Final Option Selection Report

Uncertainty Mechanism Submission

Wormington Compressor Station

August 2022

nationalgrid

Executive Summary

Project Snapshot

National Grid Gas Transmission is committed to reducing the impact of its activities on the environment. Critical to this is ensuring that our compressor fleet meets emissions limits as set out in the Medium Combustion Plant Directive (MCPD). MCPD requires that our existing compressor fleet, between 1MW and 50MW net thermal input, must not exceed 150mg/m³ Nitrogen Oxide (NO_x) by 1st January 2030.

Wormington Compressor Station utilises two Siemens (formerly Rolls-Royce) Avon gas compressors to provide the required capability and network resilience. These units are not compliant with MCPD legislation and therefore require intervention.

Wormington plays a critical role in ensuring gas can enter the National Transmission System through the Milford Haven terminal. The Milford Haven terminal has the capability of supplying up to a third of UK gas demand. As the UK becomes more import dependent, it is critical that the entry capability and resilience is maintained to ensure UK security of supply. For this reason, a long-term secure and reliable solution needs to be implemented at the site.

This Final Option Selection Report provides a summary of all the work performed to date to evaluate, cost, analyse and justify the full suite of feasible options available to achieve emission legislation compliance while ensuring the right levels of network capability and availability are maintained for our customers.

Following a detailed and in-depth option selection process, this report recommends the investment of two new gas-driven compressor units by 2030 at Wormington, with an indicative total project value of [redacted] [redacted] %, as the most economic and efficient solution for UK consumers.

This project aligns with our RIIO-T2 stakeholder priorities "I want you to care for the environment and communities" and "I want to take gas on and off the transmission system where and when I want". Our strategy is set out within the Compressor Emissions Asset Management Plan (CE-AMP) which accompanies, and gives an updated view of, our Compressor Emissions Compliance Strategy (CECS) that was released in 2019 as part of our RIIO-T2 submission. CE-AMP focuses on the impact of MCPD on our compressor fleet, while including other ongoing Industrial Emissions Directive investments. CE-AMP will further develop into the Compressor Asset Management Plan to be released in support of our RIIO-T3 Business Plan.

Why Are We Submitting this Report?

1. National Grid Gas Transmission (referred to in this regulatory submission as 'NGGT'), is submitting this Final Options Selection Report (FOSR) for Wormington Compressor Station's Emissions Compliance. As per the Gas Transporter Licence Special Condition 3.11 Compressor Emissions Re-opener and Price Control Deliverable, Part C, and as per Price Control Deliverable Reporting Requirements and Methodology Document[1] and RIIO-T2 Re-opener Guidance and Application Requirements Document[2]. Our Compressor Emissions Asset Management Plan (CE-AMP), in support of this FOSR, details our approach for how the whole of our compressor fleet will comply with emissions legislation, while maintaining the network's resilience and meeting our customer's needs.

What is the Driver for this Investment?

2. The purpose of this FOSR is to seek Ofgem's approval of NGGT's proposed Final Preferred Option for Wormington Compressor Station to comply with Medium Combustion Plan Directive (MCPD) emissions legislation, providing a detailed view of the project, its associated timings and setting out the different options considered. In addition to ensuring compliance to the aforementioned emissions legislation, NGGT must also ensure the right level of network capability and resilience is maintained in order to fulfil our customer's needs and our operational requirements. This ensures we efficiently minimise network constraints, meet the peak demand of a 1-in-20 scenario[3] and provide security of supply. We must ensure that our network is safe, reliable, and available, and that it delivers value for our consumers and stakeholders, while minimising impact on the environment.

The Importance of Wormington to the NTS – Today & Future

3. Compression requirements at Wormington Compressor Station are heavily influenced by entry flows at the Milford Haven terminals. NGGT uses Felindre, Wormington and Churchover Compressor Stations, amongst other compressors, to move high volumes of gas, up to a third of Great Britain's daily demand, away from Milford Haven into the rest of the network. Milford Haven is an Aggregated System Entry Point (ASEP), consisting of two Liquified Natural Gas (LNG) terminals (South Hook LNG and Dragon LNG). A gas fired power station is also located at Milford Haven (Pembroke). The LNG terminals can increase and decrease their supplies throughout the year depending on national and international market conditions. Due to its bi-directional flow capabilities, Wormington is also required to support demand extremities in South Wales when Milford Haven inputs are low, and in the South West when demand is high.

4. The outlook for increased flows through Wormington is further reinforced following a "Planning and Advanced Reservation of Capacity Agreement" (PARCA) request to increase entry capacity by 17% at Milford Haven (25% at South Hook LNG Terminal).

[1] Version 2, published by Ofgem on 17 March 2021
[2] Version 2, published by Ofgem on 3 February 2022
[3] National Grid (2021), Transmission Planning Code, Standard Special Condition A9: Pipe-Line System Security Standards

The associated Needs Case was approved by Ofgem in December 2021[4] which identified a Final Preferred Option to accommodate the increased capacity with a series of asset investments and possible future reinforcement. This need case identified a continued need for compression at Wormington.

5. The Annual Network Capability Assessment Report 2022 (ANCAR)[5] shows that the South Wales zone is likely to require a further increase in capability. The capability and resilience provided by Wormington is a critical part of the South Wales zone, particularly given the PARCA request and increasing requirement for imports into the UK, thereby minimising the possibility of passing significant constraint costs onto industry and consumers. We are already experiencing a decline in the supply of gas from the UK Continental Shelf (UKCS), which resulted in capacity baseline reductions at St Fergus and Theddlethorpe at the start of RIIO-T2. This increasing need for imports is coming from LNG sources through the Milford Haven and Isle of Grain terminals. With the current global situation, supplies from Europe through the two interconnectors at the Bacton terminal will be significantly reduced, further increasing the need for supplies through the LNG terminals. Supplies of LNG at Milford Haven are already at a significant level, and are forecast to increase further, leading to higher utilisation and network reliance on Wormington Compressor Station.

Existing Compressor Units at Wormington

6. Wormington Compressor Station comprises of two Gas Turbine (GT) Siemens Avon compressors (Units A and B) and one electric-driven Siemens Variable Speed Drive (VSD) compressor (Unit C). Unit C is the lead unit on site, and in cases of high gas flow (>50mscm/day), there is a requirement for Unit A or B to operate in parallel with Unit C to provide sufficient capability in order to avoid the risk of entry constraints. Units A and B operating in parallel provide resilience when the electric-driven unit is not available due to planned or unplanned outages. Avon Units A and B are not compliant with MCPD and therefore, a solution needs to be operational before the compliance date of 1st January 2030.

7. The age of Units A and B, both over 30 years old, has been taken into consideration in this investment recommendation. Both units are already beyond their originally intended design life of 25 years, and therefore would require significant levels of initial asset health investment to ensure unit reliability beyond 2030 and ongoing investment until 2050 to maintain unit availability.

8. To understand existing unit condition and how specific asset health interventions impact the NTS overall, we commissioned [redacted] to develop a Reliability Availability Maintainability (RAM) model, which has evaluated unit availability across the entire NGGT fleet. In addition to this, we have also developed a site-specific availability model for Wormington. These unit availability statistics have fed directly into our option feasibility analysis.

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[4] https://www.nationalgrid.com/gas-transmission/wgn

[5] ANCAR 2022 - https://www.nationalgrid.com/gas-transmission/insight-and-innovation/network-capability

Option Selection Process

9. We have considered a full suite of solutions to enable Wormington to comply with MCPD. The high-level options considered include:

- Doing nothing to reduce site emissions (counterfactual), where Units A and B are placed on Emergency Use Derogation (EUD) i.e. limited to 500 run hours per year beyond 2030
- Modification (retrofit) of our existing compressors with emissions abatement technology to enable them to comply with MCPD
- Building new low-emission, high efficiency gas-turbine (GT) compressor units
- Delaying our investment decision, to account for uncertainties in the energy landscape

10. Our option selection process has considered a number of abatement innovation technologies, which can be used in isolation or in combination with new build units, to reduce NO_x emissions. Control System Restricted Performance (CSRP), Dry Low Emissions (DLE) and Selective Catalytic Reduction (SCR) emission abatement technologies, have been investigated through dedicated external studies and performance trials. A number of solutions have also been discounted, including addition of supplementary VSD units and solutions which would reduce site resiliency, i.e. reduction in the number of site units to less than three.

11. An options shortlist was derived where each of the main solutions (derogation, decommissioning, abatement, new build, etc.) is represented across ten key options. These key options and detail on unit status can be seen in **Table 1** below. The shortlist also contains consideration for Unit C compressor re-wheeling (replacement of the impeller bundle to better match forecast requirements). To ensure consistency in the Cost Benefit Analysis (CBA), the cost for decommissioning Unit A & B has been included. However, the decision to decommission them is subject to an assessment on network capability at the time of new unit commissioning.

Option Shortlist	Unit A	Unit B	Unit C	Unit D	Unit E
1 – Counterfactual	500Hr EUD	500Hr EUD	No Change	/	/
2 - 2 x CSRP	CSRP Retrofit	CSRP Retrofit	No Change	/	/
3 - 2 x SCR	SCR Retrofit	SCR Retrofit	VSD Re-Wheel	/	/
4 – 1533 DLE + 500 Hr	1533 DLE Retrofit	500Hr EUD	No Change	/	/
5 - 2 x 1533 DLE	1533 DLE Retrofit	1533 DLE Retrofit	No Change	/	/
6 - 2 x 1535 DLE	1535 DLE Retrofit	1535 DLE Retrofit	VSD Re-Wheel	/	/
7 - New GT + 500	500Hr EUD	Decom.	VSD Re-Wheel	New GT (Greenfield)	/
8 - New GT + CSRP	CSRP Retrofit	Decom.	VSD Re-Wheel	New GT (Greenfield)	/
9 - New GT + DLE	1533 DLE Retrofit	Decom.	VSD Re-Wheel	New GT (Greenfield)	/
10 - 2 x New GT	Decom.	Decom.	VSD Re-Wheel	New GT (Greenfield)	New GT (Greenfield)

Table 1 - Option Shortlist[6]

12. We have evaluated delaying our investment decision to account for uncertainties in the energy landscape. This has taken the form of a series of fully costed CBA sensitivities, including the two new unit option (Option 10) where we considered installing the first unit by 2028, allowing time prior to 2030 for operational acceptance, and the second new unit by 2035 when constraint costs are projected to increase significantly. This sensitivity option is known within the report as “Option 10+”. This delay would entail exposure to a period of depleted network capability and system resilience in the period 2028-2035, the impact of which could be highly detrimental to consumers under two of the four Future Energy Scenarios studied. Our view is that this is not a risk that should be burdened onto consumers. This delay option would also require more outages than if both units were built together, reducing network capability, and reducing efficiencies as work streams would be duplicated.

Our Investment Recommendation

13. A CBA was run comparing the ten shortlisted options, which were costed to [redacted] accuracy. The constraint costs associated with the differing levels of capability and availability under each of these options fed into the CBA to arrive at the lowest overall cost to consumers, represented by the option with the highest positive Net Present Value (NPV). However, it should be noted that neither the longer-term increase in gas prices caused by the level of constraint nor the societal/economic cost of a constraint that may lead to an interruption to supply to consumers has been factored into the CBA.

[6] Unit decommissioning will be subject to an assessment on network capability at the time of new unit commissioning

A cost breakdown can be seen in **Table 2.** This includes total installed cost, combined initial asset health and ongoing asset health investment until 2050, annual operating costs and decommissioning costs (if applicable). A range of constraint costs dependent on the 2021 Future Energy Scenario's until 2050 is also provided.

Option Cost Comparison Table (18/19 Prices)	Total Installed Cost (£m)	Total Asset Health (£m)	Operating Cost (£m/pa)	Decom. Cost (£m)	Total Constraint Cost (£m)	Cost Accuracy
1 – Counterfactual	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
2 - 2 x CSRP	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
3 - 2 x SCR	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
4 – 1533 DLE + 500 Hr	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
5 - 2 x 1533 DLE	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
6 - 2 x 1535 DLE	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
7 - New GT + 500	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
8 - New GT + CSRP	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
9 - New GT + 1533 DLE	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
10 - 2 x New GT	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 2 - CBA Cost Input Table

14. The output from the CBA can be seen in **Table 3**. Option 10 is the lead option in both Steady Progression and System Transformation. In Consumer Transformation and Leading the Way "New GT + 500Hr" (Option 7) solution is the lead option. The recommended option has a consumer saving of £4.3bn compared to the counterfactual in the "System Transformation" future scenario and the investment shows a positive NPV, relative to the counterfactual from 2032 onwards. Without these new units there is a risk that entry and exit capacity obligations and/or 1-in-20 demand obligations would not be met if the existing electric drive unit is unavailable, which in turn would increase the short-term gas supply costs for consumers when alternative lower-cost sources of gas (LNG) could be available. The potentially significant longer-term impact of constraints on the gas market price hasn't been factored into the CBA evaluation.

Option	Steady Progression	Consumer Transformation	Leading the Way	System Transformation
1 – Counterfactual	£0 m	£0 m	£0 m	£0 m
2 - 2 x CSRP	£2829 m	£196 m	£141 m	£3846 m
3 - 2 x SCR	£2933 m	£200 m	£139 m	£4057 m
4 – 1533 DLE + 500 Hr	£2802 m	£181 m	£136 m	£3832 m
5 - 2 x 1533 DLE	£2719 m	£153 m	£113 m	£3780 m
6 - 2 x 1535 DLE	£2722 m	£144 m	£104 m	£3796 m
7 - New GT + 500	£3334 m	£327 m	£233 m	£4531 m
8 - New GT + CSRP	£3326 m	£315 m	£220 m	£4560 m
9 - New GT + 1533 DLE	£3287 m	£303 m	£211 m	£4509 m
10 - 2 x New GT	£3377 m	£309 m	£209 m	£4639 m

Table 3 - CBA Results vs. FES 2021 - Relative NPV

15. To support our option selection process, we have produced a Best Available Techniques (BAT) assessment[7]. This BAT assessment, which was produced by [redacted] ([redacted]), was also supportive of the two new unit option (Option 10) as being the recommended option from an operational and environmental perspective. The assessment featured qualitative scoring of all options against key technical and environmental criteria, as well as whole life emissions and costs. Option 10 scored the highest technical score when compared to all other options in terms of ability to meet compression requirements (versatility), maintenance complexity and availability of spares (ownership), future resilience against tightening of energy efficiency and emissions limits (future proofing) and environmental control (hazard). Regarding emissions reduction, a key factor in this FOSR, two new units (alongside SCR) ranked as the leading solution for emissions reduction through improved efficiency and fuel consumption. Overall scores assuming the VSD is unavailable can be seen in **Table 4,** and **Appendix G**.

[7] National Grid is legally bound under the Industrial Emissions Directive (IED) to comply with the requirements of BAT in respect of its gas turbine compressor installations. Beyond this, National Grid made a policy decision in 2013 that BAT would be the primary selection mechanism for all new and substantially modified compressor machinery trains. The BAT assessment methodology has been developed by National Grid in consultation with the Environmental Agency (EA) and Scottish Environmental Protection Agency (SEPA).

Option Number	Technical / Environmental Score (qualitative assessment)	Environmental Score based on (quantitative assessment)	Total Score
1 – Counterfactual	32%	10%	42%
2 - 2 x CSRP	32%	11%	43%
3 - 2 x SCR	28%	30%	58%
4 – 1533 DLE + 500 Hr	28%	12%	40%
5 - 2 x 1533 DLE	40%	15%	55%
6 - 2 x 1535 DLE	46%	13%	59%
7 - New GT + 500	29%	15%	44%
8 - New GT + CSRP	35%	16%	51%
9 - New GT + DLE	44%	23%	67%
10 - 2 x New GT	54%	25%	79%
Max. weighted score available	65%	35%	100%

Table 4 - BAT Assessment Final Scores

16. Overall, based on the outcome of the CBA, BAT assessment and considering the criticality of Wormington Compressor Station to the UK's security of supply, the installation of two new gas–driven compressor units is our Final Preferred Option. This recommendation is justified following comparison against a variety of key investment metrics. The summary breakdown of key investment criteria against each of the options is highlighted in **Table 5**.

- Option 10 is one of the highest performing solutions (alongside SCR) from an emissions reduction perspective. New GT compressors offer highly efficient, reliable and low emission compression.
- While new build units incur the highest capital investment cost, this is offset against reductions in future constraints. This option provides the best return on investment for consumers while relative NPV is expected to turn positive from 2032 based on projections from the Steady Progression scenario.
- From a technical perspective, Option 10 received the highest overall technical rating compared to the alternative investment options. New units scored highest in terms of network versatility, future proofing against changes in energy legislation, maintainability and environmental hazard control. Please note, technical scores have been translated from 65% to 100%. See FOSR Databook for calculation.

Investment Summary Table (18/19 Prices)	Emissions (Tonnes NOx)	Total Installed Cost (£m)	Relative NPV (ST Scenario)	Constraint Costs (ST Scenario)	Technical Score (BAT)
1 – Counterfactual	1897	[redacted]	£0 m	[redacted]	49%
2 - 2 x CSRP	1751	[redacted]	£3846 m	[redacted]	49%
3 - 2 x SCR	134	[redacted]	£4057 m	[redacted]	43%
4 – 1533 DLE + 500 Hr	1050	[redacted]	£3832 m	[redacted]	43%
5 - 2 x 1533 DLE	496	[redacted]	£3780 m	[redacted]	62%
6 - 2 x 1535 DLE	618	[redacted]	£3796 m	[redacted]	71%
7 - New GT + 500	701	[redacted]	£4531 m	[redacted]	45%
8 - New GT + CSRP	655	[redacted]	£4560 m	[redacted]	54%
9 - New GT + DLE	318	[redacted]	£4509 m	[redacted]	68%
10 - 2 x New GT	256	[redacted]	£4639 m	[redacted]	83%

Table 5 - Investment Summary Table

Key Investment Considerations

17. The Final Preferred Option of two new units ensures the highest unit availability possible. When comparing the availability values of new build units against retrofit Avon's, we can expect an increase of 11%; 79%[8] to 90%[9]. Given the critical function of Wormington, availability has a significant impact, network capability and security of supply. GTs at Wormington are required to provide backup compression capability when the VSD is not available, due to planned or unplanned outages, as well as primary duty for capability requirements that cannot be achieved by Unit C (VSD) alone (i.e. high flow and high head conditions). The improved availability of new GTs compared to the existing Avon's has a significant impact on network constraints and consistency of supply.

18. Required outages during construction and commissioning are a key investment consideration, as these have significant impact on the short-term availability of Wormington. The Final Preferred Option, involving installation of two new units on an area of NGGT owned land outside the current site plot, allows the majority of construction works to be completed away from operational plant with minimal outages required for tie-in and commissioning of the new units. Conversely options which involve retaining Units A and/or B involve significant amounts of brownfield scope which would require more outages to allow construction and commissioning activities to progress safely. This presents construction challenges and impacts site availability through the construction period. Due to the location of Wormington on the NTS and its criticality, outages during the construction phase may result in network constraints with an associated cost to consumers. Constraint costs due to these construction outages haven't been included in the CBA. Gas supply from Milford Haven has the potential to remain high throughout the year, including the summer months, reducing the availability of site outages.

19. While Option 10 was highlighted as the most cost-effective option within the Steady Progression and System Transformation future scenarios, it was not the lead option in

[8] See Appendix K – NG Fleet RAM Study
[9] See CE-AMP – Appendix F – Process; New unit availability value of 90% has been derived from Felindre B & C units, which are the newest operational gas driven units on the NTS.

Customer Transformation and Leading the Way. These scenarios see immediate reductions in annual gas demand with consumers changing their behaviour and making significant investment in thermal insulation and heat pumps. There are currently limited incentives in place to drive this behaviour making the predicted reductions seen in the Customer Transformation and Leading the Way scenarios ambitious and unlikely to occur. A strong reliance on gas is likely beyond 2030, a more detailed assessment of the scenarios and what is driving the change is detailed in CE-AMP. It should be noted that any delay to a mass electrification of heating by 2030, as seen in the Customer Transformation and Leading the Way scenarios, would result in the need for two new units. NGGT continue to monitor these scenarios against real world demand to inform our other investment decisions.

20. In view of the above, we have used the System Transformation scenario as the base case for this report as it provides an appropriate central case for Wormington's expected range of operation. Sensitivities to the analysis against the other three scenarios have also been included.

21. To assess the delay option, we completed Real Option Analysis to define the impact of the delay in each of the four scenarios. The CBA has already shown that two new units is not the preferred option in Customer Transformation and Leading the Way. When the scenarios are weighted equally this analysis does show that delaying the decision provides a benefit of £5.0m, see **Table 6**. However, when assessing the deferral in our high price and high LNG sensitivities this potential is reduced to almost nothing. The delay to investment does pose a risk to consumers in both the Steady Progression and System Transformation scenarios. This is because we would have lower availability on the network due to the delay to the investment. In these scenarios the risk of delaying the investment five years would be around £10m, see **Table 7**. This risk increases in both our high price and high LNG sensitivities to between £15-20m. Given the lack of progress towards both Leading the Way and Customer Transformation as detailed in CE-AMP, delaying the investment could pose a significant risk to Security of Supply and increase the chances of serious disruptions to the UK gas market.

Option	Steady Progression	Consumer Transformation	Leading the Way	System Transformation
Second Unit Delay until 2035	[redacted]	[redacted]	[redacted]	[redacted]
One New unit / One 500 hr Avon	[redacted]	[redacted]	[redacted]	[redacted]
Two new units by 2028	[redacted]	[redacted]	[redacted]	[redacted]
Overall Delay Value	£5.0m			

Table 6 - Real Options Analysis Delay investment

Investment Deferral - Consumer Risk (£m)	
Steady Progression	£12 m
Consumer Transformation	-£18 m
Leading the Way	-£24 m
System Transformation	£10 m

Table 7 - Investment Deferral Analysis - Consumer Risk

22. Within our recommendation of two new gas-driven units, we have considered decommissioning of Units A and B, once the new compressors are commissioned and operational. In the event that site resilience is required post 2030, we would consider options to maintain Units A and B beyond 2030. Retaining Unit A and/or B would increase site resilience during normal operation and during planned and unplanned outages, minimising network constraints. This would require future engagement with Ofgem depending on the need at that particular point in time.

Conclusion & Next Steps

23. Following an in-depth data-driven option selection process, this report recommends the investment for two new gas-driven compressor units by 2030 at Wormington as the most economic and efficient solution for UK consumers.

24. Wormington is critical in supporting LNG imports through the Milford Haven terminal. These flows contribute significantly to UK security of supply, both by providing access to global gas markets and acting as a source of flexible supplies to respond rapidly to changes in supply and demand. Any disruptions which limit the capability and resilience of Milford Haven could pose a significant risk to Security of Supply and increase the chances of serious disruptions to the UK gas market. Our recommended option provides appropriate levels of resilience at Wormington to minimise these risks.

25. Ofgem are invited to assess and approve the proposed Final Preferred Option for Wormington Compressor Station in line with Special Condition 3.11, Part C, 3.11.9. Following Ofgem's decision on the Final Preferred Option, NGGT will use the received Baseline allowances to develop our preferred option further and submit a Re-opener application in line with Special Condition 3.11, part D and appendix 2 for Ofgem's consideration in November 2024. We welcome the engagement with Ofgem throughout the option selection process and intend to keep engaging with the regulator at all relevant project development stages, so they remain informed throughout and ensure we successfully deliver our proposed solution at Wormington Compressor Station.

