IPPC compressor units that we propose to decommission by the end of RIIO-2. Beyond RIIO-2, we propose to decommission fourteen MCPD units and two LCP units by 1 January 2030. However, further stakeholder engagement will be carried out to develop our RIIO-3 plans and if there are any unforeseen, significant asset health issues then these plans would be re-assessed and decommissioning or disconnection may take place sooner.

- **We will not decommission any MCPD compressor units in RIIO-2.**
  All decommissioning of MCPD compressor units will take place beyond RIIO-2 and are subject to network capability requirements
- **We propose to decommission fourteen MCPD units by 1 January 2030.**
- **We propose to decommission six LCP/IPPC units in RIIO-2.**
- **We propose to decommission two LCP/IPPC units between RIIO-2 and 1 January 2030.**

Additional Compressors to be Decommissioned

9.15 There are an additional seven compressor units that are proposed for decommissioning in RIIO-2:

- Churchover A and B
- Kirriemuir D
- Moffat A and B
- Warrington A and B

9.16 These units are in the Annex A16.08 Redundant Assets Justification Paper. Five of these are already disconnected from the NTS today. The decommissioning of Moffat and Warrington is subject to employee and trade union consultation.

Table 22 Summary of compressor units to be decommissioned in RIIO-2 and where their costs are captured in the submission

Site (Units)	Unit Types	Action	Notes
Churchover (A and B)	2 x RB211	2 decommissioned	Costs are captured in the redundant assets paper as the units are no longer required operationally.
Hatton (B and C)	2 x RB211	2 decommissioned	Units are being replaced due to LCPD. Decommissioning costs are included in this plan
Huntingdon (A and B)	2 x Avon	2 decommissioned	Units are being replaced under IPPC (May 2018 reopener). Decommissioning costs are included in this plan.
Kirriemuir (D)	1 x RB211	1 decommissioned	Costs are captured in the redundant assets paper as the units are no longer required operationally.
Moffat (A or B)	2 x RB211	2 decommissioned	Costs are captured in the redundant assets paper as the units are no longer required operationally.
Peterborough (A and B)	2 x Avon	2 decommissioned	Units are being replaced under IPPC (May 2018 reopener). Decommissioning costs are included in this plan.
St Fergus (2A, 2B and 2D)	1 x Avon 2 x RB211	3 decommissioned	Units are being replaced due to LCPD and MCPD. Decommissioning costs are included in this plan.
Warrington (A and B)	2 x RB211	2 decommissioned	Costs are captured in the redundant assets paper as the units are no longer required operationally.
Total		**16**	

Plan summary

9.17 Table 23 summarises our recommended option for each affected site with the associated cost, as reflected in the December data tables.

Table 23 Summary of recommended options

Site	Legislation Compliance	Total Cost (RIIO-2 and RIIO-3) £m	RIIO-2 £m	RIIO-3 £m	Proposal (post RIIO-2 investments subject to review)
Alrewas	MCP	[redacted]	[redacted]	[redacted]	Decommission 2 units
Cambridge	MCP	[redacted]	[redacted]	[redacted]	Decommission one unit, Derogate 1 unit
Carnforth	LCP	[redacted]	[redacted]	[redacted]	Decommission 2 units
Chelmsford	MCP	[redacted]	[redacted]	[redacted]	Decommission one unit, Derogate 1 unit
Diss	MCP	[redacted]	[redacted]	[redacted]	Decommission one unit, Derogate 2 units
Hatton	LCP	[redacted]	[redacted]	[redacted]	Decommission 2 units
Hatton Reopener	IED	[redacted]	[redacted]	[redacted]	Build 2 new units
Huntingdon	IPPC/MCP	[redacted]	[redacted]	[redacted]	Decommission 2 units, Derogate 1 unit
King's Lynn FEED	MCP	[redacted]	[redacted]	[redacted]	FEED
King's Lynn UM	MCP	[redacted]	[redacted]	[redacted]	Decommission 2 units, Build 2 new units
Kirriemuir	MCP	[redacted]	[redacted]	[redacted]	Decommission 3 units
Peterborough FEED	IPPC/MCP	[redacted]	[redacted]	[redacted]	FEED
Peterborough	IPPC	[redacted]	[redacted]	[redacted]	Decommission 2 units
Peterborough UM	MCP	[redacted]	[redacted]	[redacted]	Decommission 1 unit, Build 1 new unit
St Fergus FEED*	IED	[redacted]	[redacted]	[redacted]	FEED
Wisbech	MCP	[redacted]	[redacted]	[redacted]	Decommission 1 unit
Wormington	MCP	[redacted]	[redacted]	[redacted]	Decommission 2 units, Build 2 new units
Standby Generators	MCP	[redacted]	[redacted]	[redacted]	Replacements
Water bath heaters	MCP	[redacted]	[redacted]	[redacted]	Replacements
Total Cost (£m)		**348.6**	**209.6**	**139.0**	

*Note that this does not include post-FEED costs at St Fergus. This is subject to a UM and current assumptions amount to £174.4m across RIIO-2 and RIIO-3.