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1. Summary Table

Name of Project	Wormington MCPD		
Scheme Reference	[redacted]		
Primary Investment Driver	Compliance with MCPD legislation		
Project Initiation Year	2019		
Project Close Out Year	2028		
Total Installed Cost Estimate (£)	[redacted]		
Cost Estimate Accuracy (%)	[redacted]		
Project Spend to date (£)	[redacted]		
Price Base	2018/19 prices		
Current Project Stage Gate	4.2 - Option Selection		
Reporting Table Ref	RRP Table 6.2 (Projects) and Table 6.1 (CAPEX_Summary)		
Outputs included in RIIO-T1	No		
Outputs included in RIIO-T2	<u>Compressor Emissions PCD:</u> PCD to ensure NGGT delivers a Final Options Selection Report, long lead items and Re-opener submission[10]. Final Option Selection Report: August 2022[11] Re-opener application window: November 2024 Baseline allowances: [redacted] (excl. RPEs)		
Spend Apportionment	**RIIO-T1**	**RIIO-T2**[12]	**RIIO-T3**[13]
	[redacted]	[redacted]	[redacted]
Applicable Future Energy Scenario (FES) Edition	2021		

Table 8 - FOSR Summary Table

[10] Detailed in Special Condition 3.11 Compressor emissions Re-opener and Price Control Deliverable
[11] FOSR submission date updated in line with Ofgem Consultation of 1 August 2022
[12] [redacted]
[13] [redacted]

2. Project Status and Request Summary

Overview

26. National Grid Gas (NGGT) requires its compressor fleet to achieve compliance with the Medium Combustion Plant Directive (MCPD) legislation by 1 January 2030. As part of our RIIO-T2 submission in December 2019, we proposed to install two new gas driven compressor units at Wormington Compressor Station by 2030. Once the new units received operational acceptance, decommissioning of the existing two non-MCPD compliant Avon's would take place. As part of Final Determinations, Ofgem determined that there was still uncertainty around the final solution, providing funding to complete the options selection (including engineering assessments) within this Final Option Selection Report (FOSR) and to complete a Re-opener submission in November 2024 (cost submission) once the project has gone through a full Front End Engineering and Design (FEED) and tender process for the Final Preferred Option.

27. This FOSR has been created through our Option Selection (Stage 4.2 of the Network Development Plan (NDP); overview in CE-AMP[14]) process to assess credible options aimed at meeting MCPD legislative compliance while meeting customer and stakeholder needs.

Project Status

28. Since 2019, NGGT have selected an Option Selection Consultant, [redacted], to support in further evaluating the available options to achieve MCPD compliance by 2030. All options proposed as part of the RIIO-T2 submission have been further evaluated, along with new Emission Abatement technology options.

29. A preliminary BAT assessment undertaken by [redacted] ([redacted]) supports the CBA, and feeds into the decision-making process. BAT analysis is an assessment of the available techniques best placed to prevent or minimise emissions and impacts on the environment. Options that were considered in the preliminary BAT assessment are aligned to those described in **Section 5** and include abatement options identified since the previous assessments included in our 2019 RIIO-T2 business plans. The preliminary BAT Assessment report can be found in **Appendix G**.

30. The required initial and ongoing Asset Health expenditure applicable for each of the shortlisted options described in **Section 5** has been investigated, see **Appendix D** for the Asset Health Report, and used along with operational running costs within the updated CBA.

31. A qualitative risk assessment has been undertaken for all options with a focus on risks that may differentiate between options for concept selection purposes. As part of the risk assessment process, significant areas of risk requiring onward management and opportunities to be further investigated as part of value engineering were also identified. Risks relating to specific options can be found within **Appendix F**.

[14] CE-AMP Appendix F - Process

32. All four of the Future Energy Scenarios (FES 2021) and new Network Capability modelled flow data has been used in the updated CBA.

33. The inability to accept gas at Milford Haven due to site outages, unit unavailability and planned and unplanned outages, could result in high constraint costs being passed onto UK consumers. These have been assessed and included in the updated CBA.

34. South Hook LNG have issued a request for a 25% increase in entry capacity through the Planning and Advanced Reservation of Capacity Agreement (PARCA) at Milford Haven, net increase at Milford Haven of 17%. This will have a direct impact on compression requirements at Wormington Compressor Station, which has been assessed as part of the Western Gas Networks (WGN) project and is factored within this project.

Request Summary

35. To achieve MCPD legislative compliance at Wormington Compressor Station, NGGT's Final Preferred Option is to install two new gas-driven compressors at Wormington by 2030, with an associated cost of [redacted], funded through the Re-opener following submission in November 2024. Funding to decommission the non-MCPD compliant units has been included in this total cost, where actual decommissioning will be considered after operational acceptance of the new units, and not included within the Re-opener funding request. The total project cost includes the already received Baseline funding of [redacted] (excl. Real Price Effects (RPEs)). The Baseline funding will be subject to true up following our Re-opener submission in November 2024.

36. Our Final Preferred Option is supported by the CBA and BAT assessment which have considered investment costs for compressors, the constraints and contracts, and compressor running costs. The increase in availability that two new units provide, will minimise network constraints associated with import flows from Milford Haven. Increasing capability and minimising network constraints is supported by stakeholders and customers. Further information on this can be found in CE-AMP.

37. The Final Preferred Option is the most cost efficient for consumers as it minimises constraint costs, provides the right level of network capability, delivers a significant reduction in greenhouse gas emissions and is proven to be the most cost beneficial with a short payback time. This option has been selected from a complete range of potential options that have been analysed and developed extensively to ensure a robust decision is presented.

38. Ofgem are invited to assess and approve our proposed Final Preferred Option for Wormington in line with Special Condition 3.11, Part C, 3.11.9. NGGT's view is that the PCD should be viewed as fully delivered once we have submitted our Re-opener application at which point the PCD will be revised to reflect the outputs and allowances related to the delivery of our preferred option. NGGT is reporting on our PCD progress and spend as part of the annual Regulatory Reporting Pack (RRP).

39. Following Ofgem's decision on the Final Preferred Option, NGGT will use the received Baseline allowances to develop our preferred option further and submit a Re-opener

application in line with Special Condition 3.11, part D and appendix 2 for Ofgem's consideration in November 2024. We welcome engagement with Ofgem throughout the Option Selection process and intend to keep engaging with them at relevant project development stages, so they remain informed throughout and ensure we successfully deliver our proposed solution at Wormington Compressor Station.

3. Problem/Opportunity Statement

Why are we doing this work and what happens if we do nothing?

40. NGGT is legally obligated to have its compressor fleet compliant with MCPD legislation[15] by the deadline of 1 January 2030. Two of the compressors at Wormington Compressor Station, Units A and B, fall within the MCPD category and can breach the NO_x limits imposed. Therefore, Units A and B require intervention to ensure the site remains legally compliant.

41. There are a total of three units at Wormington that can run in multiple configurations. Units A and B are Siemens (formerly Rolls-Royce) Avon compressors and Unit C is an electric driven Siemens Variable Speed Drive (VSD). See **Figure 1** for a site overview. Unit C is the lead unit on site, and in cases of high gas flow from Milford Haven, there is a requirement for Unit A or B to operate in parallel with Unit C to provide maximum capability. Units A and B operating in parallel provide resilience when the VSD is not available, either due to planned or unplanned outages.

[redacted]

Figure 1 - Wormington Compressor Station overview

42. Utilisation of the compressors at Wormington is strongly linked to the supply and demand levels in South Wales. In recent years, Wormington has become critical in enabling high volumes of gas to enter the NTS through Milford Haven, increasing UK's security of supply and enabling gas transit from Milford Haven LNG terminals towards Europe. As Milford Haven flows are forecast to increase over a wide range of future energy scenarios, Wormington will continue to play a critical role in supporting the supply of gas into the NTS.

43. Due to bi-directional flow capabilities, Wormington is a critical site to support the offtakes in South Wales when demands are higher than Milford Haven inputs. The Southwest is also supported by Wormington's ability to move gas from Milford Haven and/or from the centre of the network, pushing it South to the demand extremities in the Southwest. Wormington is a critical site in supporting our 1-in-20 peak demand obligation.

[15] https://www.gov.uk/guidance/medium-combustion-plant-mcp-comply-with-emission-limit-values

44. Wormington is the primary compressor station to support Milford Haven supplies. Felindre and Churchover can operate in series with Wormington to create a compressor chain, which provides maximum capability for Milford Haven. Unavailability of Wormington would lead to a significant reduction in capability, leading to entry constraints in certain scenarios at Milford Haven. Felindre and Churchover provide some resilience to Wormington unavailability, however this is limited as operating Churchover without Wormington leads to low station inlet pressure, and the potential of Assured Offtake Pressure breaches. The location of these compressor sites is illustrated in **Figure 2**.

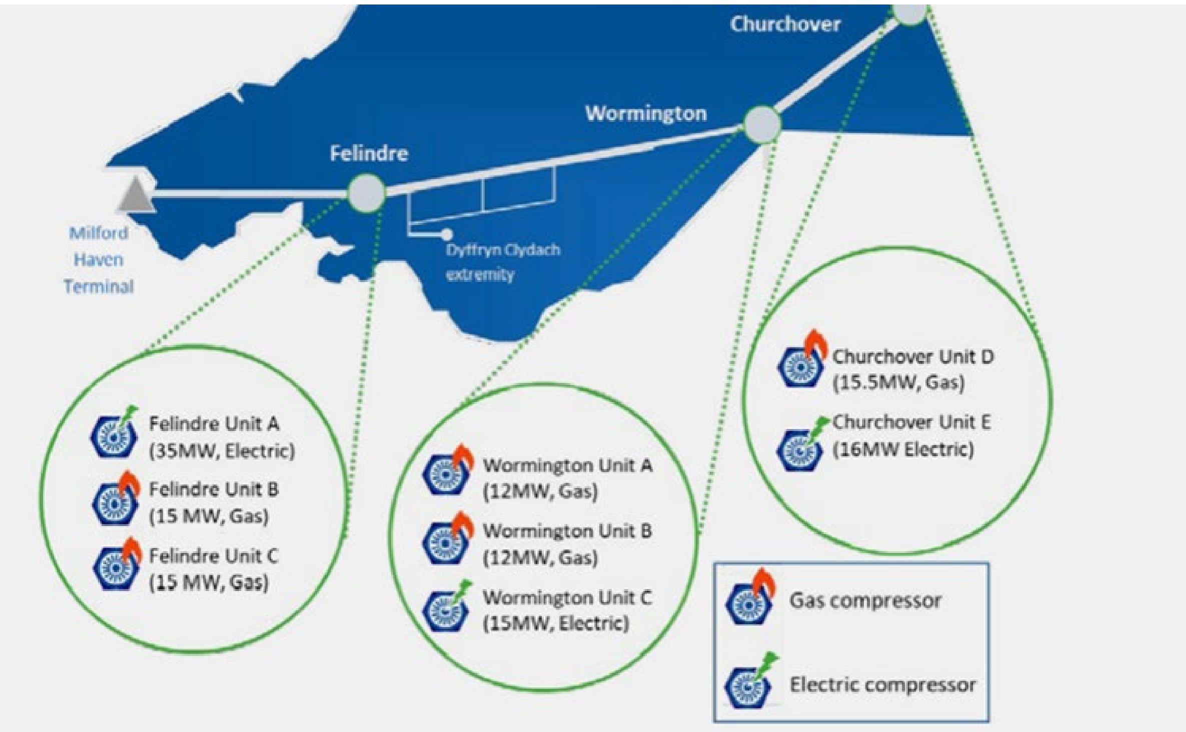


Figure 2 - Location of Milford Haven terminal and related compressor sites

45. The inability to accommodate gas supply at Milford Haven, will lead to network constraints and curtailment of supplies to Britain, resulting in higher gas prices and a reduction in security of supply. Due to Wormington's critical location on the network, high compression availability is required to minimise constraints and maintain network capability. See **Section 4** for more detail on compressor availability & capability.

46. Doing nothing for this project is defined as the 'Counterfactual' within this FOSR. This is where no action is taken, other than asset health works and Unit A and B are operated under Emergency Use Derogations (EUD). This would limit them to 500 run hours per year over a five-year rolling average, with no reduction in emissions from the units during their operation.

47. Limiting the available run hours of Unit A and B will impact the ability to maintain network capability, preventing us from meeting our customers' requirements and impacting the UK's security of supply. We have a licence obligation to have a 1-in-20 demand capability, which having limited run hours would impact. Commercial contracts would not be cost effective in minimising the impact of constraints to the consumers.

48. This FOSR has considered and compared multiple options, to ensure that the Final Preferred Option, replacing Unit A and B with new units, meets the MCPD requirements and also accommodates increased flows at Milford Haven to provide the most cost-effective option for our customers and UK's gas consumers.

Under what circumstances would the need or option change for this project?

49. The Final Preferred Option of two new units by 2030 is further reinforced with any delay to the FES scenario's stated speed of UK electrification, as detailed in CE-AMP[16].

50. Any increase in the net gas supply at Milford Haven will increase the requirement for two new units at Wormington. Two new units will increase the site's reliability, availability and capability, therefore minimising constraints. Below is a list of changes that could increase the net gas supply at Milford Haven:

- Closure of storage sites on the NTS, resulting in additional LNG being supplied to the network, increasing supplies at Milford Haven.
- Reduction in either distribution network demand prior to Wormington and/or a reduction/cessation in Pembroke power station's demand, resulting in a net increase of gas being transported through Wormington.
- Changes in the interconnectors' operating models or services that increase supplies to Europe, increasing LNG supply to the network to meet the increase in demand.
- Increase of Europe's gas demand, reducing gas imports to supply the UK through the interconnectors, and increasing LNG supplies to accommodate this supply reduction.
- UK, Europe and Norway move to a predominantly blue[17] hydrogen based market. This could increase UK demand as export through the interconnectors increase, with increasing LNG supplies to meet the increase in demand.
- The European Union plans to make Europe independent from Russian fossil fuels by 2030. Currently 45% of Europe's annual gas demand comes from Russia. This could result in a sustained increase of LNG gas supply at Milford Haven to meet the increase in interconnector export demand as seen in 2022.
- Changes in world markets could increase the amount of LNG coming to the UK, increasing the supply at Milford Haven.
- Any delay and/or reduction to the electrification scenarios in FES would increase the duration and volume of gas supplied into Britain through Milford Haven.
- If the UK moved towards a hydrogen market sooner than 2030 and on a bigger scale, this could reduce the demand in Wales before Wormington, increasing the required capability of the site. This can already be seen in an increase in the UK Government's hydrogen production target[18], from 5GW (FES 21) to 10GW (FES 22).

[16] CE-AMP Customer Demand Patterns
[17] Blue hydrogen is produced from natural gas, and other non-renewable energy sources
[18] https://www.gov.uk/government/publications/uk-hydrogen-strategy

- A global shift away from natural gas could result in an increase in LNG supplies into Milford Haven prior to LNG production facilities ceasing and/or reducing operation.

51. Any decrease in the gas supply at Milford Haven will reduce the requirement for two new units at Wormington, due to less reliance on the site's availability and capability. Below is a list of changes that could decrease gas supply at Milford Haven:

- Investment or new discoveries in UK gas production (UKCS, Shale and green gas) reducing LNG importation dependency.
- Changes in the interconnectors' operating models or services that reduce export to Europe, reducing LNG supply to the network.
- Changes in world markets resulting in a reduction of LNG coming to the UK.
- The electrification scenarios within FES happen sooner than forecast, and/or at an increased rate, leading to a reduction in natural gas demand and supply at Milford Haven.
- UK, Europe and Norway move to a predominantly green[19] hydrogen based market. This could reduce UK demand as export through the interconnectors reduce, resulting in a reduction of LNG supplies.
- The hydrogen scenarios in FES happen sooner than forecast, and/or at an increased rate, leading to a reduction in the UK's natural gas demand and supply at Milford Haven. This can already be seen in an increase in the Government's hydrogen production target, from 5GW (FES 21) to 10GW (FES 22).

52. Any changes in legislation could impact the preferred option for two new units. Below is a list of changes that could impact the Final Preferred Option:

- Unilateral change in the UK environmental legislation to rescind or alter the conditions of MCPD. Lowering the required NO_x levels and/or including CO limits would favour new more efficient units over existing units that just meet the current legislative levels.
- Introduction of legislation that defines the required energy efficiency of our compressors would favour new units.
- Changes in Gas Safety (Management) Regulations requirements allowing entry of different quality gas from suppliers and the blending of Hydrogen. This has the potential to increase LNG supplies as the gas requires less processing.

53. Any other changes that could impact the preferred option for two new units, are listed below:

- Increasing energy costs would favour new units that are more efficient than the existing ones.
- Increasing material costs is less favourable to new units due to the larger material quantities required when compared with retrofit options

[19] Green hydrogen is produced by renewable or low-carbon energy sources

- Unforeseen maintenance and/or failure of the existing Avon's resulting in increased asset health costs would favour new units.
- Reduction in the availability of spares for the existing Avon's could result in increased down time, favouring new units.
- Reduction in OEM support for the existing Avon's would favour new units.
- Preference of FES faster electrification scenarios are less favourable than new units due to the low demand and constraints.
- Preference of FES which include a slower pace of electrification are more favourable than new units due to high demand and constraints.

What are we going to do with this project?

54. In order to achieve MCPD compliance at Wormington Compressor Station, NGGT's Final Preferred Option is to install two new gas-driven compressor units before the MCPD deadline. Once these new units have been commissioned and are operationally accepted, Unit A and B will be considered for decommissioning. More detail on our Final Preferred Option can be found within **Section 8.1.**

What makes this project difficult?

55. Uncertainties around UK's energy landscape and the wide range of energy scenarios detailed within FES has led to two new units being assessed as the highest NPV option in CBA analysis for two scenarios, Steady Progression and System Transformation, and not for the other two high electrification scenarios, Customer Transformation and Leading the Way. If Milford Haven supplies are above those stated in FES, high constraint costs are highly likely.

56. Construction of new units on our network takes approximately six years from confirmation of preferred option to operational acceptance. To ensure that the Final Preferred Option of two new units are operationally accepted by the 2030 deadline, construction cannot be delayed. For the Option 10 Level 2 programme, please see **Section 8.2**. Construction of two new units only requires one site outage to connect them to the existing site, where the alternative options required additional outages. Outages have to be carefully aligned with Milford Haven supply to minimise constraints. Milford Haven supply has the potential to remain high throughout the year, reducing the available site outages.

57. The main driver for this project is MCPD, however there is also a customer driver for increased capability at Milford Haven, via the Western Gas Network (WGN) project, see **Section 3.2**. Although these are separate drivers, and follow different funding mechanisms, the Option Selection stage of this project has bundled the compression requirements at Wormington with the aim of ensuring efficient spend and delivering the greatest value to end consumers.

58. Wormington Compressor station is located in a rural area close to the Cotswold AONB. Therefore, early stakeholder engagement and careful consideration of noise and visual impacts in design will be required to minimise the risk of potential delays to the permitting and approvals process.

59. Due to Wormington's critical location on the network, any maintenance and/or down time on the existing units will reduce capability at Milford Haven, potentially leading to constraints. Construction of two new units on greenfield will minimise the impact on the existing units, maintaining the current level of availability and capability during construction.

60. The current national and international geopolitical situation is creating significant uncertainty in prices and availability of materials and labour which makes estimating project delivery costs more challenging. This will need to be a consideration when finalising the delivery strategy after confirmation/approval of the preferred option. A sensitivity has been included within the CBA which considers the impact of increasing capex costs.

61. Risks and opportunities associated with the preferred option can be found in **Section 8.3** and details of risks and opportunities of all shortlisted options can be found in **Appendix F**.

What are the key milestone dates for project delivery?

62. The project aims to have the two new units commissioned in 2028, allowing time for them to become operationally accepted prior to the 2030 deadline. Milestone dates have been informed by scheduling of this project against other planned investment work. This has identified that the opportune time to begin the design and build phase at Wormington is in 2025 with operational acceptance and project closure in 2028 as summarised in Figure 3.

ND500 – Network Development Stage Gates & Key Milestones			
ND500 Phase	**Key Activities**	**Sanction**	**Indicative**
4.0 Needs Case 4.1 Establish Scope and Options	• Identification of Needs Case • Define strategic approach and outputs required to deliver • F1 Sanction – Optioneering	T0	N/A
		T1	April 2019
		F1	April 2019
4.2 Option Selection	• F2 Sanction - Feasibility • BAT Assessment and Compressor Machinery Train selection • Final Option Selection Report Submission • Agreement to Proceed to Conceptual Design • F3 Sanction - Conceptual Design and Long Lead Items	T2	April 2021
		F2	April 2021
		T3	May 2023
		F3	May 2023
4.3 Concept Design & Development	• UM Cost Reopener Submission • Scope Freeze	T4	November 2024
4.4 Project Execution	• F4 Sanction – Detailed Design & Build • DDS Challenge, Review and Sign off • Maintenance Requirements Identified	F4	January 2025
		T5	March 2026
4.5 Acceptance/Closure	• Post Commissioning Handover to GT • Operational Acceptance • Project Closure	T6	March 2028
		F5	December 2028

Figure 3 - Key Project Milestones

63. The stage gates within our NDP process ensure minimum requirements are met for each phase of investment development.

64. Decommissioning of Unit A and B will be reassessed after operational acceptance of the new units.

How will we understand if the project has been successful?

65. Overall project success will be confirmed by operational acceptance of the preferred option, meeting customer demands throughout the construction period, compliance with MCPD requirements as well as the project completed safely and to time, quality and cost.

66. For this Option Selection stage, the project will be deemed a success if the PCD set out in Special Condition 3.11 will be deemed as fully delivered. The PCD entails the FOSR being submitted to Ofgem by August 2022 and the Re-opener submission in November 2024 following Ofgem's review of the preferred option that provides the best value for consumers.

3.1. Related Projects

67. There are key interactions with other significant investments, both at Wormington and across the National Transmission System (NTS):

- Western Gas Network (WGN) project[20] (relating to the PARCA at Milford Haven) has pipeline build, pipeline pressure uprating, Above Ground Installation (AGI) and compressor modifications at Wormington, Felindre and Churchover compressor stations included within the project's preferred option. WGN capability assessments were based off NGGT's business plan submission of two new units at Wormington. The current programme timelines show completion of the WGN project in December 2024 (capacity release in January 2025) while the Wormington MCPD project is scheduled for completion in March 2028.
- Wormington station and Unit C control system replacement is planned for 2025 delivery. This cyber and asset health driven investment is not planned to commence FEED until 2023/24. The decision to bundle these investments for efficient delivery will be made after Ofgem's response to the FOSR. Options that involve retaining units A and/or B beyond 2030 will require the associated unit control systems to be replaced.
- Funding has been granted through RIIO-T2 Asset Health to replace Unit A and B's cab ventilation systems to prevent overheating under certain conditions. Unit A will be completed in 2022 and Unit B the following year in 2023. This will aid in maintaining the availability of the units, minimising constraints until our Final Preferred Option is implemented by 2030.
- Milford Haven regularly maintains high flows throughout the year, which reduces the ability to facilitate outages at Wormington with minimal impact on capability and impact to our customers and end consumers. Outages at Wormington during periods of high Milford Haven flows will directly impact the volume of gas that can be brought onto the NTS, leading to high constraint costs.

68. To increase the options available to comply with MCPD legislation, NGGT are trialling emissions abatement technologies to determine their viability and legal acceptance. These technologies are:

- Control System Restricted Performance (CSRP). This involves permanently derating or reducing the power output of an Avon through modification of the control system. A CSRP proof-of-concept trial was conducted at Huntingdon and Chelmsford Compressor Stations in winter 2021. It successfully confirmed a correlation between Exhaust Cone Temperature and NO_x emissions. More information can be found within a dedicated CSRP report which can be found in **Appendix J** and in CE-AMP[21].
- Dry Low Emissions (DLE). An Avon DLE retrofit modifies the combustion system within the Avon engine so that air and fuel are premixed before combustion. This reduces the peak combustion temperature, which in turn

[20] https://www.nationalgrid.com/gas-transmission/wgn
[21] CE-AMP Appendix C – Compliance Option

reduces the amount of NO_x produced. NGGT have funded development of a DLE retrofit 1533 Avon in partnership with [redacted], beginning with combustor can trials in early 2022. A full engine test bed performance trial to determine NO_x reduction, and operational trial on an NTS unit to determine unit availability has been planned. As the performance trials are ongoing, an interim summary report is provided within **Appendix H.**

- Selective Catalytic Reduction (SCR). Exhaust gas NO_x levels are reduced through the use of ammonia injection and a catalyst. A report on the feasibility of the use of SCR technology across the NGGT compressor fleet was produced by [redacted] in 2017, which was updated and revised by consultant [redacted] in June 2022, see **Appendix I**.
- This project has no impact on planned investments at other compressor stations on the network.