Key

Proposal Type	Reopener	FEED	UM	New Build	Decom/Derog

9.18 Figure 19 highlights how the cost of the recommended option at each site is split between RIIO-2 and RIIO-3.

Figure 19 Summary of option cost split between RIIO-2 and RIIO-3

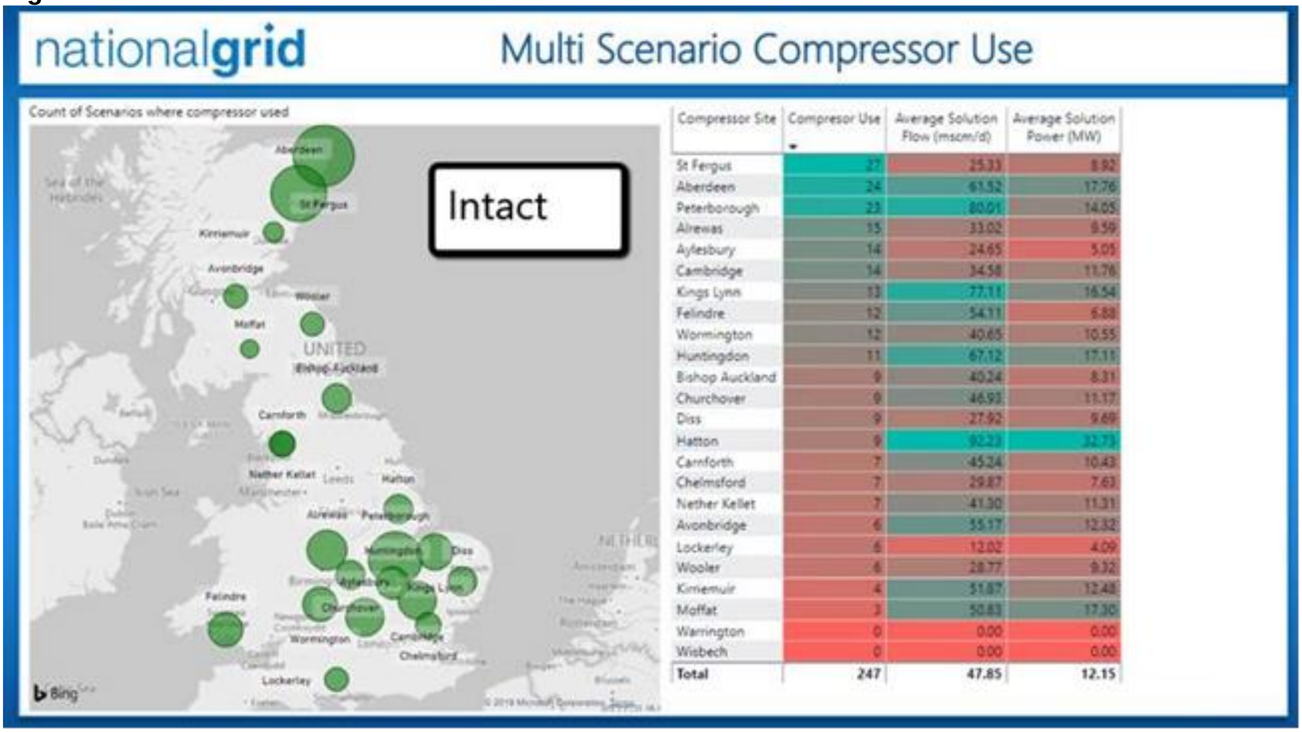
[redacted]

Additional System Modelling

9.19 In addition to our Network Capability work, an external company has been engaged to develop a decision support tool combining scenario analysis, hydraulic modelling, asset reliability and optimisation modelling capabilities. Their model uses optimisation to prescribe the required network assets and design across a wide range of Future Energy Scenarios. This solution aims to fill a gap in the analytics capability between the high-level scenario analysis conducted through the Future Energy Scenarios and the detailed network analysis carried out using Simone. The project is still ongoing, and we are currently working to incorporate the tool into our suite of modelling tools.

9.20 So far, we have used the tool to run 28 scenarios and evaluate how often various compressors sites are required across those scenarios. The results can be seen in Figure 18.

Figure 20 Results for 28 scenarios



Compressor Site	Compresor Use	Average Solution Flow (mscm/d)	Average Solution Power (MW)
St Fergus	27	25.33	8.92
Aberdeen	24	61.52	17.76
Peterborough	23	80.01	14.05
Alrewas	15	33.02	9.59
Aylesbury	14	24.65	5.05
Cambridge	14	34.58	11.76
Kings Lynn	13	77.11	16.54
Felindre	12	54.11	6.88
Wormington	12	40.65	10.55
Huntingdon	11	67.12	17.11
Bishop Auckland	9	40.24	8.31
Churchover	9	46.93	11.17
Diss	9	27.92	9.69
Hatton	9	92.23	32.73
Carnforth	7	45.24	10.43
Chelmsford	7	29.87	7.63
Nether Kellet	7	41.30	11.31
Avonbridge	6	55.17	12.32
Lockerley	6	12.02	4.09
Wooler	6	28.77	9.32
Kirriemuir	4	51.87	12.48
Moffat	3	50.83	17.30
Warrington	0	0.00	0.00
Wisbech	0	0.00	0.00
Total	**247**	**47.85**	**12.15**

9.21 The results are very similar to those produced internally and align with our ongoing fleet strategy as described in the network capability chapter of the business plan (Chapter 11). This external analysis shows that all of the units we have proposed to replace are predicted to run frequently. This verdict helps provide us with additional confidence that we have made the correct investment decisions.

10 Delivery Plan

10.1 This section discusses the compressor delivery plan and how new units have been prioritised. The timelines for each site can be found in the individual Justification Papers.

10.2 The plan has been assessed holistically alongside our other RIIO-2 and RIIO-3 investment and maintenance activities to minimise the risk of customer interruption. Where possible we have ensured there are no conflicting outages on the network and that there is always sufficient compression available.

Delivery of new units

10.3 Our current proposals assume new units are built on unused land within National Grid site boundaries; reducing the need for extended outages and giving more certainty of timescales in terms of land availability. Compressor build projects take six years to complete, with site outages in years four and five. This means the plan to deliver MCPD investment in time for the 2030 deadline is challenging and some work on compressors due to be delivered beyond RIIO-2 will need to be started in RIIO-2.

10.4 Deliverability plans have been reviewed across the business and we are confident we can accommodate the outages required for this work. The new build plan is set out in Table 24. The shaded cells show full project timelines, with darker shading indicating outages.

Table 24 Compressor new build plan from the start of RIIO-2 to 1 January 2030

Project Name	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Kings Lynn x 1 med new										
Kings Lynn x 1 med new										
Peterborough x 1 med new										
Wormington A new										
Wormington B new										
St Fergus x 1 new										
St Fergus x 1 new										
St Fergus x 1 new										

10.5 For the RIIO-2 plan, we have prioritised new units at Wormington. The CBA for Wormington supports the decision to build units and the future requirement for the site is clear. Additionally, the Planning and Advanced Reservation of Capacity Agreement (PARCA) application for increased flows into Milford Haven further supports the investment proposal, and is a key driver for doing the work early in RIIO-2, to minimise the impact of the outage on the terminal.

10.6 Investment at King’s Lynn has also been prioritised to start early in RIIO-2. King’s Lynn is a critical site for Bacton flows and South East pressures. Unit A has recently been disconnected so we are currently running at a lower capability than is required going forward. We would, therefore, seek to complete the MCPD investment as soon as possible.

10.7 Replacement projects are expected to start at Peterborough in RIIO-2, with delivery post RIIO-2. We are considering opportunities to move the Peterborough work forward for completion in RIIO-2, due to criticality of the site.

10.8 There is compressor replacement work under IED planned at nearby Hatton in RIIO-2, which limits the outages we can accommodate in that area of the network. The Hatton outage will impact our ability to take outages coincidentally at King’s Lynn and Peterborough.

10.9 St Fergus planning work starts in RIIO-2, with the delivery phases beyond RIIO-2 to deliver the combined emissions-driven compression and Plant 2 redevelopment works.

Delivery plan for Derogated Units

10.9 Investment in derogated units focuses on the ongoing costs to maintain and operate them. Therefore, the delivery of this work is out of scope of this paper but is included in the Asset Health Justification Papers for compressors, Annexes A14.10 and A14.11.

Delivery Plan for Decommissioning

10.10 Where we have identified that we no longer need an MCPD compressor unit or station, we plan to decommission it after works are completed on other sites where new units are being built. This enables delivery of the investment and maintenance work plan over the period to 2030, providing resilience during outages. The timing of decommissioning will be driven by the result of ongoing stakeholder engagement, FES forecasts of declining flows and the overall deliverability of work on the network.

10.11 Where units are being replaced on the existing compressor footprint, decommissioning of the redundant units will take place during delivery of the new units. For redundant assets being replaced by new units on adjacent land, the redundant asset will, where possible, be decommissioned the year following commissioning. This allows time for us to build confidence in and test the new units. However, this approach may not be possible if the older unit becomes non-compliant in that time.

Compressor Emissions Compliance Delivery Plan

Table 25 Compressor Emissions Compliance Delivery Plan (key on next page)

	Action	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Hatton - reopener											
Carnforth A	Decom										
Carnforth B	Decom										
Hatton B	Decom										
Hatton C	Decom										
Alrewas A	Decom										
Alrewas B	Decom										
Cambridge A	Decom										
Cambridge B	Derogate										
Chelmsford A	Decom										
Chelmsford B	Derogate										
Diss x1	Decom										
Diss x1	Derogate										
Diss x1	Derogate										
Huntingdon A	Decom										
Huntingdon B	Decom										
Huntingdon C	Derogate										
New-build MCPD FEED	FEED										
King's Lynn A	Decom										
King's Lynn x 1 med new	New										
King's Lynn B	Decom										
King's Lynn x 1 med new	New										
Kirriemuir A	Decom										
Kirriemuir B	Decom										
Kirriemuir C	Decom										
New-build MCPD FEED	FEED										
Peterborough A	Decom										
Peterborough B	Decom										
Peterborough C	Decom										
Peterborough x 1 med new	New										
Wisbech B	Decom										
Wormington A	Decom										
Wormington A med new	New										
Wormington B	Decom										
Wormington B med new	New										
St Fergus FEED (new site with 3x new compressors)	FEED										
Water bath heaters											
Standby Generators											

Key to Table 25

Key				
Work covered in 2018 reopener				
Up front FEED works				
Decommissioning Project (2 years)	Develop	Deliver (Outage)		
Build Project (6 years)	Develop		Deliver (Outage)	Close
Derogation (from 2030)				

11 Stakeholder Engagement

11.1 We have heard from and agree with our stakeholders that it is important to do the right thing for society in terms of reducing the impact of our activities on the environment. This Compressor Emissions Compliance Strategy sets out how we intend to reduce our environmental impact through compliance with emissions legislation through RIIO-2 and beyond. We will deliver our strategy, whilst ensuring there is adequate compression capability on the gas network, to meet broader stakeholder needs. Summaries of stakeholder feedback and how they have influenced the CECS is shown in the tables below.