69. To support our Option Section process we have developed a detailed Reliability Availability Maintainability (RAM) model which has evaluated unit availability across the entire NGGT fleet. This study was developed in collaboration with [redacted]. An overview of the RAM model and how it has been applied and used in the CBA is in **Appendix K,** and an overview can also be found in CE-AMP[22]. In addition to this, NGGT are also developing a Network Capability and Resilience model with [redacted], where South Wales was used as the Proof of Concept. This highlighted the need for investment to increase the zone's capability. See **Section 4** for more detail on Annual Network Capability Assessment Report (ANCAR) 2022.

70. An updated version of our Compressor Emission Compliance Strategy (CECS), that was released to support our 2019 RIIO-T2 Business Plan, has been produced. CE-AMP (Compressor Emissions Asset Management Plan) supports this and our other MCPD FOSR submissions. CE-AMP outlines our approach to how our compressor fleet will comply with the emissions legislation, including units to be decommissioned, derogated, retrofitted with emissions abatement technology, and replaced with new units.

[22] CE-AMP Appendix F - Process

3.2. Project Boundaries

71. The scope of this project is delivery of emissions compliant compression which meets forecast network capability requirements. For Wormington, these are costs associated with construction of two new gas-driven compressor units and re-wheeling of the VSD driven compressor. Other costs such as ongoing asset health costs, decommissioning of redundant compressor units post 2030 and operational running costs for the existing units and site are included in the CBA, although we will not request funding for these through the planned Re-opener submission in November 2024.

72. Decommissioning costs for redundant compressor units are included within this option selection report to inform overall decision making. However, a request for decommissioning funding will not be included within the 2024 cost Re-opener as decommissioning investment will be reassessed once the new units have been operationally accepted, and if required requested as part of the RIIO-T3 decommissioning business plan.

73. The WGN project and its associated investment activities are not included in this project.

74. As detailed within **Section 3.1**, asset health investment which is already funded as part of our RIIO-T2 business plan is not included within this report. This includes station and Unit C control system replacement and Unit A and B ventilation systems.

4. Project Definition

4.1. Expected Flows and Site Operation

75. The details in the following section are drawn from the Needs Case which is based on the analysis undertaken in support of our 2019 RIIO-T2 business plan submission to Ofgem. The information within the needs case has been updated and refined to support the FOSR. Ofgem accepted the Needs Case to retain compression capacity at Wormington as part of their RIIO-T2 Final Determinations in December 2020. As such the Needs Case was established in our RIIO-T2 Business Plan and has not been issued in a separate Needs Case document. The associated Annex A16.10 Wormington Compressor Engineering Justification Paper dated December 2019 also informs the Needs Case and was issued as part of the NGGT Business Plan Submission.

Supply and Demand Scenario Discussion and Selection

76. To fully assess the project, a network assessment to define the capability boundaries was completed. The output from this was used in a risk and constraint assessment to define the associated constraint costs. For more information on how capability boundaries are produced, refer to ANCAR 2022[23].

77. FES 2018 was originally used for this and our other RIIO-T2 submissions. This FOSR has used FES 2021 data, as this was the most recently available FES. FES 2022 was published on 18 July 2022, giving insufficient time to make use of the FES 2022 data to update network models, carry out network analysis and subsequently update the associated CBAs in time for issue of this FOSR. FES 2021 data will be used for our other UM submissions to maintain consistency.

78. The gas landscape has changed considerably in the last 20 years. With the continued decline of UK Continental Shelf (UKCS) supplies and the need to decarbonise, NGGT expects gas supply and demand patterns to continue to change going forwards. There are many factors which create uncertainty on the extent and speed of change. Given this uncertainty, it is impossible to forecast a single energy future over the long term. FES is updated and published annually by National Grid ESO in July. These scenarios are created using National Grid ESO's own analysis and input from stakeholders across the energy industry.

79. For FES 2020 the published scenario framework was updated (see **Figure 4** below), with net zero targets included. This framework was continued for FES 2021.

[23] https://www.nationalgrid.com/gas-transmission/insight-and-innovation/network-capability

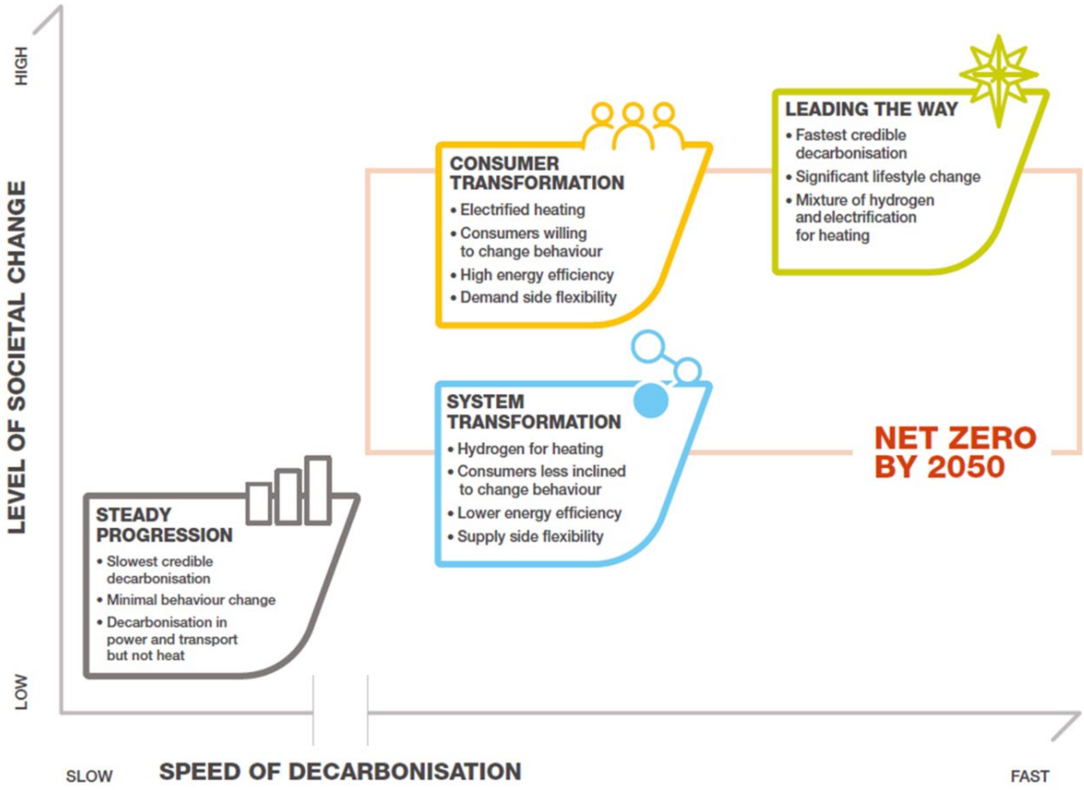


Figure 4 - FES 2021 Scenario Framework

80. The four FES scenarios as described in the National Grid ESO Future Energy Scenarios[24] provide different pathways to a net zero future. These range from the Steady Progression (SP) scenario, that falls just short of the net zero target, to Leading the Way (LW) which achieves net zero ahead of 2050. Each scenario is dependent to varying degrees on a series of changes to; government policy and legislation, energy delivery and consumption, consumer behaviour, technological change, and government incentives and investment. In many ways these different pathways, also represent different potential extremes of energy industry change. As such, FES on its own provides no validation of the most appropriate investment option, instead it provides a broad envelope of energy backgrounds against which the merit of alternative investments may be appraised.

81. The two low natural gas scenarios (Customer Transformation and Leading the Way) meet the targets via electrification either at a transmission or distribution level and involve changes in consumer behaviour and high improvements in energy efficiency. The use of hydrogen is considered in Leading the Way (LW) and System Transformation (ST) scenarios. With LW hydrogen is produced from green sources only and with ST from a combination of green and blue sources, which is the reason for the high long term natural gas need for ST. In many ways, ST is the most balanced scenario with a mixture of electrification, conversion to hydrogen and increased energy

[24] https://www.nationalgrideso.com/future-energy/future-energy-scenarios

efficiency and demand lead consumption. The Customer Transformation scenario features a supply led consumption. With ST, there is less consumer behaviour change and lower energy efficiency with hydrogen providing significant space heating energy.

82. Considering the factors discussed above, we have used the System Transformation scenario as the base case scenario for this FOSR as it provides an appropriate central case for Wormington's expected range of operation. Sensitivities have also been applied against the other three scenarios.

Key Flows and boundaries

83. **Figure 5** shows the peak 1-in-20 peak diversified demand for each of the FES 2021 scenarios, demonstrating that there are a wide range of potential demand scenarios between now and 2050. The Steady Progression (SP) scenario has the highest gas flows, but there are also very significant gas flows for the System Transformation (ST) scenario. Comparing SP with Leading the Way (LW) in 2050 the projected range of peak demand varies between just below 5000 GWh/d for ST, compared to close to zero for LW.

84. Gas flows are much lower in the Consumer Transformation and Leading the Way scenarios, as there is a move away from natural gas use in achieving the net zero target in 2050. These are the most ambitious scenarios with the reductions seen between now and 2030 driven by reductions in heat demand. For the last 5 years the level of reduction characterised in these scenarios has not happened and is unlikely to occur until suitable incentives are in place. A more detailed review of the FES 2021 can be found in CE-AMP.

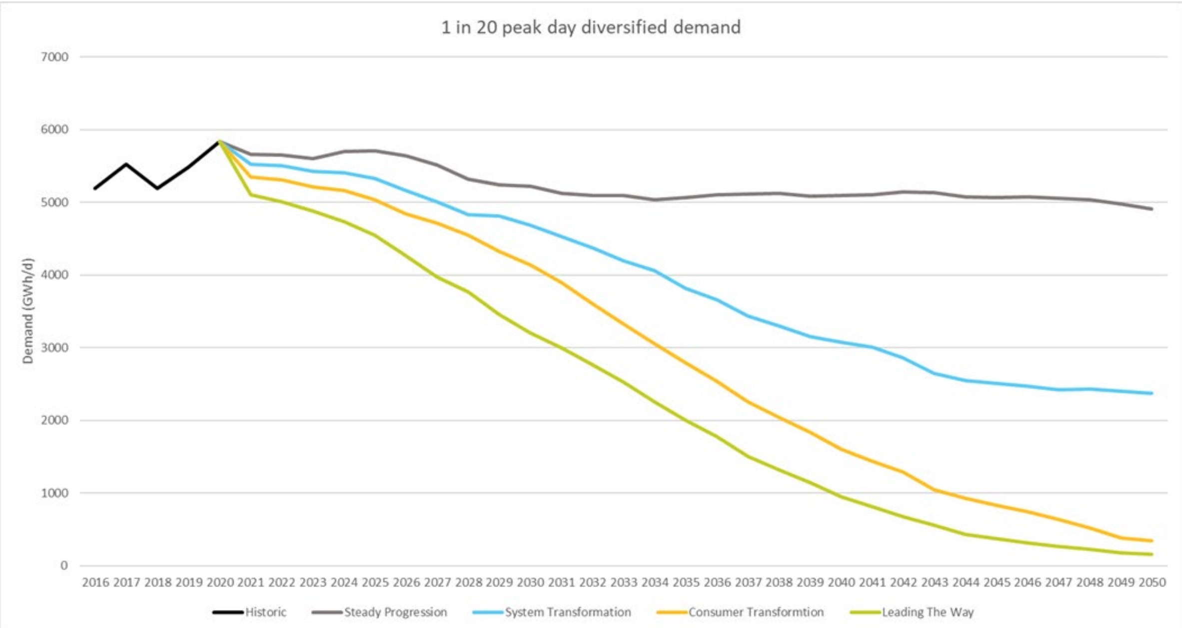


Figure 5 - Peak 1-in-20 diversified demand for each of the FES 2021 scenarios

85. **Figure 6**, **Figure 7**, **Figure 8** and **Figure 9** below show the distribution of gas supplies for each of the four FES 2021 scenarios together with the percentage import dependency. Although the overall supply varies between scenarios, in most cases the dependency on imports increases over time, with an increasing dependence on LNG /

Generic imports[25]. It is difficult to predict the impact of supplies from Europe in 2030 but we are likely to see the majority of that import dependency needing to be met via LNG.

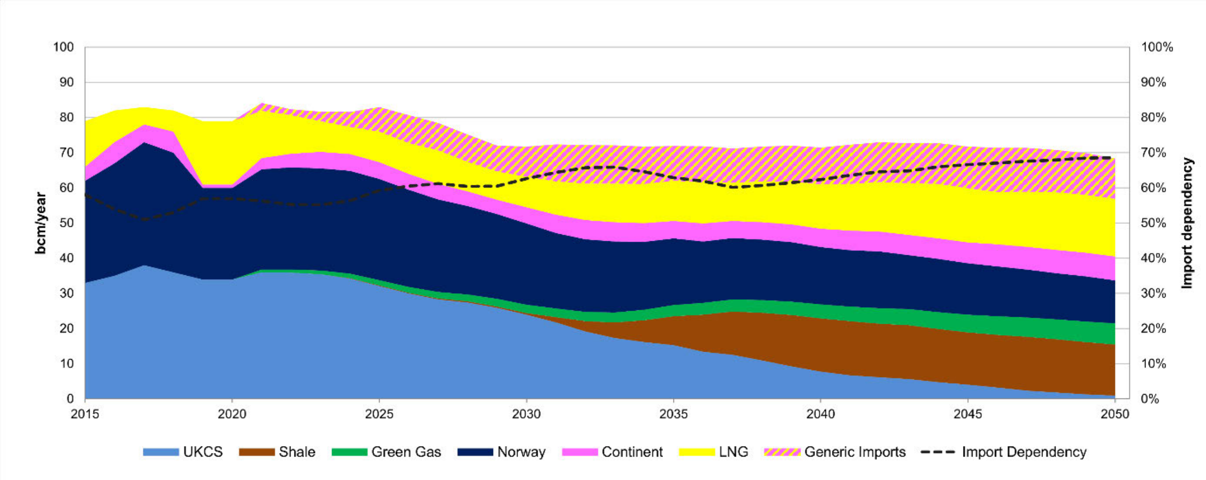


Figure 6 - Steady Progression: FES 2021 Annual gas supply and Import dependency

86. For Steady Progression scenario both overall supply and import dependency are high until 2050. In 2030 import dependency is estimated to be 63%.

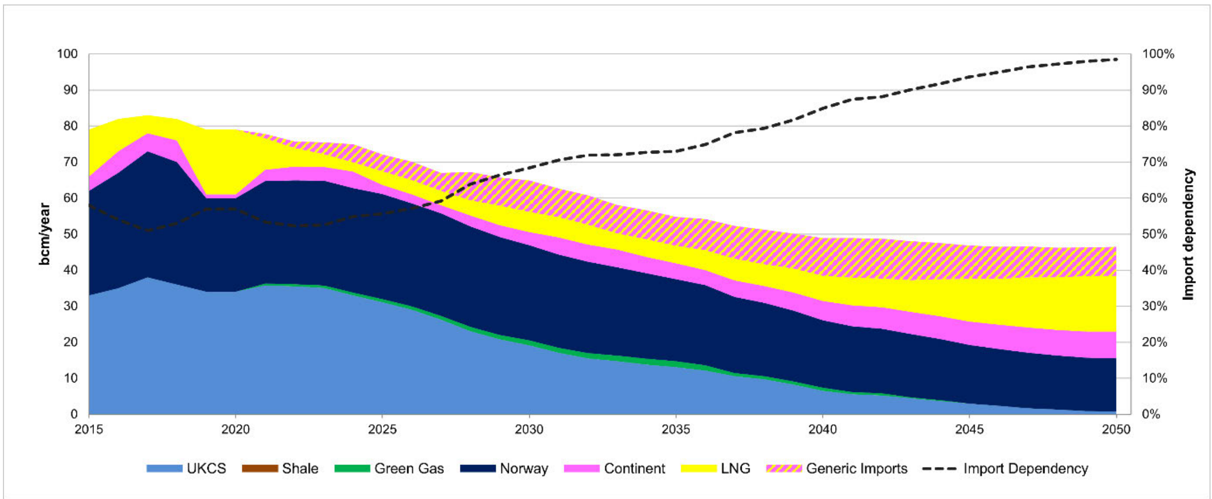


Figure 7 - System Transformation: FES 2021 Annual gas supply and Import dependency

87. For System Transformation scenario overall supply is high and import dependency is projected to be towards 100% by 2050. In 2030 import dependency is estimated to be 68%.

88. The above two scenarios demonstrate the potential continued importance that imports via Milford Haven will continue to have post 2030 and into the foreseeable future.

[25] In FES, generic imports comprise both LNG and continental imports to ensure balancing of supply and demand in the model, and also that import terminal maximum capacities are not exceeded.

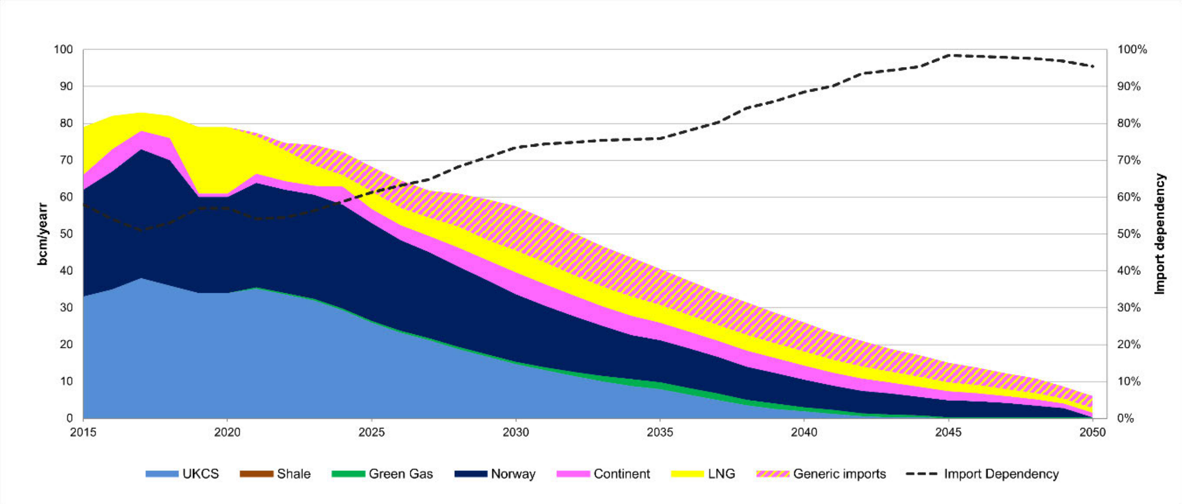


Figure 8 - Consumer Transformation: FES 2021 Annual gas supply and Import dependency

89. For Consumer Transformation scenario overall supply reduces to low levels by 2050, although the import dependency is projected to be towards 100% by then. In 2030 import dependency is estimated to be 73%.

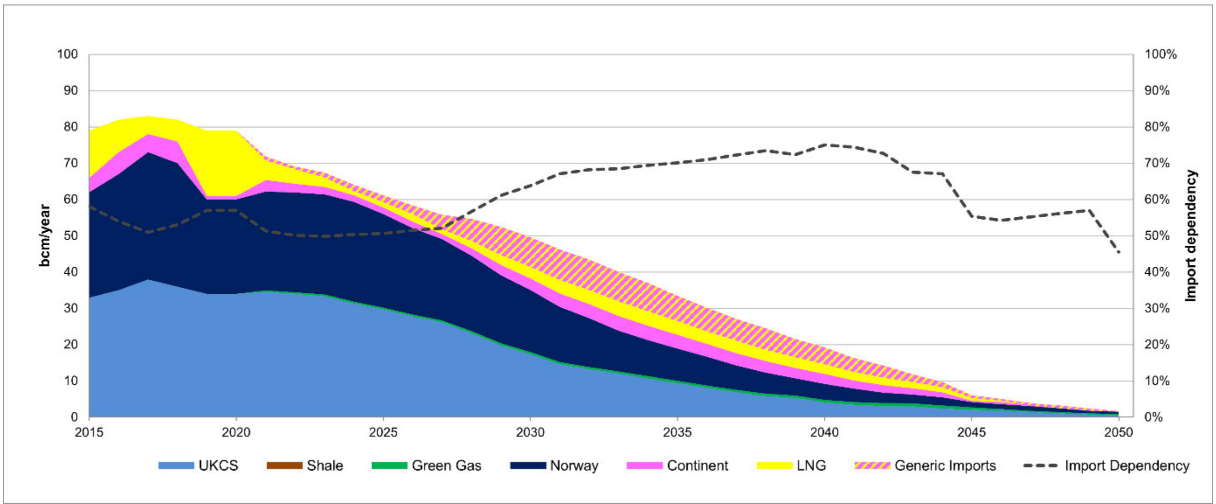


Figure 9 - Leading the Way: FES 2021 Annual gas supply and Import dependency

90. For Leading the Way scenario overall supply is low by 2050, with corresponding low import dependency for the small level of gas supply still remaining for the scenario. In 2030 import dependency is estimated to be 64%.

91. Imported LNG entering at the Milford Haven terminal is routed through South Wales along Feeder 28, proceeding into the Midlands, North and the South West. Entry capability is facilitated by compression at Felindre, Wormington and Churchover, and is also impacted by the demand in South Wales. When demand in South Wales is low, there is a greater need for LNG entering at Milford Haven to be transported away from South Wales, increasing the requirement for compression at Felindre, Wormington and Churchover. The trend over time is for reducing demand in South Wales which means that in the future the expectation is that there will be greater flows through each of these

compressor sites towards the areas of demand, leading to an increased requirement to operate these compressors.

Current Operation

92. Wormington Compressor Station is critical in supporting NTS gas entering through the Milford Haven terminal and utilisation is likely to remain high over a wide range of network conditions as shown in the flame charts in **Figure 12**, **Figure 13** and **Figure 14** below. Due to bi-directional flow capabilities, it is also used to support the extremities in Wales when Milford Haven terminal inputs are low and Churchover is on outage.

93. The electric drive (Unit C) has become the lead unit onsite since its commissioning, accounting for most of the run hours. The unit is limited to 50 mscm/d and would not be able to meet obligated entry levels from the Milford Haven terminal on its own, and currently relies on parallel operation with the existing GT units.

Compressor Utilisation

94. The annual (financial year) running hours of the three units are shown in **Figure 10**. Changes in the level of run hours are due to changes in the supply level at Milford Haven terminal. For example, running hours in 2015/16 were associated with higher supplies, leading to a need for compression to move gas out of South Wales; whereas the high run hours in 2017/18 were associated with low supplies requiring Wormington Unit C to support South Wales demand. The running hours in 2019/20 and 2020/21 show a significant increase over previous years, with parallel running of units required more often, due to increased supplies at Milford Haven terminal.

	Individual Unit Running Hours (financial year)							
	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
Wormington Unit A	27	32	26	145	12	11	418	567
Wormington Unit B	58	27	67	190	23	19	29	198
Wormington Unit C	1048	1381	1873	968	2121	788	2631	2242
Total	1133	1440	1966	1303	2156	818	3078	3007

Figure 10 - Run Hours – as reported in the Regulatory Reporting Pack

95. The predicted hours, as seen in **Figure 11,** are driven by the Future Energy Scenarios which are primarily driven by long-term supply/demand balances, rather than shorter term market trends. As such the running hours at the start of the period are towards the lower end of the historical dataset. It is not until the later years that we see running at the levels seen over the last two years.

96. To ensure our decision is robust we run sensitivities in the CBA to test the impact of higher levels of LNG in the earlier years.