	Air quality
Stakeholder segments engaged	Consumer interest group, Consultant/supply chain, Customers (entry, exit, shippers), Energy network operator, Env. interest groups, Gas distribution networks, Industry/trade bodies, other energy industry, Regulator/government, University/think tank, Domestic consumers, Non-domestic consumers, Major energy users
Objective	Understand stakeholders' views on how we manage NOx emissions resulting from operating the compressor fleet and becoming compliant with legislation Understand consumers' views on local air quality impacts
Channel/method	Workshops, bilaterals, Webinars, Acceptability testing, consumer listening
Key messages	Stakeholders value our work on reducing emissions to improve local air quality and believe we should get on with it as soon as possible. Managing and reducing emissions is very important Customers want us to assess the impacts of any projects against environment, society and operational parameters Consumers listening outcomes: • Local air quality is important to consumers due to the health concerns associated with it • National Grid has a responsibility in improving local air quality because they are part of the transmission process of pollutants to the atmosphere • National Grid should use existing solutions such as the conversion of existing compressors to electric or other solutions that offset emissions such as planting trees. Domestic consumers consider air quality to be important and the majority agree with the proposed investments and its bill impact. A significant proportion agree with the proposals, but not with the bill impact (around a quarter). There is also some support from domestic consumers for doing more on air quality than currently proposed, but specific actions are not specified.
Influence on CECS	Our proposals to comply with environmental legislation are in line with stakeholder expectations.

	Future proof compressor build
Stakeholder segments engaged	Independent stakeholder user group, consumer interest groups , Major energy users, Other non-energy industry, Regulator or government, University/think tank , Industry/trade body, Gas distribution network, Consultant/supply chain, Customers (entry, exit, shippers)

Objective	Understand the challenges to our compressor proposals Understand stakeholder's views on future proofing our assets
Channel/method	Stakeholder group, webinars, bilaterals, conferences
Key messages	You challenged us to ensure that we were giving due consideration to the UK Government's target to achieve net zero emissions by 2050, including whether we should consider any compressor replacement to be electric drive or hydrogen compatible units. Stakeholders believe we should consider future uses of the gas transmission network when undertaking asset health works. Major energy users stressed the importance of keeping options open, in relation to compressors.
Influence on CECS	We have laid out our consideration of electric drives and hydrogen compatible units within the CECS. We have deferred some of our decisions around whether to decommission or derogate units into RIIO-3.

Network capability	
Stakeholder segments engaged	Customers: Gas Distribution, Networks, Shippers, Entry, Exit Consumers: Domestic, Non-Domestic, Consumers, Representatives Stakeholders: Regulators, Industry/Trade Bodies, Energy Industry, Consultants/ Supply Chain
Engagement Objective	Do our metrics give you useful information on the current and future capability of the gas transmission network? Are the levels of risks that consumers are exposed to suitable now and in the future? How should we balance the interactions across the 3 consumer priorities now and into the future?
Channel/method	Webinars, one-to-ones, Gas Operations Forum, industry meetings and a consumer engagement programme
Key messages	Overall acceptability of network capability proposals A very high proportion of domestic consumers accept the business plan proposals in this area. Stakeholders, including entry and exit customers, were also broadly supportive of the plans. Specific concerns were raised around flexibility and zonal capacity and the need to consider net zero. Some asked for more information on the bill implications of network capability. Use of metrics Stakeholders had mixed views on whether the level of information provided was sufficient. Most felt the metrics were either useful or somewhat useful. Additional information requested included: impact on flows/pressures during incidents; charts for all entry and exit zones; more detailed information around flows and pressures in each zone, and potential longer term impact; iterative feedback on the impact of asset closure/reduction on all zones; more on the quantification of risk; the level of capability we are proposing to retain. One stakeholder pointed out the analysis did not take account of the underlying value of the capacity to users. We found that there is broad support from stakeholders for our proposal for an enduring annual process for engaging on and producing network capability metrics.

	Trading of priorities and risk There is evidence that domestic and non-domestic consumers are prioritising reducing reliability risks over affordability. • Domestic consumers would generally like at least as much reliability as they have at present and would be happy to pay more for investments in this area. • Domestic and non-domestic consumers would be happy to pay more in this area for a 1/10,000 reduction in the probability of a supply interruption. • Major energy users stressed the importance of reliability and have pointed out that there are financial and commercial consequences for them of supply interruptions but have not directly commented on current levels and expected future levels of reliability. • This is consistent with UKERC's study of domestic consumers[28], which finds that there is acceptance of additional costs among consumers for 'ensuring a reliable energy supply. There is some divergence on the trade-offs domestic consumers are making between reliability and affordability. A significant proportion of domestic consumers prefer to maintain current supply risk levels, while a slightly larger proportion prefers to pay more for a more secure supply. While it could be argued that NGGT should go further to reduce reliability risk, there is limited evidence suggesting that stakeholders are unhappy with the current levels of risk.

[28] *http://www.ukerc.ac.uk/publications/paying-for-energy-transitions.html*

12 Interactions

12.1 This topic also has several interactions with other aspects of our business plan. In particular, our asset health and cyber investment proposals have been developed alongside the emissions compliance work proposed in this document to ensure a consistent overall RIIO-2 investment proposal. Key interactions are discussed below.

Asset health

12.2 Decisions to replace, abate or derogate will incur different levels of asset health spend. Asset health costs will be higher the more units we derogate or abate as we will need to maintain old units for continued use. In some cases, the unit may need a full refurbishment to bring it back to the required operational condition. For others, we may invest the minimum to keep them available until there is a major asset health investment needed, in which case a decision on the future of that unit will need to be made.

12.3 The phasing of the final proposals has significant impact upon the levels of asset health work required at the relevant sites to maintain safe and reliable operation. For example, if a compressor unit is due to be replaced early in RIIO-2, then less ongoing asset health work will be required than if it is scheduled for the end of the period.

External threats (Cyber)

12.4 Cyber costs will be higher the more units we derogate or abate as new units are expected to come with an element of cyber compliance built in (unit control systems). Major cyber investment has been deferred until beyond RIIO-2 on compressor sites with the least future certainty.

Redundant Assets

12.5 The Redundant Assets paper (annex A16.08) covers all assets which are no longer operationally required, which could include compressors which would otherwise be captured by this paper due to non-compliance with emissions legislation. The key driver for those works is operational requirement and they are therefore not included in the scope of this paper.

13 Summary

13.1 We believe the proposals presented within this Compressor Emissions Compliance Strategy document deliver the most cost effective network solution to meet the current and future needs of our stakeholders.

13.2 Our integrated programme, developed through stakeholder engagement and a robust approach to options assessment, represents a total funding request of £210.3 across the RIIO-2 period with £156.7m as upfront funding and £53.6m through uncertainty mechanism. Our current view of emission compliance spend beyond RIIO-2 is £139m. Note these costs exclude costs at St Fergus post-FEED. A further £174.4m is subject to an uncertainty mechanism across RIIO-2 and RIIO-3 at the St Fergus site.

13.3 Table 26 summarises our recommended option for each affected site with the associated cost to ensure we deliver the required emissions reduction in line with the LCP, IPPC and MCPD.

Table 26 Summary of recommended options (Costs in £m, 18/19 price base)

Site	Legislation Compliance	Total Cost (RIIO-2 and RIIO-3) £m	RIIO-2 £m	RIIO-3 £m	Proposal (post RIIO-2 investments subject to review)
Alrewas	MCP	[redacted]			Decommission 2 units
Cambridge	MCP				Decommission one unit, Derogate 1 unit
Carnforth	LCP				Decommission 2 units
Chelmsford	MCP				Decommission one unit, Derogate 1 unit
Diss	MCP				Decommission one unit, Derogate 2 units
Hatton	LCP				Decommission 2 units
Huntingdon	IPPC/MCP				Decommission 2 units, Derogate 1 unit
King's Lynn FEED	MCP				FEED
King's Lynn UM	MCP				Decommission 2 units, Build 2 new units
Kirriemuir	MCP				Decommission 3 units
Peterborough FEED	IPPC/MCP				FEED
Peterborough	IPPC				Decommission 2 units
Peterborough UM	MCP				Decommission 1 unit, Build 1 new unit
Wisbech	MCP				Decommission 1 unit
Wormington	MCP				Decommission 2 units, Build 2 new units
Hatton Reopener	IED				Decommission 2 units, Build 2 new units
St Fergus FEED	IED				FEED
Standby Generators	MCP				Replacements
Water bath heaters	MCP				Replacements
Total Cost (£m)		**348.6**	**210.3**	**138.3**	

Key

Proposal Type	Reopener	FEED	UM	New Build	Decom/Derog

13.4 Table 27 summarises how these costs are split out between different types of proposals and funding mechanisms.

Table 27 Summary of funding costs (Costs in £m, 18/19 price base)

Proposal Type	Funding Mechanism	Total Cost (RIIO-2 and RIIO-3) £m	RIIO-2 £m	RIIO-3 £m
Reopener	**Upfront**	[redacted]	[redacted]	[redacted]
FEED	**Upfront**	[redacted]	[redacted]	[redacted]
UM	**UM**	[redacted]	[redacted]	[redacted]
New Build	**Upfront**	[redacted]	[redacted]	[redacted]
Decomm/Derogate	**Upfront**	[redacted]	[redacted]	[redacted]
Total Cost (£m)		**348.6**	**210.3**	**138.3**

13.5 Table 28 summarises how the proposed costs are split between upfront expenditure and the uncertainty mechanism.

Table 28 Summary of funding mechanism costs (Costs in £m, 18/19 price base)