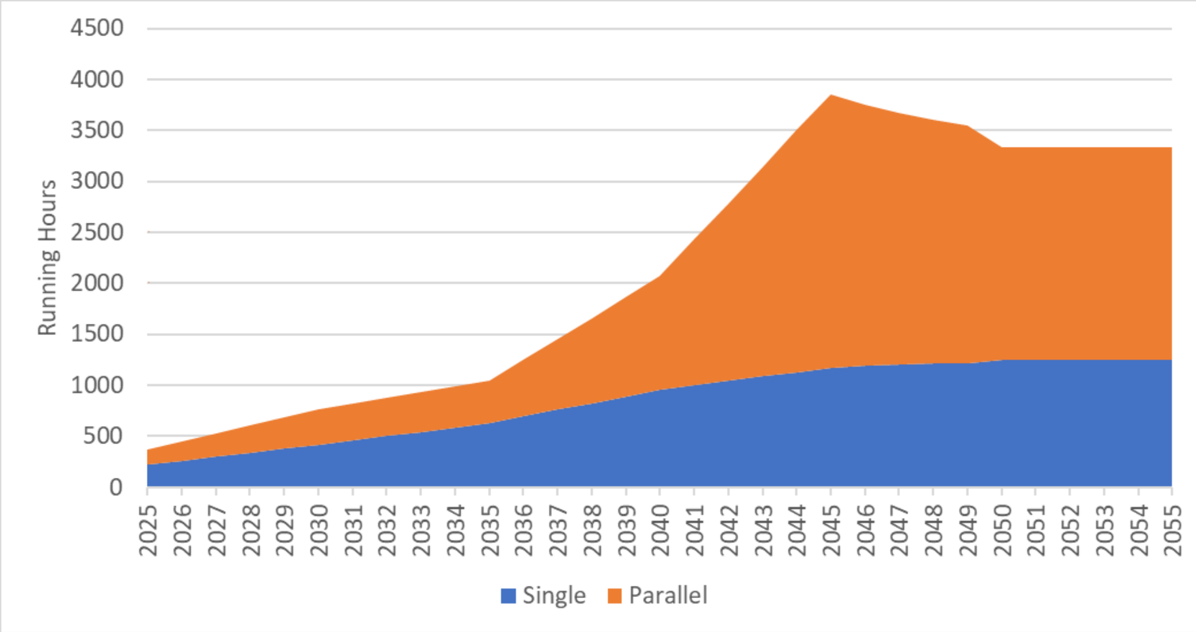


Figure 11 - Predicted Running Hours System Transformation

4.2. Capability and Availability

Network Capability

97. The network analysis has been carried out using our capability analysis process which has been developed to assist in defining the capability of the NTS. The capability analysis results are shown in the form of 'Flame Charts' in **Figure 12**, **Figure 13** and **Figure 14** below. Further details of the capability analysis process and the creation of the Flame Charts are given in our annual publication Gas Ten Year Statement (GTYS) 2021[26], and in our annual ANCAR[27] statement.

98. The Flame Charts contain dots plotted onto the chart where one dot is associated with one day in that year, and for every day there are 7840 alternative supply and demand patterns across the four FES scenarios and associated high and low LNG sensitivities[28]. The frequency of a particular flow point is represented by the colouring on the chart, as defined in the chart key. Charts are shown for years 2030 and 2040 showing how we expect supply and demand patterns to change over time, covering the period of focus for the CBA analysis.

99. Analysis and CBA Assessments of the options for Wormington, for both FES 2021 flows and for the WGN PARCA flows, have been carried out. In **Figure 12** and **Figure 13** below are the flame charts showing both circumstances.

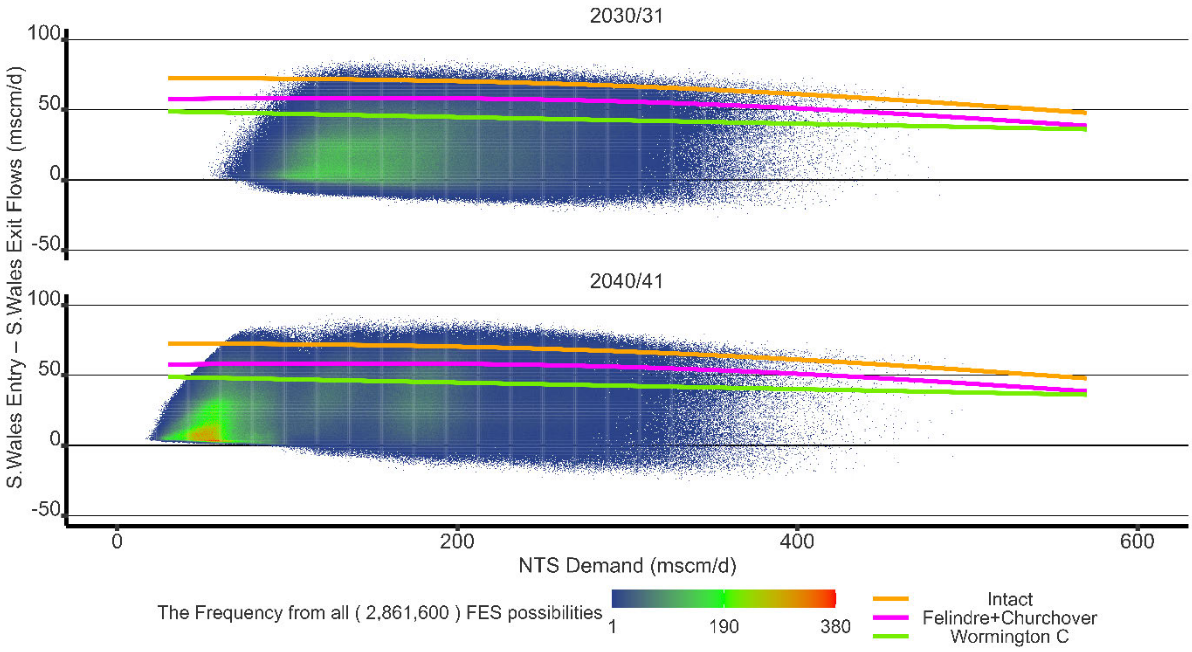


Figure 12 - South Wales Entry flame charts for the years 2030/31 and 2040/41 - FES 2021 with WGN PARCA Flows

[26] https://www.nationalgrid.com/gas-transmission/insight-and-innovation/gas-ten-year-statement-gtys
[27] https://www.nationalgrid.com/gas-transmission/insight-and-innovation/network-capability
[28] Within each FES scenario, sensitivities for high continental and high LNG imports are also included, and these are included in the flame charts in this section.

100. **Figure 12** above shows boundary lines for forecast FES 2021 flows at Milford Haven including the WGN PARCA flows. It shows the expected level of capability which would be maintained most of the time based on compressor availability estimates.

101. The upper orange line is the intact condition with all compression available (Felindre, Wormington parallel configuration and Churchover). With full availability of compression there is capability to deal with most of the expected flows, although there are some flows above the intact boundary line in both 2030 and 2040.

102. The middle pink line shows just Felindre and Churchover operational, this is the level of capability we can meet if we do not have parallel units at Wormington available.

103. The lower green line is the capability provided by a single unit at either Felindre, Wormington or Churchover (lower demand levels only). Demonstrating the level of capability we can provide with only a single station available out of Felindre, Wormington and Churchover.

104. In summary, the pink and green lines show the capability we can provide with different combinations of sites in operation. The options considered in this FOSR that retain the highest availability levels will be more resilient and spend less time at these lower capability levels resulting in lower constraint costs.

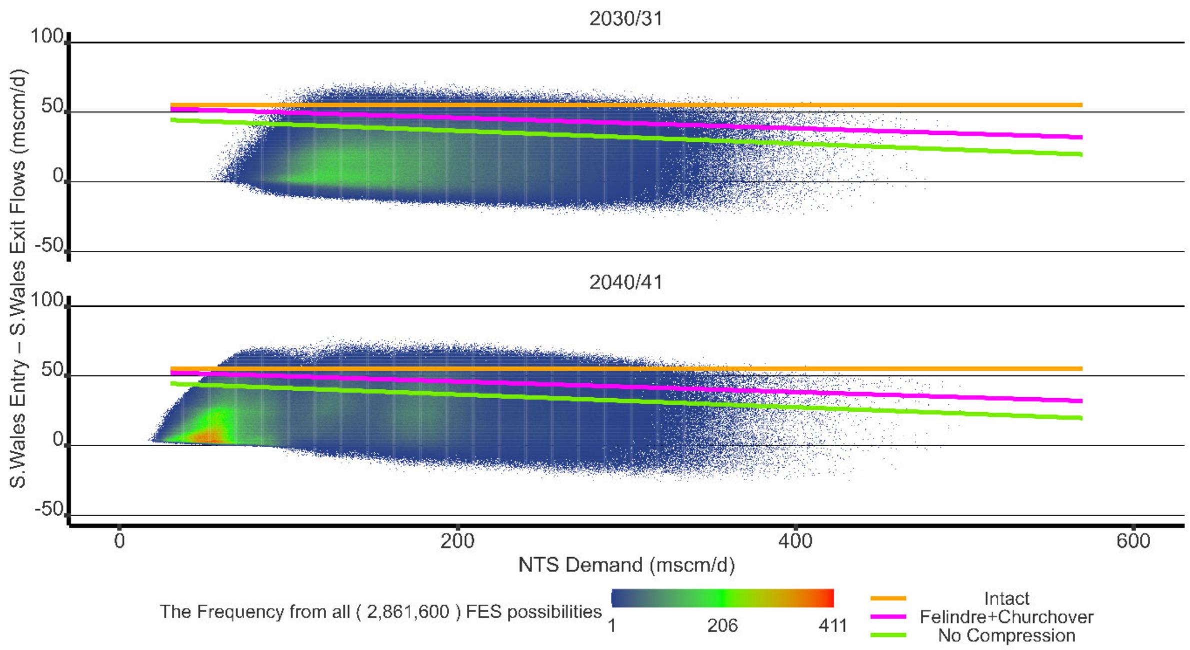


Figure 13 - South Wales Entry flame charts for the years 2030/31 and 2040/41 - FES 2021 Flows

105. **Figure 13** above shows boundary lines for forecast FES 2021 flows at Milford Haven, excluding the impact of the PARCA application. It shows the expected level of capability which would be maintained most of the time based on compressor availability estimates.

106. The upper orange line is the intact condition with all compression available (Felindre, Wormington in parallel and Churchover). With full availability of compression there is capability to deal with most of the expected flows, although there are some flows above the intact boundary line in both 2030 and 2040.

107. The middle pink line shows the capability we can provide when parallel operation is not availability at Wormington. We can achieve this capability with either Wormington single unit or Felindre and Churchover together.

108. The lower green line shows the capability we can provide with no compression available at Felindre, Wormington or Churchover.

109. In summary, the pink and green lines show how our capability changes based on different levels of compression. Options in this FOSR with the highest level of availability will spend more time at the intact capability and less time at the lower capability levels resulting in lower constraint costs.

110. **Figure 12** and **Figure 13** above show how the entry capability of the network in South Wales is reduced if two units at Wormington are not available to operate in parallel. It compares the capability of Wormington Compressor Station to move gas away from the terminal against our forecasts of entry supplies through the Milford Haven terminals and exit demands between the terminal and Churchover Compressor Station under the four FES 2021 scenarios.

111. This illustrates the significant potential disruption to customer entry flows when Units A and B are not available to operate in parallel. This could be due to either planned or unplanned outages, or limits on running hours if a derogation has been applied. The entry capacity constraint costs associated with this reduction in capability have been included in our CBA assessments of the options for Wormington, for both 2021 FES flows and for the WGN PARCA flows.

112. It should be noted that we are currently unable to support baseline level flows when LNG imports via Milford Haven are very high (typically spring and summer months), with the risk of constraints increasing over time even with Units A and B available. This is caused by network constraints further into the network than Wormington compression station and is outside the scope of this project.

113. The occurrence of LNG imports at Milford Haven have historically tended to occur in spring and summer. The drivers for LNG imports are commercially driven with the international LNG market gravitating towards the most favourable LNG prices. This has typically meant low UK LNG imports when the Asian markets have their highest demand. As a result there is little certainty during the year when LNG imports into GB will occur, however with UKCS imports declining, the trend currently is for increasing LNG imports. Currently European countries are aiming to reduce the import of Russian sourced gas supplies, leading to an increase in LNG imports to the continent, including LNG being routed via Milford Haven and then exported to the continent from Bacton via the interconnectors. This arises due to the limited LNG importation facilities on the continent. It is expected that this will continue in the short term, although there remains uncertainty about how this will develop over the long term.

114. Over the next 20 years, UKCS supplies will continue to decline. In some scenarios, this supply is replaced through the development of other indigenous sources such as; shale gas, biomethane and bio-substitute natural gas (bioSNG). This is seen in particular in the FES Steady Progression scenario, which is the only scenario with shale supplies and is also the scenario with the greatest supply of biomethane and bioSNG (green gas). However the volume of these supplies is small in comparison to overall supplies, and some of these may connect either to the NTS or to the distribution networks. In three out of four scenarios, these are insufficient to meet demand and therefore imported gas will become more important. These imports could be from continental Europe or as LNG.

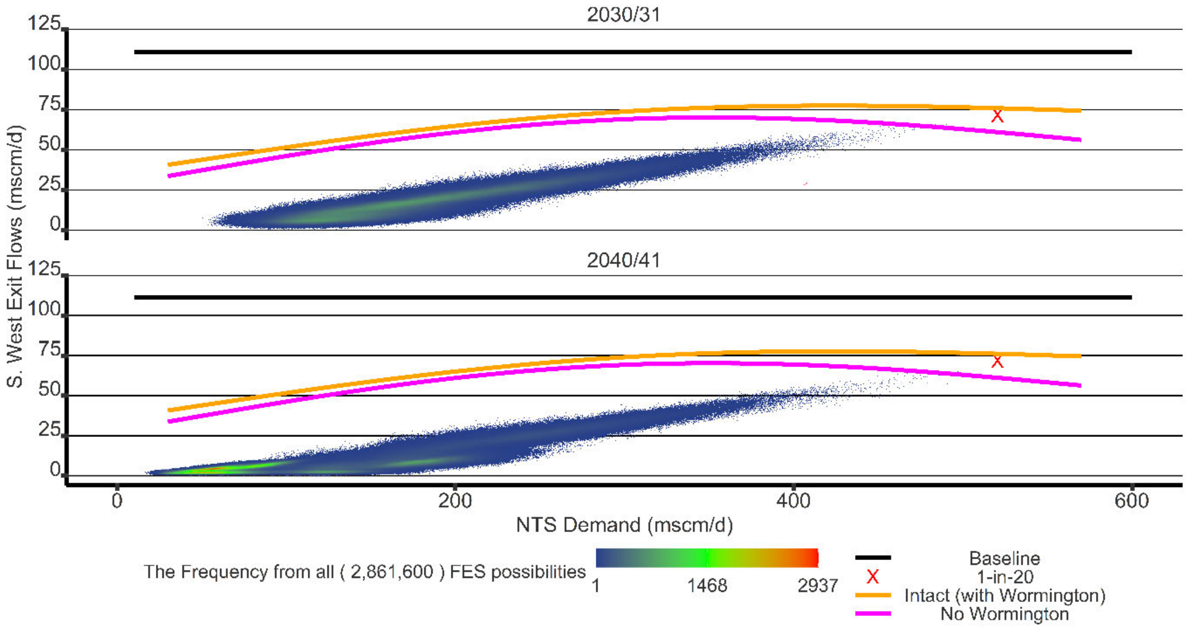


Figure 14 - South West Exit flame charts for the years 2030/31 and 2040/41

115. **Figure 14** above shows the exit flame chart for the Southwest for years 2030/31 and 2040/41. With no entry sites in the Southwest, except for a small contribution from storage, the capability to deliver offtake exit flows in the Southwest is influenced by the availability and use of Wormington Compressor Station. The orange line shows the fully intact network capability, including the use of Wormington, and shows all expected exit scenarios for the Southwest being achieved, including our 1-in-20 security of supply obligation (notated by the red cross). The pink line shows that without the use of parallel units at Wormington the network would not be compliant with the 1-in-20 security standard.

Compressor Availability

116. The compressor availability, **Table 9** used in our assessment has been based on the RAM model developed in collaboration with [redacted]. An overview of the RAM model and how it has been applied and used in the CBA is in **Appendix K**, and an overview can also be found in CE-AMP.

Unit	Train Type	Availability used in Prelim CBA	Aligns with RAM Scenario
Unit C Base Availability	VSD	81.70%	Base
Unit C Availability (Enhanced)	VSD	86.60%	V1
Avon Base Availability	Avon	62.40%	Base
Avon Availability (Enhanced)	Avon	79.50%	A3
DLE Availability 1533/1535	Avon	74.50%	A3
Avon availability with CSRP	Avon	79.50%	A3
Avon availability with SCR	Avon	79.50%	A3
New Unit availability (assume new Solar Titans)	Solar Titan	90%	N/A

Table 9 - Compressor Availability

117. Availability for Wormington MCP is based on the likely scenarios from the RAM study that represents the interim investments that would be made for the proposed option.

118. [redacted]

119. The CSRP option uses the same scenario and investments as this is limiting peak temperature and NO_x emissions on the same unit so expect no operational reduction

120. Avon DLE assumes a 5% reduction on the same A3 scenario reducing availability to 74%. It would undertake the same investments, but the technology is unproven in operation and is likely to see commissioning and design issues in the short to medium term and also the possibility of this not becoming a viable long-term solution with cost and capital outages needed to return the berth to a standard Avon with optional CSRP. The p10 of the range for the A3 scenario is 69% so this is comfortably within the lower range for the scenario.

121. [redacted]

122. For each option the site availability is defined based on the compressors required to meet the required capability and the availability of the compressors on site for that option. This availability is then adjusted to account for any 500-hour restrictions which may apply, these are calculated for each scenario every five years. These are detailed further in **Appendix B**.

Summary

123. The Needs Cases to retain compression capacity at Wormington was established in our RIIO-T2 Business Plan, using FES 2018 data. Updates for this FOSR have used FES 2021 data and associated scenarios.

124. The FES 2021 scenarios show a wide range of potential flows across the four scenarios. We have used the System Transformation scenario as the base case for this FOSR as it provides an appropriate central case for Wormington's expected range of operation. We have also included sensitivities to the analysis against the other three scenarios. Current market trends and levels of actual supply/demand indicate that Customer Transformation and Leading the Way scenarios can be considered ambitious and that a strong reliance on gas is likely beyond 2030, as detailed in CE-AMP.

125. Analysis and CBA Assessments of the options for Wormington, for both 2021 FES flows and for the WGN PARCA flows, have been carried out. Flame charts have been created to show the range of potential flows arising from the FES 2021 scenarios. The flame charts include capability lines for a range of compressor configurations, from which it can be seen the importance of maintaining full capability at Wormington. From the flame chart showing exit capability in the South West, our 1-in-20 security of supply obligation cannot be met where Wormington parallel operation is not available.

126. The analysis demonstrates the importance of the Wormington site in terms of ensuring expected flows can be accommodated. Due to bi-directional flow capabilities, Wormington is a critical site to support the offtakes in South Wales when demands are higher than Milford Haven inputs. The South West is also supported by Wormington's ability to move gas from Milford Haven south to the demand extremities in the South West. Wormington is a critical site in supporting a 1-in-20 peak demand scenario, and to ensure consumers will be able to take gas on and off the system where and when they want providing the necessary energy needs for domestic, commercial and industrial use.

127. If Wormington capability is curtailed, the flame charts demonstrate this will lead to network constraints, resulting in higher gas prices and a reduction in security of supply. Due to Wormington's critical location on the network, reliable and available compressors are required to minimise constraints, and maintain network capability.

4.3. Project Scope Summary

128. Our Final Preferred Option is for two new units at Wormington to achieve emissions compliance, maximum resilience, long-term site availability and support to a wide range of Milford Haven and South-West flows, particularly relevant given the recent entry capacity increase request from South Hook Gas at the Milford Haven terminal. **Table 10** provides a summary of the project scope.

Final Preferred Option	Two New Gas Driven Compressor Units		
Location	Greenfield		
Unit Investment Details	Unit C	Unit D	Unit E
Investment Action	Compressor Re-Wheel	New Build	New Build
Year of Commission	2009	2028	2028
Size[29]	15MW	~15MW	~15MW
Type of unit	VSD	GT	GT
Scope Boundaries	The scope of this project is for costs associated with the implementation of MCPD emissions compliance. At Wormington, these are costs associated with building two new units (incl. Unit C re-wheel). Decommissioning the existing two non-compliant units will be considered once the new units are operational. Two new units are recommended to be located on a greenfield[30] site which is partially outside of the existing site boundary but still within National Grid owned land.		
Station Design Discharge Pressure	75 barg		
Station Suction Trip Pressure	38 barg		
Availability Required	The optimum level of availability is determined by the cost benefit analysis.		
Supply & Demand Scenario	All four supply and demand scenarios, FES 2021, were detailed as part of the scope to examine the effectiveness of each investment option against a wide envelope of future energy backgrounds. WGN PARCA flows are also included within our CBA assessments for Wormington.		

Table 10 - Wormington Project Scope Summary

[29] Unit size will be appropriately sized to meet capability requirements. To be determined during tender event.

[30] See **Section 5.1** for more information.

5. Option Selection

5.1. Options Considered

Introduction

130. As part of NGGT's RIIO-T2 submission in December 2019, we proposed to install two new, gas-driven compressor units and to decommission the existing Avon units ahead of 2030, following operational acceptance of the new units. However, as part of Final Determinations, Ofgem recognised that there was still uncertainty around the final solution and therefore provided funding to continue project development.

131. The options described within the Wormington Engineering Justification Paper (EJP) that supported the RIIO-T2 business plan have been investigated in more detail as part of this Option Selection process including previously discounted solutions and new emission abatement technology. As outlined previously in detail within **Section 3** NGGT have considered the full suite of solutions to enable Wormington to comply with the MCPD.

132. This section focuses on the engineering options and commercial rules and tools available to solve the problem described in **Section 3.1** and uses the project scope in **Section 4** to generate plausible engineering solutions. This section will describe the option selection process used to identify the Final Preferred Option for this investment, starting from option identification, through option development to option selection. **Figure 15** below serves to identify the various stages involved in a typical option selection process.

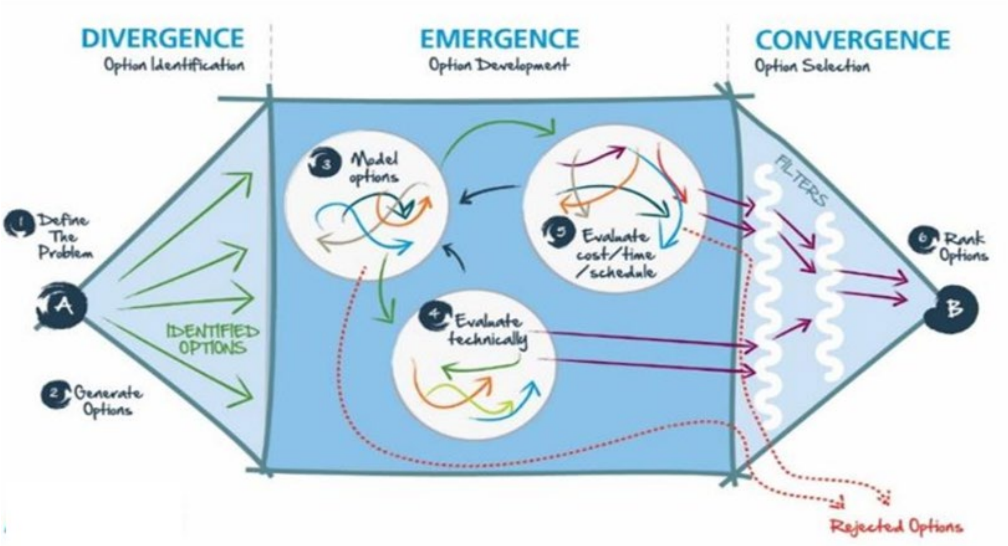


Figure 15 - Generic Options Selection Process

Options Interaction with CBA & BAT

133. The options considered for MCPD compliance are evaluated in a CBA and also in a BAT assessment. The CBA compares the costs of installation and maintenance of new units, existing units, emissions abatement technology, and a combination of these. The constraint costs associated with the differing levels of capability and availability under each of these options manifest as disbenefits feeding into the CBA to arrive at the lowest overall cost to consumers, represented by the option with the highest positive NPV.

134. NGGT is legally bound under the Industrial Emissions Directive to comply with the requirements of BAT in respect of its GT compressor installations on the NTS. The BAT assessment methodology, which was developed by NGGT in discussion with the EA and SEPA, is a stepwise process underpinned by an environmental cost-benefit analysis methodology, which draws together environmental and operational priorities to support decision making. The Preliminary[31] BAT assessment, led by [redacted] ([redacted]), was undertaken separately from the CBA using a different methodology; it does however incorporate common assumptions on cost (incl. constraint costs) and future gas supply predictions. For more information on the BAT process and result, see **Appendix G**.