Funding Mechanism	Total Cost (RIIO-2 and RIIO-3) £m	RIIO-2 £m	RIIO-3 £m
Upfront	198.8	156.7	42.1
UM	149.8	53.6	96.2
Total Cost (£m)	**348.6**	**210.3**	**138.3**

14 Glossary

Glossary	
Above Ground Installation (AGI)	Above ground gas assets (including, but not limited to; pipework, valves, pigtraps, meters and regulators) located within a fence line for the safe operation and maintenance of the National Transmission System
Aggregated System Entry Point (ASEP)	A system entry point where there is more than one, or adjacent connected delivery facility; the term is of the used to refer to gas supply terminals.
Anticipated Normal Operating Pressure (ANOP)	A pressure that we may make available at an offtake to a large consumer connected to the NTS under normal operating conditions.
Assured Offtake Pressure (AOP)	A minimum pressure at an offtake from the NTS to a DN that is required to support the downstream network.
Avon unit	a small Rolls Royce (Siemens) gas turbine engine which forms part of the compressor machinery train.
Best Available Technique (BAT)	The most effective and advanced stage in the development of activities and their methods of operation which indicates the practical suitability of particular techniques for providing the basis for emission limit values and other permit conditions designed to prevent (and where that is not practicable), to reduce emissions and the impact on the environment as a whole.
BAT Reference Documents (BRef)	A series of reference documents covering, as far as is practicable, the industrial activities listed in Annex 1 of the EU's IPPC Directive. They provide descriptions of a range of industrial processes and their respective operating conditions and emission rates. EU Member States are required to take these documents into account when determining best available techniques generally or in specific cases under the Directive.
Brownfield	Construction of new units on land that is already occupied by existing assets / infrastructure. Under the brownfield option, this existing infrastructure would need to be demolished or renovated.
Buyback	National Grid may request to buyback Firm capacity rights to manage a constraint on the NTS after any Interruptible/Off-peak capacity has been scaled back.
Capability	The physical limit of the NTS to flow a volume of gas under a given set of conditions; this may be higher or lower than the capacity rights at a given exit or entry point.
Entry Capacity	Holdings give NTS users the right to bring gas onto the NTS on any day of the gas year. Capacity rights can be procured in the long term or through shorter term processes, up to the gas day itself. Each NTS Entry point has an allocated Baseline which represents a level of Capacity that National Grid is obligated to make available for delivery against on every day of the year.
Exit Capacity	Holdings give NTS users the right to take gas off the NTS on any day of the gas year. Capacity rights can be procured in the long term or through shorter term processes, up to the gas day itself. Each NTS Exit point has

Glossary	
	an allocated Baseline which represents a level of Capacity that National Grid is obligated to make available for offtake on every day of the year.
Carbon Monoxide (CO)	A colourless, odourless and tasteless gas produced from the partial oxidation of carbon-containing compounds. It forms when there is not enough oxygen to produce carbon dioxide (CO2), such as when operating an internal combustion engine in an enclosed space.
Carbon Dioxide (CO_2)	A naturally occurring chemical compound composed of 2 oxygen atoms and a single carbon atom. If there is not enough oxygen to produce CO2, carbon monoxide is formed.
Compressor Unit	Comprises of the gas generator, gas turbine and gas compressor.
Control of Substances Hazardous to Health (COSHH)	The law that requires employers to control substances that are hazardous to health.
Cost Benefit Analysis (CBA)	A mathematical decision support tool to quantify the relative benefits of each site option.
Counterfactual	The counterfactual option represents current network with minimum interventions to comply with emissions legislation.
Gas Distribution Network (GDN or DN)	An administrative unit responsible for the operation and maintenance of the local transmission system and <7barg distribution networks within a defined geographical boundary.
Dry Low Emissions (DLE)	A technology that reduces NOx emissions when producing power with gas turbines.
Environment Agency (EA)	A non-departmental public body, sponsored by DEFRA, with responsibilities relating to the protection and enhancement of the environment in England.
Emergency Use Derogation (EUD)	Derogation provided under the IED for equipment used in emergencies and less than 500 hours per year.
Emission Limit Values (ELV)	Limits set for industrial installations by the LCP directive and IPPC under the umbrella of the IED.
Front End Engineering Design (FEED)	The FEED is basic engineering which comes after the conceptual design or feasibility study. The FEED design process focusses on the technical requirements as well as an approximate budget investment cost for the project.
Future Energy Scenarios (FES)	An annual industry-wide consultation process encompassing questionnaires, workshops, meetings and seminars to seek feedback on latest scenarios and shape future scenario work. The Future Energy Scenarios document is produced annually by National Grid and contains our latest scenarios.
Greenfield	Construction of new units on land that has never been used, where there is no need to demolish or rebuild any existing structures.
High Voltage (HV)	Electrical energy above a particular threshold.

Glossary	
Industrial Emissions Directive (IED)	An EU directive that came into force in January 2011. It combined 7 existing directives including the LCP directive and IPPC detailed below.
Integrated Pollutions Prevention and Control (IPPC)	An EU directive which requires industrial installations to have a permit containing emission limit values and other conditions based on the application of Best Available Techniques (BAT). It is set to minimise emissions of pollutants likely to be emitted in significant quantities to air, water or land.
Interconnector UK (IUK)	The pipeline transporting gas between Bacton and Zeebrugge. It is capable of flowing gas in either direction and provides a strategic energy link between the UK and continental Europe.
Intrusive Outage	Significant outage works impacting the whole station and where the station cannot be returned to service until the scheduled works are completed.
Large Combustion Plant (LCP)	An EU directive to reduce emissions from combustion plants with a thermal output of 50 MW or more. Combustion plant must meet the emission limit values (ELVs) given in the LCP directive for NOx, CO, SO2, and particles.
Limited Lifetime Derogation (LLD)	Derogation under the IED that a combustion plant may be exempted from compliance with the ELVs for installations above 50 MW provided certain conditions are fulfilled, including the plant is not operated for more than 17,500 operating hours within the derogation period.
Linepack	The stock of gas within the gas transmission system.
Liquefied Natural Gas (LNG)	Gas stored and/or transported in liquid form.
Local Distribution Zone (LDZ)	A geographic area supplied by one or more NTS Offtakes, consisting of local transmission and distribution system pipelines.
Medium Combustion Plant (MCP) Directive	A directive to reduce emissions from combustion plants with a net thermal input between 1-50 MW.
Mg/Nm^3	A measurement of milligrams per normal meter cubed.
Mega Watt (MW)	A unit of power equal to one million watts.
Maximum Operating Pressure (MOP)	Maximum pressure at which a system can be operated continuously under normal operating conditions.
National Transmission System (NTS)	The high-pressure system consisting of terminals, compressor stations, pipeline systems and offtakes. Designed to operate at pressures up to 85 barg. NTS pipelines transport gas from terminals to NTS offtakes.
Network Development Process (NDP)	The process by which National Grid identifies and implements physical investment on the NTS.
Network Review	The Network Review process allows National Grid to identify the key environmental priorities with regard to ongoing operation of the compressor fleet and agree National Grid's Network Environmental Investment and Regulatory Strategy with both the EA and SEPA.

Glossary	
Nitrogen Oxide (NOx)	A molecule with chemical formula NO and is a by-product of combustion of substances in the air, such as gas turbine compressors.
Net Present Value (NPV)	NPV is the discounted sum of future cash flows, whether positive or negative, minus any initial investment.
Office of Gas and Electricity Markets (OFGEM)	The regulatory agency responsible for regulating Great Britain's gas and electricity markets.
Operating Envelope	All NTS compressors have been designed to operate within a certain range of parameters, namely maximum and minimum gas flow rates and maximum and minimum engine speeds. The limits of these ranges define the performance of a compressor and are referred to as the operating envelope.
Operationally Proven	A unit is operationally proven when it can be shown to be operating reliably and post commissioning / early life issues have been resolved.
Operations Margin (OM) Contracts	Operating Margins (OM) relate to how we use gas to manage short-term impacts of operational stresses (e.g. supply loss) where the market response is not sufficient, or during a gas system emergency. OM gas can be provided under contract by a number of operators: storage and LNG facility operators, offers for a guaranteed level of supply increase or offtake reduction (or combination thereof) from a shipper's portfolio; and offers for a site to be available for supply increase or offtake reduction.
P50	This is a level of cost estimate which represents the cost likely if 50% of the risks occur.
Plant	In the context of the Limited Lifetime Derogation, plant refers to an individual compressor unit.
Proximity Outage	Significant works on a site for which safety precautions must be put in place which make the station unavailable, but the station is capable of being returned to service in a few hours if required as the works taking place are not intrusive to the operation of the station.
Replacement	Installing a new unit to replace the capability provided; this may not be a like-for-like replacement.
RIIO (Revenue = Incentives + Innovation + Outputs)	The new regulatory framework set out by OFGEM, building on the previous RPI-X regime. RIIO-T1 is the first transmission price control review to reflect the framework; it sets out what the transmission network companies are expected to deliver and details of the regulatory framework that supports both effective and efficient delivery for energy consumers over the eight years from 2013 – 2021. RIIO-T2 will be the second price control review.
1-in-20	The 1-in-20 peak day demand is the level of demand that, in a long series of winters, with connected load held at the levels appropriate to the winter in question, would be exceeded in one out of 20 winters, with each winter counted only once.

Glossary	
RB211 unit	A medium sized Rolls Royce (Siemens) gas turbine engine which forms part of the compressor machinery unit.
Selective Catalytic Reduction (SCR)	A means of converting nitrogen oxides (NOx) with the aid of a catalyst into diatomic nitrogen, N2, and water, H2O. A gaseous reductant, typically anhydrous ammonia, aqueous ammonia or urea, is added to a stream of flue or exhaust gas and is adsorbed onto a catalyst. Carbon dioxide (CO2) is a reaction product when urea is used as the reductant.
Scottish Environment Protection Agency (SEPA)	Scotland's environmental regulator and flood warning authority.
Shipper	A company with a Shipper Licence that is able to buy gas from a producer, sell it to a supplier and employ a transporter to convey gas to consumers.
System Flexibility	The ability of the gas transmission network to cater for the rate of change in the supply and demand levels which results in changes in the direction and level of gas flow through pipes and compressors and which may require rapid changes in the flow direction in which compressors operate.
Unit Outage	Significant outage works impacting a single or only some of the units on a compressor station, the unit cannot be returned to service until the scheduled unit works are completed, however, the station can still operate with other available units.
United Kingdom Continental Shelf (UKCS)	The region of waters surrounding the United Kingdom, in which the country claims mineral rights.
Uniform Network Code (UNC)	The Uniform Network Code replaced the Network Code and, as well as covering the arrangements within the Network Code, covers the arrangements between National Grid Transmission and the Distribution Network Operators.