Ofgem FOSR Pre-Engagement

135. Robust and regular engagement is essential to bring internal and external stakeholders along on the investment journey. We have prioritised monthly touchpoints with Ofgem to update them on our investment progress, outline the next steps and seek their feedback on any gaps or technical challenges we have discovered. The following is a series of Ofgem engagements which have influenced the Options Selection process for Wormington:

- 26th July 2022: Avon DLE progress, FES 2021 review & Wormington BAT update
- 23rd June 2022: Wormington Investment Deferral Sensitivity Review
- 7th June 2022: General compressor NO_x emissions, Wormington Needs Case, BAT Update & Preliminary CBA Results
- 3rd May 2022: Wormington FOSR structure review, general Wormington progress update, CBA/BAT interface presentation
- 1st April 2022: Reliability, Availability and Maintainability (RAM) model
- 22nd March 2022: Avon DLE/CSRP initial results & Options shortlisting
- 25th January 2022: High level programme review to consider inputs from Avon DEL/CSRP studies, decision to move FOSR submission from May 22 to August 22

[31] Final BAT will be part of the permit variation submission. For New Units, the BAT is also part of the tender process for new units under T/SP/ENV/21 and the Strategic Sourcing Process

Initial Option Selection & Justification

136. In November 2021, NGGT selected an Option Selection Consultant, [redacted], to support us in quantifying and evaluating the feasibility of our potential investment solutions. In consultation with [redacted], NGGT have considered the full suite of solutions to enable Wormington to comply with MCPD including:

- Investing the absolute minimum to improve the site (counterfactual), where Units A and B are derogated to run only 500 hours per year from 2030
- delaying our investment decision, to account for uncertainties in the energy landscape
- retrofit or modification of our existing compressors with emissions abatement technology to enable them to comply with the MCPD
- building new low-emission, more efficient gas-driven compressors or VSD units

137. NGGT assessed the full range of options above via an engineering study led by [redacted] and supported by other specialist contractors. The complete list of all solutions considered is provided in **Table 11**. This table also includes detail on the solutions which have been discounted from further investigation and the solutions that have been shortlisted. Further detail on how each investment solution has been considered during option selection is provided in the following pages. Please see **Appendix C** for more information on the option evaluation methodology used.

Investment Solutions	**Assessed**	**Option & Compressor Unit Reference Or Option Discounting Justification**
Derogation 500-hours Derogation	✓	Option 1 "Counterfactual[32]" (Units A & B) Option 4 (Unit B) Option 7 (Unit A)
Emissions Abatement[33] Control System Restricted Performance	✓	Option 2 (Units A & B) Option 8 (Unit A)
Emissions Abatement Selective Catalytic Reduction (SCR)	✓	Option 3 (Units A & B)
Emissions Abatement Dry Low Emissions (DLE) technology retrofitted to Avon's	✓	Option 4 (Unit A – 1533) Option 5 (Units A & B – both 1533) Option 6 (Units A & B – both 1535) Option 9 (Unit A - 1533)
Decommissioning[34] Disconnect & Decommission Avon once alternative solutions are commissioned	✓	Option 7 (Unit B) Option 8 (Unit B) Option 9 (Unit B) Option 10 (Unit A & B)
Deferral[35] Option Deferral	✓	Included as a CBA sensitivity
New Build – Total Site Units (>2)[36]	✓	Option 7 (Unit D) Option 8 (Unit D) Option 9 (Unit D)

[32] See 138 for additional information on assessment of the counterfactual
[33] See 139 for additional information on assessment of emissions abatement technologies
[34] See 140 for additional information on how decommissioning is been considered within options selection
[35] See 141 for additional information on how investment deferral
[36] See 142 for additional information on new build investment considerations

New Gas Turbine Compressors, decommission Avon's once new units are operational. Three or more units available across site.		Option 10 (Unit D & E)
<u>VSD Modification</u> VSD Re-Wheel[37]	✓	Option 3 (Unit C) Option 6 (Unit C) Option 7 (Unit C) Option 8 (Unit C) Option 9 (Unit C) Option 10 (Unit C)
<u>Commercial Actions</u>[38] Commercial contracts to manage constraints and to ensure compliance with 1-in-20 obligations	✓	Contracts not required to ensure 1-in-20 compliance. Value of entry constraint calculated for all options.
<u>New Build – Total Site Units (2)</u>[39] One Gas Turbine Compressor, decommission Avon's once new unit is operational. Total of two units available across site.	✗	Ruled out due to fact that having only one unit as back-up to VSD does not provide any resilience in case of planned/unplanned outages.
<u>New Build – Dual VSD</u>[40] Two new 15 MW Electric Drive Compressors, decommission Avon's once new units are operational.	✗	Wormington's lead unit is an electric drive; therefore, additional electric drives are not considered for network security and reliability reasons. Our principle is that backup to electric drives will be through gas turbine units for network security and continued supply in the event of loss of electricity supplies. Further context on this is provided below.
<u>New Build – Single Large VSD</u>[41] One new 30 MW Electric Drive Compressor, decommission Avon's once new unit is operational.	✗	
<u>Emissions Abatement Mixing</u> Combinations of abatement technology (SCR + CSRP, etc.)	✗	A mix of abatement technology would add significant complexity from operational & maintainability perspective for very little benefit. Abatement solutions have been considered individually and combined with new units for greater flexibility.

Table 11 - Full List of Investment Solutions

138. In order to evaluate the impact for no further investment at Wormington, NGGT have included the "counterfactual" or "do minimum" investment option in our CBA **[Option 1; Table 12]**. It should be noted that while the counterfactual option considers no additional capital investment, asset health investment is still necessary to ensure reliable unit operability beyond 2030. Should no investment be made to achieve MCPD compliance by 1 January 2030, Units A and B will fall into Emergency Use Derogation (EUD) where they will be limited to 500 hours run time per year.

139. We have considered several emission abatement innovation technologies, which can be used in isolation or in combination with new build units, to reduce NO_x emissions **[Options 2-6, 8-9; Table 12]**. Control System Restricted Performance (CSRP), Dry Low Emissions (DLE) and Selective Catalytic Reduction (SCR) emission abatement technologies have been investigated through dedicated external studies and

37 See 143 for additional information on VSD re-wheeling. VSD re-wheels are considered for options which include Avon 1535 or New Build Units.
38 See 144 for how commercial rules & tools are addressed within options selection
39 See 146 for additional information on why the single large GT solution has been discounted
40 See 147 for justification why additional VSD's have been discounted
41 See 147 for justification why additional VSD's have been discounted

performance trials. For more information on these abatement solutions and their respective reports please see **Section. 3.1** and **Appendix H, I & J**.

140. Existing unit disconnection or decommissioning is considered across several options **[Options 7-10; Table 12**]. For the purpose of CBA and BAT assessment, decommissioning costs have been included where operation of Unit A and/or B is not required beyond 2030. The requirement for decommissioning will be reassessed following operational acceptance of the new units and an evaluation of network capability at that time.

141. We have also evaluated delaying our investment decision to account for uncertainties in the energy landscape. This has taken the form of a series of fully costed CBA sensitivities (see **Section 7.3**) including the two new unit option **[Option 10; Table 12**] where we would install one unit by 2028, and the second new unit by 2035 when constraint costs are projected to increase significantly. Delay of the second unit is treated as a sensitivity on the new build options and is not discussed as an option in its own right. This delay would entail exposure to a period of depleted network capability and system resilience in the period 2028-2035, the impact of which could be highly detrimental to consumers under two of the four energy system backgrounds studied. Our view is that this is not a risk that should be burdened onto consumers. More information on these delay sensitivities and the use of Real Options Analysis to quantify the value of delay can be found in **Section 7.4**.

142. A number of new build options were also considered as part of NGGT's full suite of measures to reduce emissions **[Options 7-10]**. Several site locations were considered for these new build options including greenfield and brownfield locations. The selected location for new units is an area of National Grid owned land to the south of the existing plot as shown in **Figure 16**. This option has been used as the basis for all new unit options. Due to minimum separation distances between process plant for safety and operational reasons there were no suitable brownfield options. For additional information on the selection of site locations for new build units and engineering layout drawings, please see the Engineering Report; **Appendix C**.

[redacted]

Figure 16 – Selected Location for New Compressors

143. Re-wheeling the VSD's compressor has been considered within options for new build and Avon 1535 engine upgrades **[Options 3, 6-10; Table 12]**. Re-wheeling involves replacing the impeller to ensure that compressor operational envelopes are aligned across all units. Further engineering review is required following Options Selection (confirmation of Final Preferred Option) to investigate site re-wheel requirements further. See the **Appendix C** for more detail.

144. All options have included consideration of rules and tools which may be available as an alternative to proposed capital investment. In this context, amendments to rules relate to code changes. With these being relevant to all sites, no code rule changes have been identified for Wormington which would also be appropriate to all other sites. Regarding available tools, in all options there are no commercial contracts required to ensure compliance with the 1-in-20 design standard. Network Entry constraints would be managed using existing tools.

145. Our counterfactual was based on the option which required the least intervention but still represented a course of action we would consider pursuing. In this case it was to continue to maintain the units and place them on a 500-hour derogation. Given the previous assessment as part of our RIIO-T2 submission, the expected flows along with the WGN PARCA, it was not prudent to consider an option where both compressors were removed with no replacements, so this has not been included in the assessment.

146. Options which result in a site consisting of only two units (e.g. a single GT compressor combined with the existing VSD) have been discounted due to lack of adequate site resilience offered across the range of scenarios. Currently all options provide the required compression capability through two emissions compliant GTs and the VSD. The current operating philosophy is where bulk compression capability is provided by

the VSD, with back up provided by the GTs when the VSD is not available. Any two of three compressors operate in parallel to meet high flow/head discharge conditions that cannot be provided by the VSD alone (>50mscm/day). To reduce the number of compressors on site from three to two would require each unit to be capable of the full compression capability requirements. This would require an unachievable level of turndown and therefore compromise on low head/flow capability would be required.

147. Replacement of Avon Unit A & B with new electric driven compression has been discounted for Wormington. This is for network security purposes, preventing the site being fully reliant on the electricity network. Gas-driven units ensure site capability in scenarios where electricity supply is disconnected, allowing the site to remain operational. More information on this can be found in CE-AMP[42].

148. To understand existing unit condition (availability) and how specific asset health interventions impact unit availability, we developed a site-specific availability model for Wormington. In addition to this we commissioned [redacted] to develop a Reliability Availability Maintainability (RAM) model, which has evaluated unit availability across the entire NGGT fleet. In addition to this we commissioned [redacted] to develop a Reliability Availability Maintainability (RAM) model which evaluated unit availability across the entire NGGT fleet. These unit availability statistics are a key CBA input which ultimately influences network capability, constraint cost and informs the NPV for each particular option.

Final Option Selection & Short-Listing

149. Following on from the analysis performed on the full list of investment solutions, a shortened options list was derived where each of the main solutions (derogation, abatement, new build, etc.) is represented across 10 key options. These key options and detail on which units they have been applied across can be seen in **Table 12** below. Additional sensitivities were assessed as part of the CBA and are described in **Section 7.3**.

[42] CE-AMP Appendix C – Compliance Options

Option Shortlist	Unit A	Unit B	Unit C	Unit D	Unit E
1 – Counterfactual	500Hr EUD	500Hr EUD	No Change	/	/
2 - 2 x CSRP	CSRP Retrofit	CSRP Retrofit	No Change	/	/
3 - 2 x SCR	SCR Retrofit	SCR Retrofit	VSD Re-Wheel	/	/
4 – 1533 DLE + 500 Hr	1533 DLE Retrofit	500Hr EUD	No Change	/	/
5 - 2 x 1533 DLE	1533 DLE Retrofit	1533 DLE Retrofit	No Change	/	/
6 - 2 x 1535 DLE	1535 DLE Retrofit	1535 DLE Retrofit	VSD Re-Wheel	/	/
7 - New GT + 500	500Hr EUD	Decom.	VSD Re-Wheel	New GT (Greenfield)	/
8 - New GT + CSRP	CSRP Retrofit	Decom.	VSD Re-Wheel	New GT (Greenfield)	/
9 - New GT + DLE	1533 DLE Retrofit	Decom.	VSD Re-Wheel	New GT (Greenfield)	/
10 - 2 x New GT	Decom.	Decom.	VSD Re-Wheel	New GT (Greenfield)	New GT (Greenfield)

Table 12 - Option Shortlist

Option Descriptions

150. Option 1 is the counterfactual which considers no future emissions related capital investment at Wormington. By 1st January 2030, Units A & B will be placed under limited run time (500 hours EUD) for the rest of their operational life. This option contains asset health investment to ensure unit reliability from 2030.

151. Option 2 considers control system modifications or restriction (CSRP) of Units A & B.

152. Option 3 considers SCR system modification to Units A & B as well as a powertrain upgrade to the 1535 Avon engine variant. This option includes a compressor re-wheel for Unit C.

153. Option 4 considers modifying Unit A[43] with DLE technology. Unit B is placed under 500 hour EUD.

154. Option 5 considers the modification of Units A & B with DLE technology.

155. Option 6 considers upgrading Units A & B to an Avon 1535 powertrain and adding DLE technology. This option includes a compressor re-wheel for Unit C.

156. Option 7 involves a new emissions compliant gas-driven compressor unit on a greenfield location with Unit A placed under 500 hour EUD from 2030. Unit B would be

[43] In all cases, abatement technology is applied on Unit A over Unit B for consistency. There is currently no preference between units from an asset health condition, constructability or cost perspective.

targeted for decommissioning once the new unit is operational. This option includes a compressor re-wheel for Unit C.

157. Option 8 involves a new gas-driven compressor unit on a greenfield site with a CSRP modification on Unit A. Unit B would be targeted for decommissioning once the new unit is operational. This option includes a compressor re-wheel for Unit C.

158. Option 9 involves a new gas-driven compressor unit on a greenfield site with Unit A modified with DLE technology. Unit B would be targeted for decommissioning once the new unit is operational. This option includes a compressor re-wheel for Unit C.

159. Option 10 involves two new gas-driven compressor units on a greenfield site. Units A & B would be targeted for decommissioning once the new units are operational. This option includes a compressor re-wheel for Unit C.

Option Assessment Criteria

160. Detailed descriptions of each considered option can be found in **Section 5.2**. Within this section, each option is discussed according to the following criteria:

- Option Description
- Cost Breakdown
- Commercial Actions
- Option Benefits & Limitations
- Option Risks

161. Option description provides context on the main features of the option.

162. Each option is provided with a cost breakdown table where total installed cost, asset health cost, operating cost, decommissioning and constraint costs are defined. Additional detail on the cost basis for each option can be found in **Section 6.2.**

163. The presence of any commercial contracts available to manage constraints and ensure compliance with 1-in-20 is detailed within “commercial actions”.

164. A high-level assessment of the advantages and disadvantages of each option is identified within “option benefits & limitations”. This section uses the technical and environmental assessment performed in the preliminary BAT[44] analysis to compare options using a traffic light methodology. The BAT assessment consists of a series of importance weighted technical and environmental criteria, against which each option is scored, see **Table 13**. BAT assessment scores and weighting were qualitatively determined by representative business stakeholders. Scores are not intended to be used to determine the Final Preferred Option but to support the decision-making

[44] National Grid is legally bound under the Industrial Emissions Directive (IED) to comply with the requirements of BAT in respect of its gas turbine compressor installations. Beyond this, National Grid made a policy decision in 2013 that BAT would be the primary selection mechanism for all new and substantially modified compressor machinery trains. The BAT assessment methodology has been developed by National Grid in consultation with the Environmental Agency (EA) and Scottish Environmental Protection Agency (SEPA).

process in parallel with cost benefit analysis. For detailed information on the BAT assessment, please see **Appendix G**.

Technical Criteria:	65%
Versatility	15%
Future Proofing	15%
Ownership	13%
Constructability	7%
Environmental Amenity	10%
Hazard	5%
Environmental Criteria:	35%
Emissions (NOx = 20%; CO2 = 10%; CO = 5%)	35%

Table 13 - BAT Assessment Technical & Environmental Comparison Criteria

165. Assessments were conducted on two scenarios; VSD available and VSD unavailable. Within this Final Options Selection Report we make reference to the VSD unavailable scenario as it is more relevant for new units which are intended to provide back-up to the VSD unit.

166. The technical and environmental criteria are defined as follows:

- **Versatility** refers to the extent and usability of the MCPD emissions compliant compressor envelope. This criterion is a combination of unit capability and availability to meet the pre-defined Process Duty Specification (PDS) points.
- **Future Proofing**[45] is defined as the headroom above current emission limits and performance against anticipated energy efficiency levels which may be contained in a future BAT Reference (BREF)[46] Document.
- **Ownership** refers to maintenance complexity and the availability of spares for the compressor unit(s).
- **Constructability** refers to the ease of construction and potential for disruption to existing site operations. Also considers number of outage periods required.
- **Environmental Amenity** refers to the potential for visual impact and noise concerns resulting from the selected option.
- **Hazard** refers to perceived risk to the environment.
- **Emissions** criteria refers to predicted NO_x, CO_2 & CO emissions for each technology solution.

167. A breakdown for option technical (65%) and environmental (35%) scores across all options can be found in **Table 13** as well as a consolidated score breakdown in **Table 38**.

[45] Future Proofing does not contain consideration for future unit hydrogen compatibility due to the lack of defined requirements associated with future hydrogen compression on the NTS and targets for blend composition.

[46] The UK environmental agencies have indicated that any forthcoming BAT Reference (BREF) document will contain energy efficiency targets

168. A semi-quantitative risk assessment methodology has been used to provide an indication of the relative level of risk associated with each option. Each identified risk is quantified in terms of probability of occurrence and severity of impact in order to determine an overall risk classification. Risks were classified as; Negligible, Minor, Significant, Major or Critical. Within **Section 5.2** only the highest risks are referenced within the discussion. The Wormington risk report and project risk register can be found in **Appendix F**. Discussion on risks associated only with the Final Preferred Option can be found in **Section 8.3**. It should be noted that the cost estimate has not been adjusted based on the output of the risk assessment process.

169. Level 2 delivery programmes have been used to determine deliverability within outage constraints and estimate capital spend profile for each option. All investments are planned to meet the legislative deadline of 1st January 2030. These programmes were also used to estimate capital spend profile for each option. The cost Re-opener planned for November 2024 will be supported by a more detailed delivery programme for the selected option based on an appropriate delivery strategy. The Level 2 programme for the Final Preferred Option can be found in **Section 8.2** while the project programme report can be found in **Appendix E**.

170. For information on the CBA & sensitivities used, please see **Section 7.3.**

171. Regarding considerations for solution design life within option selection, unit design life varies depending on the asset element in question. **Figure 17** below outlines the design life requirements for each new compressor asset on the NTS. For example, Protection and Control Systems have a design life of 15 years and therefore replacement will be required and has been considered during the CBA period. All other new assets installed as part of the MCPD project will have a design life greater than the CBA period and replacement cost has therefore not been included. Routine maintenance and estimated ad-hoc repairs have also been included in cost estimates included in the CBA.

Asset	Life (years)
Compressors	40
Gas Generators	20
Power Turbines	25
Pipework and Valves	30
Protection and Control Systems	15
Enclosures and Buildings	60

Figure 17 - T/PM/Comp/20 Asset Design Life[47]

[47] Section 11; T/PM/COMP/20 - Management Procedure for Compressor Installations for the National Transmission System

Option Summary Tables

172. Summary tables of the main options considered, as well as their costs and benefits & limitations can be found within **Section 5.3**.

5.2. Main Option Breakdown

Option 1 – Counterfactual (2 x 500 Hours Derogation)

Option Description

173. This option maintains Avon Units A and B until 31st December 2029 and places them on 500 hours EUD (Emergency Use Derogation) from 1st January 2030.

Cost Breakdown

174. The cost breakdown of the option is given in **Table 14.**

175. The project start date is the NGGT 2019 RIIO-T2 business plan submission to develop the final preferred investment option. Project finish date represents the year commissioning activities are planned to take place. Level 2 delivery programmes can be found in **Appendix E** for more details on option timeline.

Option Cost Breakdown (18/19 Prices)	Project Start Date	Project Finish Date	Total Installed Cost (£m)	Total Asset Health (£m)	Operating Cost (£m/pa)	Decom. Cost (£m)	Total Constraint Cost (£m)	Cost Accuracy
1 – Counterfactual	2019	2028	[redacted]					

Table 14 - Option 1: Cost Breakdown

Cost Basis

176. Total Asset Health Cost is a combination of "initial" and "ongoing" asset health. Initial asset health costs consider investments which are required to ensure units are of sufficient reliability to operate effectively from 1 January 2030. Ongoing asset health costs concern investments necessary to ensure future running from 2030 to 2050. More detail can be found in the **Appendix D**.

177. Total Constraint Cost is a range which considers projected constraint costs which are applicable across the four Future Energy Scenarios, see **Section 4** for more information on FES.

178. Please see **Section 6** for commentary on how the cost estimate for this option was developed.

Commercial Actions

179. There are no commercial contracts required to ensure compliance with the 1-in-20 design standard for this option. Network Entry constraints would be managed using existing tools, and these constraint costs would be expected to be significant once the derogations start in 2030.

Benefits & Limitations

180. A high-level view of how the option measures up against the comparison criteria is summarised in **Table 15**. The full option benefits table can be found in **Section 5.3** to enable comparison across options. See **Section 5.1** for the definition of each criterion and **Appendix G** for how the BAT scores were established.

Investment Option Benefit & Limitations	Cost	Versatility	Future Proofing	Ownership	Constructability	Environmental Amenity	Hazard	Emissions
1 - Counterfactual	Low	0%	0%	10%	7%	10%	5%	10%

Table 15 - Option 1: Benefits & Limitations Breakdown

181. **Cost:** Overall cost investment (CAPEX, OPEX, asset health) is considered low in comparison to other options due to the lack of future investment aside from necessary asset health investment to ensure unit reliability from 2030. Asset health investment (new control systems on Units A & B) is necessary across the counterfactual and all other abatement options.

182. **Versatility:** This solution was scored 0% out of 15% as it is critically constrained by the 500 hours limitation.

183. **Future Proofing**: This solution was scored 0% out of 15% as it achieves current emissions limits but with no headroom for future increase in legislation increase (emissions or energy efficiency).

184. **Ownership**: This solution was scored 10% out of 13% as the Avon's have acceptable service agreements in place for maintenance and there is a medium availability of spares. However, score has been discounted due to the age of the Avon units and the likelihood for increased maintenance intervention.

185. **Constructability**: This solution was scored 7% out of 7% as it provides for the least disruption on site compared to all the options. Three outage periods have been determined for:

- Outage A: Minor asset health works
- Outage B: Unit A & B control system installation
- Outage C: Unit A & B power turbine overhaul

186. **Environmental Amenity**: This solution was scored 10% out of 10% as the solution was determined unlikely to introduce a new amenity risk.

187. **Hazard**: This solution was scored 5% out of 5% as there is no significant residual risk expected to the environment or human receptors. Avon oil containment is likely to be as effective as a new GT unit.

188. **Emissions**: This solution was scored 10% out of 35% (1/20 NO_x; 8/10 CO_2; 1/5 CO) for emissions compliance due to the fact that NO_x emissions are not curtailed through system modification or power reduction, but a limitation placed on run hours. The Avon units in this solution still have the potential to exceed NO_x emissions limits.

Risks

189. Please see **Appendix F** for more detail on the risks defined for this option. The highest rated risks are identified below.

190. **Critical**: Network outage periods are not yet confirmed. Allowed outage may be shorter than anticipated.

191. **Major**: The existing Avon units are over 30 years old. This brings increased asset health maintenance exposure and higher probability of unavailability due to technical issues.

192. **Major**: Country specific and worldwide geopolitical issues affecting the supply & cost of equipment, materials and workforce.

Option 2 – Two Derated (CSRP) Avon's

Option Description

193. This option considers restricting high power running of Avon Units A and B through control system modifications to limit their performance and thereby reduce NO_x emissions to within acceptable limits.

194. This option would necessitate a control system software modification to limit Exhaust Cone Temperature which has been proven, via a CSRP performance trial, to correlate with NO_x emissions. This control system software update is controlled by the G/35 management of change process which ensures that the governor controller setpoints cannot easily be returned back to their original settings.