15 Appendix 1 – Supplementary CBA

For our December business plan, we have used our current processes to determine our preferred solution. This includes using a robust Cost Benefit Analysis (CBA) assessment. The CBA is used to quantitatively assess and compare a range of options to inform the optimal solution. The CBA was developed following feedback from the 2015 re-openers, an independent review was completed by Pöyry in 2017 and our methods have been subsequently developed to account for feedback received since our 2018 submission.

The detailed CBA and Justification Papers which set out the scope, costs and benefits of each of our RIIO-2 compressor, emissions-related investment proposals can be found in Annexes A16.10 – A16.13 and A16.16 – A16.19 of the business plan. These documents relate to the Wormington, King's Lynn, St Fergus, Peterborough and Huntingdon sites.

We felt it was appropriate to use our existing CBA process for this area of work as it explicitly considers the impact of uncertainty in its calculations. We have transferred the output to the RIIO-2 Ofgem Investment Pack template. The differences are discussed below.

Using the Monte Carlo analysis allows us to display the impact cost uncertainty has on the Net Present Value (NPV) of each of the options. To do this, we run 1000 simulations of the model, using the @Risk Excel add-in, to capture how the uncertainties in the input data impact the overall NPV. Displaying the NPV with the uncertainty ranges helps to quantify the sensitivity of the decision to these uncertainties. This is important in understanding the decision to proceed with or rule out options based on the CBA.

To enter this data into the RIIO-2 CBA template we use the predicted P50 values of all the input data. This does result in a minor difference in the NPV between the two CBA templates. These differences are caused by a difference in the predicted P50 value of the input data compared to the P50 of the simulation. The differences between the two CBAs are not material and do not impact the overall decision.

The two templates also differ slightly in the application of Social Time Preference Rate (STPR). This results in the STPR rate changing a year earlier in the National Grid CBA than the RIIO-2 CBA, due to a difference in the definition of year 1 of the assessment. This does result in a small difference in the NPV of options after year 30, although these are not significant and would not alter the decision of the assessment. Below is an example of the differences for the Wormington case, which was selected as the magnitude of the figures highlight any slight differences in the assumptions. This shows that once the STPR is changed in the same year the two templates are consistent.

Table 29 Example of STPR differences (Wormington)

Option	10 Years	20 Years	30 Years	45 Years (STPR changes 31st Year)	45 Years (STPR changes 32nd Year)
0 - Counterfactual	0.00	0.00	0.00	-3.70	0.00
1 - Two new units	0.00	0.00	0.00	-0.60	0.00

The quoted NPV in the Justification Papers is based on 2065, 45 years after the start of the spend, consistent with the depreciation period. NPVs at other times are tested to ensure this does not impact the decision. NPVs for all years can be seen in the RIIO-2 CBA templates which are provided along with the reports.

The phasing of the costs in the CBA assessment are all based on a common initial view, which was common to all sites. This view was taken before the CBA assessment had been undertaken, and consequently before the sites which required investment had been identified. Once these had been identified a delivery plan was developed for each of the sites based on when outages would be available along with other restrictions. These differences are the most notable for Peterborough and St Fergus;

- Peterborough: CBA FY22 – FY27 / BPDT FY25 – FY30
- St Fergus: CBA FY22 – FY27 / BPDT FY25 – FY30

These would not alter the decision at any of the sites.

16 Appendix 2 – BAT Reference Material

Reference materials required for the setting of the Preliminary BAT are detailed in **Preliminary BAT Assessment** section of this document.

17 Appendix 3 – Board Level Assurance Statement

CECS assurance statement

We certify that, in the opinion of the Board, the analysis and proposed solutions set out in the Compressor Emissions Compliance Strategy will provide an economically optimal solution[1] that will deliver highest consumer value[2] and reflects all information that might have been reasonably available[3] at the time of submission.

1. For the purpose of the CECS assurance statement 'economically optimal solution' is defined as the solution which provides the best balance between costs and benefits for each solution when taking the cost benefit analysis together with results of stakeholder engagement and relevant qualitative information included in the justification paper.
2. For the purpose of the CECS assurance statement 'highest consumer value' is defined as the solution that provides the most positive combination of monetary impacts (such as lower bills, wholesale energy prices), non-monetary direct impacts (such as maintained or improved reliability) and non-monetary indirect impacts (such as reduced environmental and positive community impacts) as set out in the justification paper. There may be a trade-off in benefits in some of these areas to deliver overall consumer value, these are set out in the justification paper.
3. For the purpose of the CECS assurance statement 'all information that might have been reasonably available' is defined as information that is directly used to compare costs and benefits of solutions through the engineering justification papers and Cost Benefit Analyses including stakeholder views.

NGG Board

For the business plan submission 9 December 2019