Cost Breakdown

195. The cost breakdown for the option is given in **Table 16**.

196. The project start date is the NGGT 2019 RIIO-T2 business plan submission to develop the final preferred investment option. Project finish date represents the year commissioning activities are planned to take place. Level 2 delivery programmes can be found in **Appendix E** for more details on option timeline.

Option Cost Breakdown (18/19 Prices)	Project Start Date	Project Finish Date	Total Installed Cost (£m)	Total Asset Health (£m)	Operating Cost (£m/pa)	Decom. Cost (£m)	Total Constraint Cost (£m)	Cost Accuracy
2 - 2 x CSRP	2019	2028	[redacted]					

Table 16 - Option 2: Cost Breakdown

Cost Basis

197. Total Asset Health Cost is a combination of "initial" & "ongoing" asset health. Initial asset health costs consider investments which are required to ensure units are of sufficient reliability to operate effectively from 1 January 2030. Ongoing asset health costs concern investments necessary to ensure future running from 2030 to 2050. More detail can be found in the **Appendix D.**

198. Total Constraint Cost is a range which considers projected constraint costs which are applicable across the four Future Energy Scenarios, see **Section 4** for more information on FES.

199. Please see **Section 6** for commentary on how the cost estimate for this option was developed.

Commercial Actions

200. There are no commercial contracts required to ensure compliance with the 1-in-20 design standard for this option. Network Entry constraints would be managed using existing tools, and these constraint costs would be expected to be significant once the derogations kick in from 2030.

Benefits & Limitations

201. A high-level subjective view of how the option measures up against the comparison criteria is summarised in **Table 17**. The full option benefits table can be found in **Section 5.3** to enable comparison across options. See **Section 5.1** for the definition of each criterion and Appendix G for how the BAT scores were established.

Investment Option Benefit & Limitations	Cost	Versatility	Future Proofing	Ownership	Constructability	Environmental Amenity	Hazard	Emissions
2 - 2 x CSRP	Low	0%	0%	10%	7%	10%	5%	11%

Table 17 - Option 2: Benefits & Limitations Breakdown

202. **Cost:** Overall cost investment (CAPEX, OPEX, asset health) is considered low in comparison to other options. The cost of CSRP modification is included in overall cost of control system installation as it is a software modification. Asset health investment (new control systems on Units A & B) is necessary across all the abatement options considered.

203. **Versatility:** This solution was scored 0% out of 15% as it contains insufficient power to meet all the PDS points.

204. **Future Proofing**: This solution was scored 0% out of 15% as it achieves current emissions limits but with no headroom without further significant performance restriction implications for future increase in legislation increase (emissions or energy efficiency).

205. **Ownership**: This solution was scored 10% out of 13% as the Avon's have acceptable service agreements in place for maintenance and there is a medium availability of spares. However, solution has been discounted due to the age of the Avon units and the likelihood for increased maintenance intervention.

206. **Constructability**: This solution was scored 7% out of 7% as it provides for the least disruption on site compared to all the options. Three outage periods have been determined for:

- Outage A: Minor asset health works
- Outage B: Unit A & B control system installation & CSRP modification
- Outage C: Unit A & B power turbine overhaul

CSRP software modification is targeted to take place during control system installation to minimize the impact on site operation.

207. **Environmental Amenity**: This solution was scored 10% out of 10% as the solution was determined unlikely to introduce a new amenity risk.

208. **Hazard**: This solution was scored 5% out of 5% as there is no significant residual risk expected to the environment or human receptors. Avon oil containment is likely to be as effective as a new GT unit.

209. **Emissions**: This solution was scored 11% out of 35% (2/20 NO_x; 9/10 CO_2; 1/5 CO) for emissions compliance due to the fact that NO_x emissions are reduced through restricting power output and not curtailed through more efficient unit running.

Risks

210. Please see **Appendix F** for more detail on the risks defined for this option. The highest rated risks are identified below.

211. **Critical:** Network outage periods are not yet confirmed. Allowed outage may be shorter than anticipated or at less optimum time for construction of new build units.

212. **Major:** The existing Avon units are over 30 years old. This brings increased asset health maintenance exposure and higher probability of unavailability due to technical issues.

213. **Major**: Country specific and worldwide geopolitical issues affecting the supply & cost of equipment, materials and workforce.

214. **Significant**: Potential that CSRP is not approved by Environmental Agency (EA) resulting in rejection of permit request.

Option 3 – Two SCR Retrofitted Avon's

Option Description

215. This option considers adding a Selective Catalytic Reduction (SCR) system to Units A and B to reduce NO_x emissions to within MCPD limits. SCR technology enables conversion of NO_x to Nitrogen (N_2) and water (H_2O) by reacting NO_x with Ammonia (NH_3).

216. The SCR system consists of a number of critical components such as a self-supporting exhaust stack and silencer, ammonia storage and pumping system, ammonia vaporisation system, ammonia tanker unloading system, control system modifications and a Continuous Emissions Monitoring System (CEMS) to verify that NO_x emissions have been sufficiently limited to within MCPD limits.

217. Units A & B feature engine upgrades to the more powerful 1535 Avon variant. In order to ensure operation mapping alignment across all site compressors, this option also features a VSD re-wheel.

Cost Breakdown

218. The cost breakdown of the option is given in **Table 18.**

219. The project start date is the NGGT 2019 RIIO-T2 business plan submission to develop the final preferred investment option. Project finish date represents the year commissioning activities are planned to take place. Level 2 delivery programmes can be found in **Appendix E** for more details on option timeline.

Option Cost Breakdown (18/19 Prices)	Project Start Date	Project Finish Date	Total Installed Cost (£m)	Total Asset Health (£m)	Operating Cost (£m/pa)	Decom. Cost (£m)	Total Constraint Cost (£m)	Cost Accuracy
3 - 2 x SCR	2019	2029	[redacted]					

Table 18 - Option 3: Cost Breakdown

Cost Basis

220. Total Asset Health Cost is a combination of "initial" & "ongoing" asset health. Initial asset health costs consider investments which are required to ensure units are of sufficient reliability to operate effectively from 1 January 2030. Ongoing asset health costs concern investments necessary to ensure future running from 2030 to 2050. More detail can be found in the **Appendix D.**

221. Total Constraint Cost is a range which considers projected constraint costs which are applicable across the four Future Energy Scenarios, see **Section 4** for more information on FES.

222. Please see **Section 6** for commentary on how the cost estimate for this option was developed.

Commercial Actions

223. There are no commercial contracts required to ensure compliance with the 1-in-20 design standard for this option. Network Entry constraints would be managed using existing tools, and these constraint costs would be expected to be significant once the derogations kick in from 2030.

Benefits & Limitations

224. The benefit of SCR technology is that it is a proven, well-established method of reducing NO_x emissions.

225. A high-level qualitative view of how the option measures up against the comparison criteria is summarised in **Table 19** . The full option benefits table can be found in **Section 5.3** to enable comparison across options. See **Section 5.1** for the definition of each criterion and **Appendix G** for how the BAT scores were established.

Investment Option Benefit & Limitations	Cost	Versatility	Future Proofing	Ownership	Constructability	Environmental Amenity	Hazard	Emissions
3 - 2 x SCR	Medium	6%	9%	5%	0%	6%	2%	30%

Table 19 - Option 3: Benefits & Limitations Breakdown

226. **Cost:** Overall cost investment (CAPEX, OPEX, asset health) is considered moderate in comparison to other options due to the multitude of specialist components required for the SCR system. This is in addition to the necessary asset health investment to ensure unit reliability from 2030. Asset health investment (new control systems on Units A & B) is necessary across all abatement options.

227. **Versatility:** This solution was scored 6% out of 15% as the solution is considered likely to meet the required PDS points but uncertainty remains. It has been assumed that the increase in exhaust back pressure due to the catalyst will have negligible impact on maximum GT power.

228. **Future Proofing**: This solution was scored 9% out of 15% as it achieves current emissions limits. Avon SCR includes catalyst for NO_x and CO reduction therefore good emissions headroom. Avon energy efficiency may not meet required targets in a future MCP BREF. Decreased headroom when compared to new GT solutions.

229. **Ownership**: This solution was scored 5% out of 13% as the Avon SCR retrofit is a new application on the NTS which introduces a number of new assets which require operations management and new maintenance procedures. There is expected to be a medium availability of spares. Solution has been discounted due to the age of the Avon units and the likelihood for increased maintenance intervention.

230. **Constructability**: This solution was scored 0% out of 7% as due to footprint constraints, installation of a horizontal exhaust stack will not be possible. This drives

the additional construction complexity of installing a vertical exhaust stack on top of the existing Avon units. There is significant risk in being able to complete this construction work within one outage. Four outage periods have been determined for:

Outage A: Minor asset health works
Outage B: Unit A & B control system installation
Outage C: Unit A & B rotating equipment overhaul/upgrade to 1535
Outage D: Unit A & B SCR steelwork & exhaust installation

231. **Environmental Amenity**: This solution was scored 6% out of 10% as the required vertical exhaust stack is likely to exceed 15m in height thereby creating the risk for challenges during permit & planning applications. This has the potential to cause programme delay.

232. **Hazard**: This solution was scored 2% out of 5% due to the added complexity brought by ammonia use as a reagent in SCR process. This introduces a new hazard which requires containment. Ammonia tanker deliveries require additional containment systems.

233. **Emissions**: This solution was scored 30% out of 35% (20/20 NO_x; 9/10 CO_2; 1/5 CO) for emissions compliance. Through SCR abatement, NO_x emissions will be reduced to well within existing MCPD limits.

Risks

234. Please see **Appendix F** for more detail on the risks defined for this option. The highest rated risks are identified below.

235. **Critical**: Network outage periods are not yet confirmed. Allowed outage may be shorter than anticipated or at less optimum time for construction works.

236. **Major**: SCR options result in significant increase in stack height due to the vertical SCR arrangement with notable visual impact. Impact on permitting and consent requirement. Impact on environmental and commercial negotiations. Potential for delays managing multiple stakeholders and gaining consent.

237. **Major:** The existing Avon units are over 30 years old. This brings increased asset health maintenance exposure and higher probability of unavailability due to technical issues.

238. **Major**: Country specific and worldwide geopolitical issues affecting the supply & cost of equipment, materials and workforce.

Option 4 – One Avon DLE Retrofit (1533) + One 500Hr Derogated Avon

Option Description

239. This option involves retrofitting Avon Unit A with DLE technology. Unit B is placed on 500 hour EUD from 1st January 2030.

240. Unit A modification with DLE technology is based on the existing 1533 Avon powertrain.

241. In all cases, abatement technology is applied on Unit A over Unit B for consistency. There is currently no preference between units from an asset health condition, constructability or cost perspective.

Cost Breakdown

242. The cost breakdown of the option is given in **Table 20.**

243. The project start date is the NGGT 2019 RIIO-T2 business plan submission to develop the final preferred investment option. Project finish date represents the year commissioning activities are planned to take place. Level 2 delivery programmes can be found in **Appendix E** for more details on option timeline.

Option Cost Breakdown (18/19 Prices)	Project Start Date	Project Finish Date	Total Installed Cost (£m)	Total Asset Health (£m)	Operating Cost (£m/pa)	Decom. Cost (£m)	Total Constraint Cost (£m)	Cost Accuracy
4 – 1533 DLE + 500 Hr	2019	2028	[redacted]					

Table 20 - Option 4: Cost Breakdown

Cost Basis

244. Total Asset Health Cost is a combination of “initial” & “ongoing” asset health. Initial asset health costs consider investments which are required to ensure units are of sufficient reliability to operate effectively from 1 January 2030. Ongoing asset health costs concern investments necessary to ensure future running from 2030 to 2050. More detail can be found in the **Appendix D**.

245. Total Constraint Cost is a range which considers projected constraint costs which are applicable across the four Future Energy Scenarios, see **Section 4** for more information on FES.

246. Please see **Section 6** for commentary on how the cost estimate for this option was developed.

Commercial Actions

247. There are no commercial contracts required to ensure compliance with the 1-in-20 design standard for this option. Network Entry constraints would be managed using existing tools, and these constraint costs would be expected to be significant once the derogations kick in from 2030.

Benefits & Limitations

248. A high-level qualitative view of how the option measures up against the comparison criteria is summarised in **Table 21**. The full option benefits table can be found in **Section 5.3** to enable comparison across options. See **Section 5.1** for the definition of each criterion and **Appendix G** for how the BAT scores were established.

Investment Option Benefit & Limitations	Cost	Versatility	Future Proofing	Ownership	Constructability	Environmental Amenity	Hazard	Emissions
4 - 1533 DLE + 500	Low	0%	0%	8%	6%	10%	5%	12%

Table 21 - Option 4: Benefits & Limitations Breakdown

249. **Cost:** Overall cost investment (CAPEX, OPEX, asset health) is considered low in comparison to other options due to requirement for DLE modification works and new control systems on Units A & B.

250. **Versatility:** This solution was scored 0% out of 15% as it is critically constrained by the 500 hours limitation.

251. **Future Proofing**: This solution was scored 0% out of 15% as it achieves current emissions limits, but the existing Avon limits the solution with no headroom for future increase in legislation increase (emissions or energy efficiency).

252. **Ownership**: This solution was scored 8% out of 13% as the Avon DLE retrofit is a new application on the NTS, still currently being technically validated and there are potential limitations on the availability of spares. Solution has been discounted due to the age of the Avon units and the likelihood for increased maintenance intervention.

253. **Constructability**: This solution was scored 6% out of 7% as DLE modifications are expected to be completed in one summer outage however constructability is more complex when compared to other options. Three outage periods have been determined for:

- Outage A: Minor asset health works
- Outage B: Unit A & B control system installation
- Outage C: Unit A DLE retrofit

254. **Environmental Amenity**: This solution was scored 10% out of 10% as the solution was determined unlikely to introduce a new amenity risk.

255. **Hazard**: This solution was scored 5% out of 5% as there is no significant residual risk expected to the environment or human receptors. Avon oil containment is likely to be as effective as a new GT unit.

256. **Emissions**: This solution was scored 12% out of 35% (3/20 NO_x; 8/10 CO_2; 1/5 CO) for emissions compliance. Through DLE abatement, NO_x emissions will be reduced to within existing MCPD limits.

Risks

257. Please see **Appendix F** for more detail on the risks defined for this option. The highest rated risks are identified below.

258. **Critical:** Network outage periods are not yet confirmed. Allowed outage may be shorter than anticipated or at less optimum time for construction works.

259. **Major:** The existing Avon units are over 30 years old. This brings increased asset health maintenance exposure and higher probability of unavailability due to technical issues.

260. **Major**: Country specific and worldwide geopolitical issues affecting the supply & cost of equipment, materials and workforce.

261. **Major**: While DLE technology is well established within the UK & European gas network, the retrofit of DLE technology to Avon gas turbines is not yet technically proven or commercially available. NGGT are working with [redacted] to develop an Avon DLE retrofit solution. A full engine performance trial on the NTS is currently being planned. For this reason, there are inherent risks associated with selecting an unproven technical solution (which supports the lead unit) at a critical site like Wormington.

Option 5 – Two Avon DLE Retrofits (1533)

Option Description

262. This option involves retrofitting the existing 1533 Avon's (Unit A & B) with Dry Low Emissions (DLE) technology.

Cost Breakdown

263. The cost breakdown of the option is given in **Table 22**.

264. The project start date is the NGGT 2019 RIIO-T2 business plan submission to develop the final preferred investment option. Project finish date represents the year commissioning activities are planned to take place. Level 2 delivery programmes can be found **Appendix E** for more details on option timeline.

Option Cost Breakdown (18/19 Prices)	Project Start Date	Project Finish Date	Total Installed Cost (£m)	Total Asset Health (£m)	Operating Cost (£m/pa)	Decom. Cost (£m)	Total Constraint Cost (£m)	Cost Accuracy
5 - 2 x 1533 DLE	2019	2028	[redacted]					

Table 22 - Option 5: Cost Breakdown

Cost Basis

265. Total Asset Health Cost is a combination of "initial" & "ongoing" asset health. Initial asset health costs consider investments which are required to ensure units are of sufficient reliability to operate effectively from 1 January 2030. Ongoing asset health costs concern investments necessary to ensure future running from 2030 to 2050. More detail can be found in the **Appendix D**.

266. Total Constraint Cost is a range which considers projected constraint costs which are applicable across the four Future Energy Scenarios, see **Section 4** for more information on FES.

267. Please see **Section 6** for commentary on how the cost estimate for this option was developed.

Commercial Actions

268. There are no commercial contracts required to ensure compliance with the 1-in-20 design standard for this option. Network Entry constraints would be managed using existing tools, and these constraint costs would be expected to be significant once the derogations kick in from 2030.

Benefits & Limitations

269. A high-level qualitative view of how the option measures up against the comparison criteria is summarised in **Table 23**. The full option benefits table can be found in **Section 5.3** to enable comparison across options. See **Section 5.1** for the definition of each criterion and **Appendix G** for how the BAT scores were established.

Investment Option Benefit & Limitations	Cost	Versatility	Future Proofing	Ownership	Constructability	Environmental Amenity	Hazard	Emissions
5 - 2 x 1533 DLE	Low	6%	6%	8%	6%	10%	5%	15%

Table 23 - Option 5: Benefits & Limitations Breakdown

270. **Cost:** Overall cost investment (CAPEX, OPEX, asset health) is considered low in comparison to other options due to requirement for DLE modification works and new control systems on Units A & B.

271. **Versatility:** This solution was scored 6% out of 15% as the solution is likely to have insufficient power to meet all the PDS points.

272. **Future Proofing**: This solution was scored 6% out of 15% as it achieves current emissions limits. Avon energy efficiency may not meet required targets in a future MCP BREF. Decreased headroom when compared to new GT solutions.

273. **Ownership**: This solution was scored 8% out of 13% as the Avon DLE retrofit is a new application on the NTS, still currently being technically validated and there are potential limitations on the availability of spares. However, solution has been discounted due to the age of the Avon units and the likelihood for increased maintenance intervention.

274. **Constructability**: This solution was scored 6% out of 7% as DLE modifications are expected to be completed in one summer outage however constructability is more complex when compared to other options. Three outage periods have been determined for:

- Outage A: Minor asset health works
- Outage B: Unit A & B control system installation
- Outage C: Unit A & B DLE retrofit

275. **Environmental Amenity**: This solution was scored 10% out of 10% as the solution was determined unlikely to introduce a new amenity risk.

276. **Hazard**: This solution was scored 5% out of 5% as there is no significant residual risk expected to the environment or human receptors. Avon oil containment is likely to be as effective as a new GT unit.

277. **Emissions**: This solution was scored 15% out of 35% (5/20 NO_x; 8/10 CO_2; 1/5 CO) for emissions compliance. Through DLE abatement, NO_x emissions will be reduced to well within existing MCPD limits.

Risks

278. Please see **Appendix F** for more detail on the risks defined for this option. The highest rated risks are identified below.

279. **Critical:** Network outage periods are not yet confirmed. Allowed outage may be shorter than anticipated or at less optimum time for construction works.

280. **Major:** The existing Avon units are over 30 years old. This brings increased asset health maintenance exposure and higher probability of unavailability due to technical issues.

281. **Major**: Country specific and worldwide geopolitical issues affecting the supply & cost of equipment, materials and workforce.

282. **Major**: While DLE technology is well established within the UK & European gas network, the retrofit of DLE technology to Avon gas turbines is not yet technically proven or commercially available. NGGT are working with [redacted] to develop an Avon DLE retrofit solution. A full engine performance trial on the NTS is currently being planned. For this reason, there are inherent risks associated with selecting an unproven technical solution (which supports the lead unit) at a critical site like Wormington.

Option 6 – Two Avon DLE Retrofits (1535)

Option Description

283. This option involves retrofitting Avon Unit A & B with DLE technology while upgrading the existing 1533 engine to the more powerful 1535 engine variant.

284. In order to ensure operation mapping alignment across all site compressors, this option also features a VSD re-wheel.

Cost Breakdown

285. The cost breakdown of the option is given in **Table 24**.

286. The project start date is the NGGT 2019 RIIO-T2 business plan submission to develop the final preferred investment option. Project finish date represents the year commissioning activities are planned to take place. Level 2 delivery programmes can be found in **Appendix E** for more details on option timeline.

Option Cost Breakdown (18/19 Prices)	Project Start Date	Project Finish Date	Total Installed Cost (£m)	Total Asset Health (£m)	Operating Cost (£m/pa)	Decom. Cost (£m)	Total Constraint Cost (£m)	Cost Accuracy
6 - 2 x 1535 DLE	2019	2028	[redacted]					

Table 24 - Option 6: Cost Breakdown

Cost Basis

287. Total Asset Health Cost is a combination of "initial" & "ongoing" asset health. Initial asset health costs consider investments which are required to ensure units are of sufficient reliability to operate effectively from 1 January 2030. Ongoing asset health costs concern investments necessary to ensure future running from 2030 to 2050. More detail can be found in the **Appendix D**.

288. Total Constraint Cost is a range which considers projected constraint costs which are applicable across the four Future Energy Scenarios, see **Section 4** for more information on FES.

289. Please see **Section 6** for commentary on how the cost estimate for this option was developed.

Commercial Actions

290. There are no commercial contracts required to ensure compliance with the 1-in-20 design standard for this option. Network Entry constraints would be managed using existing tools, and these constraint costs would be expected to be significant once the derogations kick in from 2030.

Benefits & Limitations

291. Upgrading the existing Avon 1533 engine to a larger 1535 engine variant increases the capability of the site to more of the projected compression requirements.

292. A high-level qualitative view of how the option measures up against the comparison criteria is summarised in **Table 25**. The full option benefits table can be found in **Section 5.3** to enable comparison across options. See **Section 5.1** for the definition of each criterion and **Appendix G** for how the BAT scores were established.

Investment Option Benefit & Limitations	Cost	Versatility	Future Proofing	Ownership	Constructability	Environmental Amenity	Hazard	Emissions
6 - 2 x 1535 DLE	Low	9%	9%	8%	6%	10%	5%	13%

Table 25 - Option 6: Benefits & Limitations Breakdown

293. **Cost:** Overall cost investment (CAPEX, OPEX, asset health) is considered low in comparison to other options due to requirement for DLE modification works and new control systems on Units A & B. Unit upgrade to 1535 is an additional cost when compared to Option 5 but in overall CAPEX comparison it is a small increase.

294. **Versatility:** This solution was scored 9% out of 15% as the solution is expected to meet all the required PDS points but operational envelope is not as wide as a new GT unit.

295. **Future Proofing**: This solution was scored 9% out of 15% as it achieves current emissions limits. Avon energy efficiency may not meet required targets in a future MCP BREF. Decreased headroom when compared to new GT solutions.

296. **Ownership**: This solution was scored 8% out of 13% as the Avon DLE retrofit is a new application on the NTS, still currently being technically validated and there are potential limitations on the availability of spares. However, solution has been discounted due to the age of the Avon units and the likelihood for increased maintenance intervention.

297. **Constructability**: This solution was scored 6% out of 7% as DLE modifications are expected to be completed in one summer outage despite Avon powertrain upgrade to 1535 variant. Three outage periods have been determined for:

- Outage A: Minor asset health works
- Outage B: Unit A & B control system installation
- Outage C: Unit A & B powertrain upgrade to 1535 & DLE retrofit

298. **Environmental Amenity**: This solution was scored 10% out of 10% as the solution was determined unlikely to introduce a new amenity risk.

299. **Hazard**: This solution was scored 5% out of 5% as there is no significant residual risk expected to the environment or human receptors. Avon oil containment is likely to be as effective as a new GT unit.

300. **Emissions**: This solution was scored 13% out of 35% (4/20 NO_x; 9/10 CO_2; 0/5 CO) for emissions compliance. Through DLE abatement, NO_x emissions will be reduced to

within existing MCPD limits. Compared to the 1533, the Avon DLE 1535 is a larger engine and when it is turned down it produces more NO_x emissions than the Avon DLE 1533. Therefore, the 1535 gets a lower score for NO_x. However, CO_2 emissions are lower for the 1535 at the lower shaft power, which suggests it is more fuel efficient. Overall, CO_2 emissions are lower for 1535 and therefore gets a higher score.

Risks

301. Please see **Appendix F** for more detail on the risks defined for this option. The highest rated risks are identified below.

302. **Critical:** Network outage periods are not yet confirmed. Allowed outage may be shorter than anticipated or at less optimum time for construction of new build units.

303. **Major:** The existing Avon units are over 30 years old. This brings increased asset health maintenance exposure and higher probability of unavailability due to technical issues.

304. **Major**: Country specific and worldwide geopolitical issues affecting the supply & cost of equipment, materials and workforce.

305. **Major**: While DLE technology is well established within the UK & European gas network, the retrofit of DLE technology to Avon gas turbines is not yet technically proven or commercially available. NGGT are working with [redacted] to develop an Avon DLE retrofit solution. A full engine performance trial on the NTS is currently being planned. For this reason, there are inherent risks associated with selecting an unproven technical solution (which supports the lead unit) at a critical site like Wormington.

Option 7 – One New GT (Greenfield) + One 500Hr Avon + One Decommission

Option Description

306. This option involves the installation of a new GT compressor unit, approximate size 15MW, which will be commissioned by 2028.

307. New unit is proposed to be installed on a Greenfield site location which is within the existing National Grid boundary.

308. This option also includes maintaining Avon Unit A on 500-hours EUD from 1st January 2030 and targets the decommission of Unit B once the new GT compressor has been commissioned. The requirement for decommissioning will be reassessed following operational acceptance of the new unit.

309. In order to ensure operation mapping alignment across all site compressors, this option also features a VSD re-wheel.

310. Unit A is maintained over Unit B for consistency. There is currently no preference between units from an asset health condition, constructability or cost perspective.

Cost Breakdown

311. The cost breakdown of the option is given in **Table 26.**

312. The project start date is the NGGT 2019 RIIO-T2 business plan submission to develop the final preferred investment option. Project finish date represents the year commissioning activities are planned to take place. Level 2 delivery programmes can be found in **Appendix E** for more details on option timeline.

Option Cost Breakdown (18/19 Prices)	Project Start Date	Project Finish Date	Total Installed Cost (£m)	Total Asset Health (£m)	Operating Cost (£m/pa)	Decom. Cost (£m)	Total Constraint Cost (£m)	Cost Accuracy
7 - New GT + 500	2019	2028	[redacted]					

Table 26 - Option 7: Cost Breakdown

Cost Basis

313. Total Asset Health Cost is a combination of "initial" & "ongoing" asset health. Initial asset health costs consider investments which are required to ensure units are of sufficient reliability to operate effectively from 1 January 2030. Ongoing asset health costs concern investments necessary to ensure future running from 2030 to 2050. More detail can be found in the **Appendix D**.

314. In the case of existing units which are targeted for decommissioning, initial asset health spend will be subject to a risk assessment to ensure only the most essential components are upgraded given the expected short lifespan of the asset.

315. Total Constraint Cost is a range which considers projected constraint costs which are applicable across the four Future Energy Scenarios, see **Section 4** for more information on FES.

316. Please see **Section 6** for commentary on how the cost estimate for this option was developed.

Commercial Actions

317. There are no commercial contracts required to ensure compliance with the 1-in-20 design standard for this option. Network Entry constraints would be managed using existing tools, and these constraint costs would be expected to be significant once the derogations kick in from 2030.

Benefits & Limitations

318. A high-level qualitative view of how the option measures up against the comparison criteria is summarised in **Table 27**. The full option benefits table can be found in **Section 5.3** to enable comparison across options. See **Section 5.1** for the definition of each criterion and **Appendix G** for how the BAT scores were established.

Investment Option Benefit & Limitations	Cost	Versatility	Future Proofing	Ownership	Constructability	Environmental Amenity	Hazard	Emissions
7 - New GT + 500	Medium	3%	0%	10%	4%	6%	5%	15%

Table 27 - Option 7: Benefits & Limitations Breakdown

319. **Cost:** Overall cost investment (CAPEX, OPEX, asset health) is considered moderate in comparison to other options due to the cost of the new GT compressor unit. A new control system is also required on Unit A and decommissioning of Unit B.

320. **Versatility:** This solution was scored 3% out of 15% as while the new unit is expected to meet the required PDS points (if adequately sized), the combined solution will be constrained by the 500 hours limitation.

321. **Future Proofing**: This solution was scored 0% out of 15% as it achieves current emissions limits but the existing Avon limits the solution with no headroom for future increase in legislation increase (emissions or energy efficiency).

322. **Ownership**: This solution was scored 10% out of 13% as the Avon's have acceptable service agreements in place for maintenance and there is a medium availability of spares. However, solution has been discounted due to the age of the Avon unit and the likelihood for increased maintenance intervention.

323. **Constructability**: This solution was scored 4% out of 7% as there is moderate complexity associated with the installation of a new GT on a greenfield location as well

as control system installation on the existing Avon. Three outage periods have been determined for:

- Outage A: Minor asset health works
- Outage B: Unit A control system installation
- Outage C: Unit D tie-in works

A dedicated outage for Unit B decommissioning works has not been specified. A decision on decommissioning will be taken once Unit D is operational and a capability assessment confirms there is no further reliance on Unit B's continued operation.

324. **Environmental Amenity**: This solution was scored 6% out of 10% as the greenfield installation location and increased stack height of the new unit has the potential to raise challenges during permit & planning applications. This has the potential to cause programme delay.

325. **Hazard**: This solution was scored 5% out of 5% as there is no significant residual risk expected to the environment or human receptors. Avon oil containment is likely to be as effective as a new GT unit.

326. **Emissions**: This solution was scored 15% out of 35% (4/20 NO_x; 10/10 CO_2; 2/5 CO) for emissions compliance. While the new unit offers very low emission running, the effectiveness of the solution to reduce NO_x emissions is limited by the existing unit on 500 hours derogation.

Risks

327. Please see **Appendix F** for more detail on the risks defined for this option. The highest rated risks are identified below.

328. **Critical:** Network outage periods are not yet confirmed. Allowed outage may be shorter than anticipated or at less optimum time for construction of new build units.

329. **Critical**: Country specific and worldwide geopolitical issues affecting equipment supply and workforce (greater impact for new build unit).

330. **Major:** Extension of the existing site boundary is necessary for greenfield new builds. This will have an impact on permitting/consents as well as environmental and commercial negotiations. Potential for schedule delay.

331. **Major:** The existing Avon units are over 30 years old. This brings increased asset health maintenance exposure and higher probability of unavailability due to technical issues.

332. **Opportunity**: A conservative basis has been taken regarding space/footprint requirement for new build compressors. Opportunity to optimise and reduce with resulting impact on fence extension requirements, foundations etc.

Option 8 – One New GT (Greenfield) + One Derated Avon (CSRP) + One Decommission

Option Description

333. This option involves the installation of a new GT compressor unit, approximate size 15MW, which will be commissioned by 2028.

334. New unit is proposed to be installed on a Greenfield site location which is within the existing National Grid boundary.

335. This option also includes derating or restricting the performance of Avon Unit A (CSRP) and targets decommissioning Unit B once the new GT compressor has been commissioned. The requirement for decommissioning will be reassessed following operational acceptance of the new unit.

336. In order to ensure operation mapping alignment across all site compressors, this option also features a VSD re-wheel.

337. Unit A is maintained over Unit B for consistency. There is currently no preference between units from an asset health condition, constructability or cost perspective.

Cost Breakdown

338. The cost breakdown of the option is given in **Table 28**.

339. The project start date is the NGGT 2019 RIIO-T2 business plan submission to develop the final preferred investment option. Project finish date represents the year commissioning activities are planned to take place. Level 2 delivery programmes can be found in **Appendix E** for more details on option timeline.

Option Cost Breakdown (18/19 Prices)	Project Start Date	Project Finish Date	Total Installed Cost (£m)	Total Asset Health (£m)	Operating Cost (£m/pa)	Decom. Cost (£m)	Total Constraint Cost (£m)	Cost Accuracy
8 - New GT + CSRP	2019	2028	[redacted]					

Table 28 - Option 8: Cost Breakdown

Cost Basis

340. Total Asset Health Cost is a combination of "initial" & "ongoing" asset health. Initial asset health costs consider investments which are required to ensure units are of sufficient reliability to operate effectively from 1 January 2030. Ongoing asset health costs concern investments necessary to ensure future running from 2030 to 2050. More detail can be found in the **Appendix D**.

341. In the case of existing units which are targeted for decommission, initial asset health spend will be subject to a risk assessment to ensure only the most essential components are upgraded given the expected short lifespan of the asset.

342. Total Constraint Cost is a range which considers projected constraint costs which are applicable across the four Future Energy Scenarios, see **Section 4** for more information on FES.

343. Please see **Section 6** for commentary on how the cost estimate for this option was developed.

Commercial Actions

344. There are no commercial contracts required to ensure compliance with the 1-in-20 design standard for this option. Network Entry constraints would be managed using existing tools, and these constraint costs would be expected to be significant once the derogations kick in from 2030.

Benefits & Limitations

345. A high-level qualitative view of how the option measures up against the criteria is summarised in **Table 29**. The full option benefits table can be found in **Section 5.3** to enable comparison across options. See **Section 5.1** for the definition of each criterion and **Appendix G** for how the BAT scores were established.

Investment Option Benefit & Limitations	Cost	Versatility	Future Proofing	Ownership	Constructability	Environmental Amenity	Hazard	Emissions
8 - New GT + CSRP	Medium	9%	0%	10%	4%	6%	5%	16%

Table 29 - Option 8: Benefits & Limitations Breakdown

346. **Cost:** Overall cost investment (CAPEX, OPEX, asset health) is considered moderate in comparison to other options due to the cost of the new GT compressor unit. A new control system is also required on Unit A and decommissioning of Unit B. CSRP modification represents a very small increase in CAPEX (implementation during control system installation).

347. **Versatility:** This solution was scored 9% out of 15% as the solution is expected to meet all the required PDS points but operational envelope is not as wide as a two new GT units.

348. **Future Proofing**: This solution was scored 0% out of 15% as it achieves current emissions limits, but the existing Avon limits the solution with no headroom for future increase in legislation increase (emissions or energy efficiency).

349. **Ownership**: This solution was scored 10% out of 13% as the Avon's have acceptable service agreements in place for maintenance and there is a medium availability of spares. However, solution has been discounted due to the age of the Avon unit and the likelihood for increased maintenance intervention.

350. **Constructability**: This solution was scored 4% out of 7% as there is moderate complexity associated with the installation of a new GT on a greenfield location as well as control system installation on the existing Avon. Three outage periods have been determined for:

- Outage A: Minor asset health works
- Outage B: Unit A control system installation & CSRP modification
- Outage C: Unit D tie-in works

351. A dedicated outage for Unit B decommissioning works has not been specified. A decision on decommissioning will be taken once Unit D is operational and a capability assessment confirms there is no further reliance on Unit B's continued operation.

352. **Environmental Amenity**: This solution was scored 6% out of 10% as the greenfield installation location and increased stack height of the new unit has the potential to raise challenges during permit & planning applications. This has the potential to cause programme delay.

353. **Hazard**: This solution was scored 5% out of 5% as there is no significant residual risk expected to the environment or human receptors. Avon oil containment is likely to be as effective as a new GT unit.

354. **Emissions**: This solution was scored 16% out of 35% (4/20 NO_x; 10/10 CO_2; 2/5 CO) for emissions compliance. Through the use of the low-emission new unit & restricting the power output of Unit A (CSRP), NO_x emissions will be reduced to well within defined MCPD limits.

Risks

355. Please see **Appendix F** for more detail on the risks defined for this option. The highest rated risks are identified below.

356. **Critical:** Network outage periods are not yet confirmed. Allowed outage may be shorter than anticipated or at less optimum time for construction of new build units.

357. **Critical**: Country specific and worldwide geopolitical issues affecting equipment supply and workforce (greater impact for new build unit).

358. **Major:** Extension of the existing site boundary is necessary for greenfield new builds. This will have an impact on permitting/consents as well as environmental and commercial negotiations. Potential for schedule delay.

359. **Major:** The existing Avon units are over 30 years old. This brings increased asset health maintenance exposure and higher probability of unavailability due to technical issues.

360. **Opportunity**: A conservative basis has been taken regarding space/footprint requirement for new build compressors. Opportunity to optimise and reduce with resulting impact on fence extension requirements, foundations etc.

Option 9 – One New GT (Greenfield) + One Avon DLE Retrofit (1533) + One Decommission

Option Description

361. This option involves the installation of a new GT compressor unit, approximate size 15MW, which will be commissioned by 2028.

362. New unit is proposed to be installed on a Greenfield site location which is within the existing National Grid boundary.

363. This option also includes modifying Unit A (Avon 1533) with DLE technology and targets decommissioning Unit B once the new GT compressor has been commissioned. The requirement for decommissioning will be reassessed following operational acceptance of the new unit.

364. In order to ensure operation mapping alignment across all site compressors, this option also features a VSD re-wheel.

365. Unit A is maintained over Unit B for consistency. There is currently no preference between units from an asset health condition, constructability or cost perspective.

Cost Breakdown

366. The cost breakdown of the option is given in **Table 30**.

367. The project start date is the NGGT 2019 RIIO-T2 business plan submission to develop the final preferred investment option. Project finish date represents the year commissioning activities are planned to take place. Level 2 delivery programmes can be found in **Appendix E** for more details on option timeline.

Option Cost Breakdown (18/19 Prices)	Project Start Date	Project Finish Date	Total Installed Cost (£m)	Total Asset Health (£m)	Operating Cost (£m/pa)	Decom. Cost (£m)	Total Constraint Cost (£m)	Cost Accuracy
9 - New GT + DLE	2019	2028	[redacted]					

Table 30 - Option 9: Cost Breakdown

Cost Basis

368. Total Asset Health Cost is a combination of “initial” & “ongoing” asset health. Initial asset health costs consider investments which are required to ensure units are of sufficient reliability to operate effectively from 1 January 2030. Ongoing asset health costs concern investments necessary to ensure future running from 2030 to 2050. More detail can be found in the **Appendix D**.

369. In the case of existing units which are targeted for decommissioning, initial asset health spend will be subject to a risk assessment to ensure only the most essential components are upgraded given the expected short lifespan of the asset.

370. Total Constraint Cost is a range which considers projected constraint costs which are applicable across the four Future Energy Scenarios, see **Section 4** for more information on FES.

371. Please see **Section 6** for commentary on how the cost estimate for this option was developed.

Commercial Actions

372. There are no commercial contracts required to ensure compliance with the 1-in-20 design standard for this option. Network Entry constraints would be managed using existing tools, and these constraint costs would be expected to be significant once the derogations kick in from 2030.

Benefits & Limitations

373. A high-level qualitative view of how the option measures up against the comparison criteria is summarised in **Table 31**. The full option benefits table can be found in **Section 5.3** to enable comparison across options. See **Section 5.1** for the definition of each criterion and **Appendix G** for how the BAT scores were established.

Investment Option Benefit & Limitations	Cost	Versatility	Future Proofing	Ownership	Constructability	Environmental Amenity	Hazard	Emissions
9 - New GT + DLE	Medium	12%	9%	8%	4%	6%	5%	23%

Table 31 - Option 9: Benefits & Limitations Breakdown

374. **Cost:** Overall cost investment (CAPEX, OPEX, asset health) is considered moderate in comparison to other options due to the cost of the new GT compressor unit. A new control system is also required on Unit A in addition to DLE modification. CAPEX also includes decommissioning of Unit B.

375. **Versatility:** This solution was scored 12% out of 15% as the solution is expected to meet all the required PDS points but operational envelope is not as wide as two new GT units.

376. **Future Proofing**: This solution was scored 9% out of 15% as new GT unit will provide for full compliance headroom. Avon DLE does not provide for CO headroom should this become a future emission limit value target.

377. **Ownership**: This solution was scored 8% out of 13% as the Avon DLE retrofit is a new application on the NTS, still currently being technically validated and there are potential limitations on the availability of spares. However, solution has been discounted due to the age of the Avon unit and the likelihood for increased maintenance intervention.

378. **Constructability**: This solution was scored 4% out of 7% as there is moderate complexity associated with the installation of a new GT on a greenfield location as well

as control system installation on the existing Avon. Four outage periods have been determined for:

- Outage A: Minor asset health works
- Outage B: Unit A control system installation
- Outage C: Unit A DLE retrofit
- Outage D: Unit D tie-in works

A dedicated outage for Unit B decommissioning works has not been specified. A decision on decommissioning will be taken once Unit D is operational and a capability assessment confirms there is no further reliance on Unit B's continued operation.

379. **Environmental Amenity**: This solution was scored 6% out of 10% as the greenfield installation location and increased stack height of the new unit has the potential to raise challenges during permit & planning applications. This has the potential to cause programme delay.

380. **Hazard**: This solution was scored 5% out of 5% as there is no significant residual risk expected to the environment or human receptors. Avon oil containment is likely to be as effective as a new GT unit.

381. **Emissions**: This solution was scored 23% out of 35% (8/20 NO_x; 10/10 CO_2; 5/5 CO) for emissions compliance. Through the use of the low-emission new unit & DLE abatement on Unit A, NO_x emissions will be reduced to well within existing MCPD limits.

Risks

382. Please see **Appendix F** for more detail on the risks defined for this option. The highest rated risks are identified below.

383. **Critical:** Network outage periods are not yet confirmed. Allowed outage may be shorter than anticipated or at less optimum time for construction of new build units.

384. **Critical**: Country specific and worldwide geopolitical issues affecting equipment supply and workforce (greater impact for new build unit).

385. **Major:** Extension of the existing site boundary is necessary for greenfield new builds. This will have an impact on permitting/consents as well as environmental and commercial negotiations. Potential for schedule delay.

386. **Major:** The existing Avon units are over 30 years old. This brings increased asset health maintenance exposure and higher probability of unavailability due to technical issues.

387. **Major**: While DLE technology is well established within the UK & European gas network, the retrofit of DLE technology to Avon gas turbines is not yet technically proven or commercially available. NGGT are working with [redacted] to develop an Avon DLE retrofit solution. A full engine performance trial on the NTS is currently being planned. For this reason, there are inherent risks associated with selecting an

unproven technical solution (which supports the lead unit) at a critical site like Wormington.

388. **Opportunity**: A conservative basis has been taken regarding space/footprint requirement for new build compressors. Opportunity to optimise and reduce with resulting impact on fence extension requirements, foundations etc.

Option 10 - Two New GTs (Greenfield) + Two Decommission Avon's

Option Description

389. This option involves the installation of two new GT compressor units which will be commissioned by 2028.

390. New units are proposed to be installed on a Greenfield site location which is within the existing National Grid boundary.

391. In order to ensure operation mapping alignment across all site compressors, this option also features a VSD re-wheel.

392. This option also contains decommissioning costs for Unit A & B once the new units are commissioned. The requirement for decommissioning will be reassessed following operational acceptance of the new units.

Cost Breakdown

393. The cost breakdown of the option is given in **Table 32**.

394. The project start date is the NGGT 2019 RIIO-T2 business plan submission to develop the final preferred investment option. Project finish date represents the year commissioning activities are planned to take place. Level 2 delivery programmes can be found in **Appendix E** for more details on option timeline.

Option Cost Breakdown (18/19 Prices)	Project Start Date	Project Finish Date	Total Installed Cost (£m)	Total Asset Health (£m)	Operating Cost (£m/pa)	Decom. Cost (£m)	Total Constraint Cost (£m)	Cost Accuracy
10 - 2 x New GT	2019	2029	[redacted]					

Table 32 - Option 10: Cost Breakdown

Cost Basis

395. Total Asset Health Cost is a combination of "initial" & "ongoing" asset health. Initial asset health costs consider investments which are required to ensure units are of sufficient reliability to operate effectively from 1 January 2030. Ongoing asset health costs concern investments necessary to ensure future running from 2030 to 2050. More detail can be found in the **Appendix D**.

396. In the case of existing units which are targeted for decommission, initial asset health spend will be subject to a risk assessment to ensure only the most essential components are upgraded given the expected short lifespan of the asset.

397. Total Constraint Cost is a range which considers projected constraint costs which are applicable across the four Future Energy Scenarios, see **Section 4** for more information on FES.

398. Please see **Section 6** for commentary on how the cost estimate for this option was developed.

Commercial Actions

399. There are no commercial contracts required to ensure compliance with the 1-in-20 design standard for this option. Network Entry constraints would be managed using existing tools, and these constraint costs would be expected to be significant once the derogations kick in from 2030.

Benefits & Limitations

400. A high-level qualitative view of how the option measures up against the comparison criteria is summarised in **Table 33** to enable comparison across options. See **Section 5.1** for the definition of each criterion and **Appendix G** for how the BAT scores were established.

Investment Option Benefit & Limitations	Cost	Versatility	Future Proofing	Ownership	Constructability	Environmental Amenity	Hazard	Emissions
10 - 2 x New GT	High	15%	15%	13%	4%	2%	5%	25%

Table 33 - Option 10: Benefits & Limitations Breakdown

401. **Cost:** Overall cost investment (CAPEX, OPEX, asset health) is considered high in comparison to other options due to the cost of the two new GT compressor units. CAPEX also includes decommission costs for Units A & B.

402. **Versatility:** This solution was scored 15% out of 15% as the solution meets all the required PDS points and offers the widest possible operational envelope of all the solutions.

403. **Future Proofing**: This solution was scored 15% out of 15% as two new units provide maximum headroom for NO_x and CO emissions. New units are more energy efficient than existing Avon units so maximum energy efficiency headroom is also achieved.

404. **Ownership**: This solution was scored 13% out of 13% as new build GTs will be purchased with dedicated service agreements and long-term availability of spares.

405. **Constructability**: This solution was scored 4% out of 7% as there is moderate complexity associated with the installation of two new GTs on a greenfield location. One outage period has been determined for:

- Outage A: Unit D & E tie-in works

A dedicated outage for Units A & B decommissioning works have not been specified. A decision on decommissioning will be taken once new units are operational and a capability assessment confirms there is no further reliance on Unit A & B's continued operation.

406. **Environmental Amenity**: This solution was scored 6% out of 10% as the greenfield installation location and increased stack height of the new units have the potential to raise challenges during permit & planning applications. This has the potential to cause programme delay.

407. **Hazard**: This solution was scored 5% out of 5% as it is expected that new GT units will comply with new standards for oil containment.

408. **Emissions**: This solution was scored 25% out of 35% (10/20 NO_x; 10/10 CO_2; 5/5 CO) for emissions compliance. Through the use of the low-emission new units, NO_x emissions will be reduced to well within existing MCPD limits. New GT units represent the most environmentally friendly solution in the NGGT suite of emissions reduction options.

Risks

409. Please see **Appendix F** for more detail on the risks defined for this option. The highest rated risks are identified below.

410. **Critical:** Network outage periods are not yet confirmed. Allowed outage may be shorter than anticipated or at less optimum time for construction of new build units.

411. **Critical**: Country specific and worldwide geopolitical issues affecting equipment supply and workforce (greater impact for new build unit).

412. **Major:** Extension of the existing site boundary is necessary for greenfield new builds. This will have an impact on permitting/consents as well as environmental and commercial negotiations. Potential for schedule delay.

413. **Opportunity**: A conservative basis has been taken regarding space/footprint requirement for new build compressors. Opportunity to optimise and reduce with resulting impact on fence extension requirements, foundations etc.

5.3. Option Table Summary

414. Option summary tables are provided for the following aspects to allow for cross comparison across the main options considered:

- Option Shortlist
- Option Cost Breakdown
- Option Benefits & Limitations
- Option Consolidated BAT Scores

415. Options are provided with a description and a numerical label to aid in referencing options throughout this report.

Option Shortlist

Option Shortlist	Unit A	Unit B	Unit C	Unit D	Unit E
1 – Counterfactual	500Hr EUD	500Hr EUD	No Change	/	/
2 - 2 x CSRP	CSRP Retrofit	CSRP Retrofit	No Change	/	/
3 - 2 x SCR	SCR Retrofit	SCR Retrofit	VSD Re-Wheel	/	/
4 – 1533 DLE + 500 Hr	1533 DLE Retrofit	500Hr EUD	No Change	/	/
5 - 2 x 1533 DLE	1533 DLE Retrofit	1533 DLE Retrofit	No Change	/	/
6 - 2 x 1535 DLE	1535 DLE Retrofit	1535 DLE Retrofit	VSD Re-Wheel	/	/
7 - New GT + 500	500Hr EUD	Decom.	VSD Re-Wheel	New GT (Greenfield)	/
8 - New GT + CSRP	CSRP Retrofit	Decom.	VSD Re-Wheel	New GT (Greenfield)	/
9 - New GT + DLE	1533 DLE Retrofit	Decom.	VSD Re-Wheel	New GT (Greenfield)	/
10 - 2 x New GT	Decom.	Decom.	VSD Re-Wheel	New GT (Greenfield)	New GT (Greenfield)

Table 34 - Option Shortlist

Option Cost Breakdown

416. **Table 35** below outlines the cost breakdown for each option including:

- Total Installed Cost
- Total Asset Health Cost (Initial + Ongoing Costs)
- Total Annual OPEX Cost
- Total Decommissioning Cost
- Total Constraint Cost

417. Detail on how project start & finish dates are determined can be found within **Section 5.1.**

418. Detail on option cost estimate accuracy can be found within **Section 6.2**.

Option Cost Comparison Table (18/19 Prices)	Project Start Date	Project Finish Date	Total Installed Cost (£m)	Total Asset Health (£m)	Operating Cost (£m/pa)	Decom. Cost (£m)	Total Constraint Cost (£m)	Cost Accuracy
1 – Counterfactual	2019	2028	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
2 - 2 x CSRP	2019	2028	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
3 - 2 x SCR	2019	2029	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
4 – 1533 DLE + 500 Hr	2019	2028	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
5 - 2 x 1533 DLE	2019	2028	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
6 - 2 x 1535 DLE	2019	2028	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
7 - New GT + 500	2019	2028	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
8 - New GT + CSRP	2019	2028	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
9 - New GT + 1533 DLE	2019	2028	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
10 - 2 x New GT	2019	2029	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 35 - Option Cost Breakdown

419. Regarding considerations for unit design life within option selection, please see **Section 5.1** for more information.

Option Benefits & Limitations

420. **Table 36** & **Table 37** contain traffic light visual representations of how the benefits & limitations of each option compare using technical & environmental analysis performed through the BAT assessment. For detailed information on the BAT assessment, please see **Appendix G**. These tables contain a traffic light graphic to aid easy recognition of the best & worst performing options. Traffic light grades are determined on a percentage basis.

421. BAT assessment scores & weighting were qualitatively determined by representative business stakeholders. Scores are not intended to be used to determine the Final Preferred Option but to support the decision-making process in parallel with cost benefit analysis.

422. Assessments were conducted on two scenarios; VSD available and VSD unavailable. Within this Final Options Selection Report we make reference to the VSD unavailable scenario as it is more relevant for new units which are intended to provide back-up to the VSD unit. BAT assessment scored for both scenarios are provided below.

423. In-depth discussion on how each option is ranked is provided within **Section 5.2.**

Investment Option Benefit & Limitations	Versatility	Future Proofing	Ownership	Constructability	Environmental Amenity	Hazard	Emissions (NOx, CO2, CO)	Total Option Score
1 - Counterfactual	0%	0%	10%	7%	10%	5%	10%	42%
2 - 2 x CSRP	0%	0%	10%	7%	10%	5%	11%	43%
3 - 2 x SCR	6%	9%	5%	0%	6%	2%	30%	58%
4 - 1535 DLE + 500	0%	0%	8%	6%	10%	5%	12%	40%
5 - 2 x 1533 DLE	6%	6%	8%	6%	10%	5%	15%	55%
6 - 2 x 1535 DLE	9%	9%	8%	6%	10%	5%	13%	59%
7 - New GT + 500	3%	0%	10%	4%	6%	5%	15%	44%
8 - New GT + CSRP	9%	0%	10%	4%	6%	5%	16%	51%
9 - New GT + 1533 DLE	12%	9%	8%	4%	6%	5%	23%	67%
10 - 2 x New GT	15%	15%	13%	4%	2%	5%	25%	79%
Total Scores	15% / 65%	15% / 65%	13% / 65%	7% / 65%	10% / 65%	5% / 65%	35% / 35%	

Table 36 - Option Benefits & Limitations (BAT Assessment – VSD Unavailable)

424. For comparison purposes, BAT assessment scores for the scenario where VSD is available are provided in **Table 37**.

Investment Option Benefit & Limitations	Versatility	Future Proofing	Ownership	Constructability	Environmental Amenity	Hazard	Emissions
1 - Counterfactual	0%	0%	10%	7%	10%	5%	14%
2 - 2 x CSRP	0%	0%	10%	7%	10%	5%	15%
3 - 2 x SCR	9%	9%	5%	0%	6%	2%	32%
4 - 1535 DLE + 500	9%	6%	8%	6%	10%	4%	23%
5 - 2 x 1533 DLE	9%	6%	8%	6%	10%	4%	23%
6 - 2 x 1535 DLE	12%	9%	8%	6%	10%	5%	25%
7 - New GT + 500	15%	15%	13%	4%	6%	5%	31%
8 - New GT + CSRP	15%	15%	13%	4%	6%	5%	31%
9 - New GT + 1533 DLE	15%	15%	13%	4%	6%	5%	31%
10 - 2 x New GT	15%	15%	13%	4%	2%	5%	31%
Total Scores	15% / 65%	15% / 65%	13% / 65%	7% / 65%	10% / 65%	5% / 65%	35% / 35%

Table 37 - Option Benefits & Limitations (BAT Assessment – VSD Available)

Option Consolidated BAT Scores

425. **Table 38** contains a breakdown of how each option was scored against the technical & environmental criteria as part of the overall BAT assessment. Technical scores (65%) and environmental scores (35%) are combined to provide for an overall 100% evaluation score. For detailed information on the BAT assessment, please see **Appendix G**. Again, tables contain a traffic light graphic to aid easy recognition of the best & worst performing options. Traffic light grades are determined on a percentage basis.

426. Assessments were conducted on two scenarios – VSD available and VSD unavailable. Within this Final Options Selection Report we make reference to the VSD unavailable scenario as it is more relevant for new units which are intended to provide back-up to the VSD unit.

Option Number	VSD Unavailable	Technical / Environmental Score (qualitative assessment)	Environmental Score based on (quantitative assessment)	Total Score
Option 1	2 x Avon 500 hrs (current equipment)	32%	10%	42%
Option 2	2 x Avon CSRP	32%	11%	43%
Option 3	2 x Avon SCR (1535)	28%	30%	58%
Option 4	1 x Avon DLE (1533) + 1 x Avon 500 hrs	28%	12%	40%
Option 5	2 x Avon DLE (1533)	40%	15%	55%
Option 6	2 x Avon DLE (1535)	46%	13%	59%
Option 7	1 x New GT + 1 x Avon 500 hrs	29%	15%	44%
Option 8	1 x New GT+ 1 x Avon CSRP	35%	16%	51%
Option 9	1 x New GT+ 1 x Avon DLE (1533)	44%	23%	67%
Option 10	2 x New GT	54%	25%	79%
Maximum weighted score available	N/A	65%	35%	100%

Table 38 - BAT Assessment Consolidated Scores (VSD Unavailable)

427. Again, for comparison purposes, BAT assessment scores for the scenario where VSD is available are provided in **Table 39**.

Option Number	VSD Unavailable	Technical / Environmental Score (qualitative assessment)	Environmental Score based on (quantitative assessment)	Total Score
Option 1	2 x Avon 500 hrs (current equipment)	32%	14%	46%
Option 2	2 x Avon CSRP	32%	15%	47%
Option 3	2 x Avon SCR (1535)	31%	32%	63%
Option 4	1 x Avon DLE (1533) + 1 x Avon 500 hrs	43%	23%	66%
Option 5	2 x Avon DLE (1533)	43%	23%	66%
Option 6	2 x Avon DLE (1535)	50%	25%	75%
Option 7	1 x New GT + 1 x Avon 500 hrs	58%	31%	89%
Option 8	1 x New GT+ 1 x Avon CSRP	58%	31%	89%
Option 9	1 x New GT+ 1 x Avon DLE (1533)	58%	31%	89%
Option 10	2 x New GT	54%	31%	85%
Maximum weighted score available	N/A	65%	35%	100%

Table 39 - BAT Assessment Consolidated Scores (VSD Available)

Option Comparison – Key Takeaways

428. From a cost perspective, the Final Preferred Option (Option 10) has the highest upfront capital cost however it is a small proportion compared to projected industry constraint costs should Wormington availability be reduced. Analysis on the differential between up-front capital cost and the potential for significant constraint cost, should this option not be implemented, is discussed further within **Section 7** alongside an estimation of expected payback duration.

429. BAT assessments were conducted on two scenarios; analysis considering Unit C (VSD) to be available and unavailable. The VSD unavailable scenario is considered to be more relevant for this investment decision as the new units are primarily intended to provide back-up to the VSD unit.

430. Option 10 offers the best solution in terms of ability to meet compression requirements (versatility), future resilience against tightening of energy efficiency & emissions limits (future proofing), maintenance complexity and availability of spares (ownership), environmental control (hazard) and emissions reduction efficiency. Ownership scores for new build units contain considerations for initial reliability uncertainty and time to

commission but these “bedding in” limitations do not significantly impact overall technical scoring.

431. It is understandable that options which contain the least complexity will have the smallest impact on site operations (constructability) and contain reduced risk in terms of planning and consent (environmental amenity). However, when these benefits are evaluated in combination with the remaining option limitations, overall option strength is reduced. It should also be noted that one large offline build has considerably less interactions with and impact on existing site operations.

432. Emissions reduction performance is a key consideration for this report. Options have been evaluated in terms of forecast tonnage of NO_x, CO_2 and CO after 2030. Two new units & SCR rank highest through their improved efficiency in reducing emissions while other abatement technologies are penalised through technological limitations and reduced run hours.

6. Cost Definition

6.1. Cost Estimate Methodology

433. As the project has developed since our 2019 RIIO-T2 business plan submission, the accuracy of the scope of works and the estimate itself has improved. The current level of cost confidence ([redacted]) is consistent with other projects at a similar stage and reflect the inherent uncertainties due to further engineering work required to finalise the scope of works; detailed design; and the completion of tendering processes engineering, procurement and construction.

434. The level of cost certainty in our estimates is aligned with an AACE Class 4[48] estimate which the classification system defines as appropriate for project screening, feasibility, concept evaluation and preliminary budget approval. The Infrastructure Projects Association (IPA) published cost estimate guidance[49] classifies a [redacted] cost estimate as suitable for "Outline Business Case".

435. The cost estimates, which are consistent between options, are appropriate to inform the option selection process including CBA and BAT assessment. As detailed in the PCD guidance, the cost Re-opener submission (planned for 2024) will be based on a finalised scope of works, Detailed Design and Build Main Works Contractor (MWC) tendered prices and order values for long lead items.

Estimate Scope

436. We have developed estimates of total installed cost for all 10 shortlisted options as well as the deferral option, consisting of Option 7 and Option 10+. We then determined approximate spend profiles for all options (per **Section 6.3**) so that discounting could be applied in the CBA and BAT assessment tools. All our estimates have been developed based on an assumed standard EPC delivery strategy consisting of the following main contracts: pre-FEED; FEED; EPC, and compressor machinery train equipment.

437. The total installed cost estimates are based on the following main cost elements:

- Installation of new build Compressor Machinery Train equipment including acoustic cab
- Tie-in of new equipment to existing station piping; control and protection systems, electrical, drainage and utilities connections, process vent
- Asset Health scope for existing Avon's to be retained considering planned interventions already funded via our RIIO-T2 business plans (see Asset Health Report**, Appendix D**)
- Re-wheel of the VSD compressor to ensure efficient load sharing between new or modified GTs
- Retrofit emissions abatement modifications to existing Avon driven compressor trains (SCR, DLE, CSRP)

[48] AACE International Recommended Practice No. 18R-97 – Cost Estimate Classification System – As Applied In Engineering, Procurement and Construction for The Process Industries
[49] IPA_Cost_Estimating_Guidance.pdf (publishing.service.gov.uk)

- Engine upgrades for applicable retrofit options
- Decommissioning of redundant compressor units

438. Whole life cost estimates also include estimated ongoing asset health spend for new and existing GTs until 2050. These costs include asset refurbishment and replacements based on our asset management policies, procedures and specifications and they are consistent with asset health plans approved as part of our 2019 RIIO-T2 business plans.

439. Other recurring costs in our whole life cost estimates include OPEX, fuel consumption, reagent use and catalyst replacement for SCR option and network constraint cost.

Base Data

Compressor Machinery Train Equipment

440. For new build options, [redacted] identified suitable compressor machinery train equipment following review of process requirements and initial engagement with original equipment manufacturers (OEMs) on our compressor machinery train supply framework. We then based equipment costs on budget prices provided by OEMs, and prices and contract costs from recent compressor projects. Wormington Compressor Station, as with many of our sites, is located in an area of low background noise meaning compressor noise must be mitigated through the use of low noise compressor acoustic enclosures. Costs for these enclosures are included in the compressor machinery train equipment cost estimates and are based on costs for similar equipment purchased for other sites.

Tie-in of New Equipment

441. New compressor machinery train equipment will be installed on a greenfield location to the south of the existing plot based on a layout developed by [redacted] as described in the Engineering Report in **Appendix C**. Tie-in of new assets into existing site infrastructure has been priced based on Material Take Offs (MTOs) produced by [redacted] with the following allowances applied:

- **Technical Allowance –** Covers design development (e.g., Equipment specifications, changes in size and valve specifications etc)
- **Growth –** Covers increase in size/complexity of the project as engineering definition develops (eg. Plot layout definition increase due to additional small bore piping, valves, non-tagged minor equipment etc)
- **Cut and Waste –** bulk material off-cuts, overages and waste
- **MTO Allowance –** margin to cater for items not included MTOs (e.g., Small bore piping and valves, bolts and gaskets, minor electrical and instrumentation material etc)

442. Procurement costs are based on in house material cost data and fabrication and installation costs are based on in house labour rates. Given the prevailing national and international geopolitical conditions, labour and material rates present a risk to the project, particularly for new build options involving larger scope. This risk is noted in the risk register in **Appendix F**.

Asset Health Interventions

443. The scope of asset health interventions required on the existing Avon compressor trains and associated equipment is defined in the Asset Health Report in **Appendix D**. Our RIIO-T2 asset health plans were based on retaining the existing Avons at Wormington until 2030 when they would be replaced with new units as part of our preferred option for MCPD compliance.

444. Asset health costs are based on unit costs agreed as part of our RIIO-T2 business plans where available as shown in the table below. These costs are total installed cost and therefore no additional cost factors or Unallocated Provision (UAP) has been applied.

Cost Element	Unit Cost ID	Total Installed Cost Estimate *(18/19 price base)*	Comment
Control			
Unit control system	N/A[50]	[redacted]	From RIIO-T2 Control System Cyber and Asset Health business plan submission
Fire and Gas Detection	N/A[51]	[redacted]	
Anti-Surge System	N/A[52]	[redacted]	
Electrical			
Distribution Boards	A22.22.4.17	[redacted]	
Auxiliary Equipment	A22.22.4.30	[redacted]	
LV Switchboards	A22.22.4.20	[redacted]	
Rotating Equipment			
Gas Generator - overhaul	A22.10.2.4	[redacted]	
Power turbine	A22.10.2.14	[redacted]	
Compressor Impeller Refurb	A22.10.2.1	[redacted]	
Compressor - dry gas seal	A22.10.1.3	[redacted]	
Compressor Acoustic Building			
Building - CAB (Major)	A22.08.1.8	[redacted]	
Building - CAB (Minor)	A22.08.1.7	[redacted]	
CAB Ventilation (Major)	A22.08.1.4	[redacted]	
CAB ventilation (Minor)	A22.08.1.5	[redacted]	
Air intake (Major)	A22.08.1.3	[redacted]	
Air intake (Minor)	A22.08.1.2	[redacted]	
Exhausts (Major/Replace)	A22.08.1.11	[redacted]	
Exhausts (Minor)	A22.08.1.10	[redacted]	
Piping & Valves			
Unit Isolation Valves	A22.14.1.22	[redacted]	
Non-Return Valves	A22.22.6.4	[redacted]	
Other Ancillary Systems			

[50] Cost based on RIIO-T2 Plan Annex 15.07 – Cyber Resilience Plan
[51] Approved RIIO-T2 funded scope excluded
[52] Intervention frequency of 20 years for 500-hour EUD

Fuel Gas Skid	A22.10.2.1	[redacted]	
Oil System (GG, PT, Comp)	A22.10.1.4	[redacted]	
Fire Suppression	A22.08.2.3	[redacted]	

Table 40 - Asset Health Costs

445. A re-wheel of the Unit C (electric VSD) compressor is included in options involving Avon 1535 unit(s) or new unit(s) to ensure efficient load sharing between GT and electric VSD compressors. The cost for this re-wheel is based on vendor quotation for similar work at another of our compressor stations.

Decommissioning

446. We have included the cost for decommissioning existing Avon compressor units where they will be replaced with new units. These costs are based on confirmed allowances for decommissioning of similar units at other sites. However, the investment decision on decommissioning scope will be made as part of an NTS wide decommissioning plan and will not form part of the MCPD cost Re-opener.

Emissions Abatement Technology

Selected Catalytic Reduction

447. The SCR system consists of a replacement exhaust stack incorporating NO_x and CO catalysts. Emissions must be monitored via a continuous emissions monitoring system connected to the control system. Aqueous ammonia is used as the reagent and is supplied by tanker to a storage and loading area which is connect to the injection points in the exhaust stacks via permanent piping connections. Equipment supply and installation costs were provided by [redacted] per the report included in **Appendix I**. We then estimated structural, civil and tie-in costs using a similar methodology to new build options.

448. Catalyst replacement cost and reagent costs are included in the OPEX estimate and are based on prices provided by [redacted] and forecast compressor run hours to 2050.

Control System Restricted Performance

449. The CSRP option involves restricting emissions through control system modifications and there are no physical asset modifications required. Therefore, option costs are assumed similar to the 500 hour EUD option and include asset health scope only. There may be some incremental costs associated with the application of the CSRP restrictions, these are assumed to be negligible in the context of the [redacted] estimates.

Dry Low Emissions

450. The Avon DLE retrofit modification involves replacement of the combustion system in the gas generator with DLE combustors, a modified engine casing and modifications to the fuel supply system and associated controller. Cost estimates for this scope is based on negotiated prices with [redacted] which are based on our Avon 1533-75G gas generators per the scope summarised in **Appendix H**.

451. We have also been in discussion with Siemens who are developing a similar retrofit modification based around the more powerful and newer Avon 1535 gas generator.

This option would involve upgrading our Avon 1533 engine to the 1535 derivative, which is a standard upgrade pathway offered by Siemens, before installing the required DLE modifications. Costs for these modifications are based on supplier provided budget quotes.

Remaining Project Cost

452. All remaining project costs were estimated based on cost factors taken from in-house cost data. These costs include the following:

- Engineering design including FEED, Detailed Design, surveys and third party consultancy
- Client and contractor project management during design and construction
- Other client costs (overhead)
- Freight
- Certification and documentation
- Commissioning and operational spares
- Insurance
- Vendor representatives
- Third Party inspection
- First Fills
- Royalties

Unallocated Provision

453. Unallocated provisions are included in the estimate to account for unidentified growth and/or uncertainties in rates, etc. A [redacted] UAP factor has been applied to the base cost for all options excluding asset health and decommissioning spend. If all the assumptions on which the base estimate was made turn out to have been valid, then the base cost estimate should represent the expected cost or [redacted]

454. There are many potential sources of over-run for a project of this type, such as schedule delays, labour disputes, supplier problems, etc. There will be many such risks on the project risk register, many of which will not occur. However, as they all have a finite chance of happening, some will occur and have a cost impact, others might require mitigation to be put in place, at a cost, to ensure that either they do not occur or they can be dealt with.

455. Moreover, not all assumptions made in the study design premise will turn out to be valid. Some will have been first guesses but there is no allowance in the base estimate for wrong assumptions. There may also be considerable uncertainty in the estimate because of work yet to be performed or finalised; e.g., flow assurance, weather or contracting strategy. Any one of these could have a significant impact on the cost estimate.

456. Because there will be problems and changes, even though we do not yet know what they will be, a provision needs to be added to the base estimate to obtain the [redacted] estimate. This provision is not a management reserve or budget contingency (such a

contingency, typically included by operating companies, would be added on top of the [redacted] estimate); instead, it is an unallocated provision for project risks, weak data and inadequate scope definition.

457. UAP does not cover force majeure, major changes, political upheaval, major location change, capacity changes >10%, major / national strikes, major legislation change, major cost inflation change, major industrial disputes, bankruptcy major contractor, major exchange rate fluctuations and natural disasters.

6.2. Option Cost Estimate Details

458. CAPEX estimates for each option are provided per the breakdown requested in the 2019 Engineering Justification Paper (EJP) guidance document. Asset health costs are included separately as they are based on RIIO-T2 unit costs. All costs are provided in 2018/19 price base year and should be considered accurate to [redacted]. An unallocated provision of [redacted] is included as detailed within **Section 6.1**. A detailed cost breakdown can be seen in **Table 41** below.

Cost Element	Description	Option Total Installed Cost [redacted] (18/19 price base), [redacted]										
		1	2	3	4	5	6	7	8	9	10	10+
Engineering Design	studies/FEED/Detailed design as appropriate.	-	-	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Project Management	Element of project costs attributed to project management, not direct or indirect company costs.	-	-	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Materials	Bulk materials, breakdown preferred	-	-	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Main Works Contractor	Project construction contractor costs.	-	-	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Specialist Services	Costs for any additional services used to support the project i.e., surveys, data procurement etc	-	-	-	-	-	-	-	-	-	-	-
Vendor Package costs	Compressor Machinery Train Equipment procurement	-	-	-	-	-	-	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Direct Company Costs	Refer to Regulatory Instructions and Guidance for definition of direct company costs.	-	-	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Indirect Company Cost	Refer to Regulatory Instructions and Guidance for definition of indirect company costs	-	-	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Contingency	Contingency included in base cost estimate	-	-	-	-	-	-	-	-	-	-	-
Total Installed Cost	**Cost excluding asset health cost and UAP**			[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Unallocated Provision (UAP)		-	-	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Asset Health	Total installed costs for asset health scope required prior to 2030	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Overall Total		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 41 - Option Cost Breakdown (Detailed)

6.3. Project Spend Profile

459. CAPEX profiles for each option have been produced and used in the CBA and BAT assessment. We have based the spend profiles on the breakdown shown below, Table 42, applied in accordance with project delivery programmes included in **Appendix E.**

Programme Phase	Proportion of Total Installed Cost
Pre-FEED	10%
FEED	10%
Consents	5%
Detailed Design	20%
Procurement and Fabrication	20%
Construction and Commissioning	35%

Table 42 - Spend Profile Programme Phase Breakdown

460. The spend profile for the preferred option is shown in **Table 43** below.

2021/22	2022/23	2023/24	2024/25	2025/26	2026/27	2027/28	Total
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 43 - Preferred Option (Option 10) Spend Profile ([redacted], 18/19 price base)

7. Business Case

461. This section shows the breakdown of operational costs for each option. These costs along with the others detailed in this section are included in the CBA to produce a NPV for each option.

7.1. Key Business Case Drivers Description

Constraints

462. The annual constraint costs are shown in **Figure 18** for the System Transformation scenario. These are clearly much higher in the counterfactual than the other options. With the Avons limited to 500 hours the availability of the compressors is significantly reduced. Overall constraints increase significantly from today's levels in all options. The increasing reliance on LNG as other supplies decline is a key reason for this. With Wormington's criticality on the network increasing, restrictions to the compression capabilities will become more significant. The increasing flows also result in a greater underlying constraint risk which results in large constraints in all options in the later years. These underlying constraint increases are not linked to the investments at Wormington but rather indicate the need for further capability work for this corridor.

[redacted]

Figure 18 - Annual Constraints

463. To avoid the underlying constraints distorting the differences between the options, **Figure 19** shows the annual constraints relative to the lowest constraint option, which is Option 10 – Two New units. The counterfactual has also been removed to show how the other options perform relative to each other.

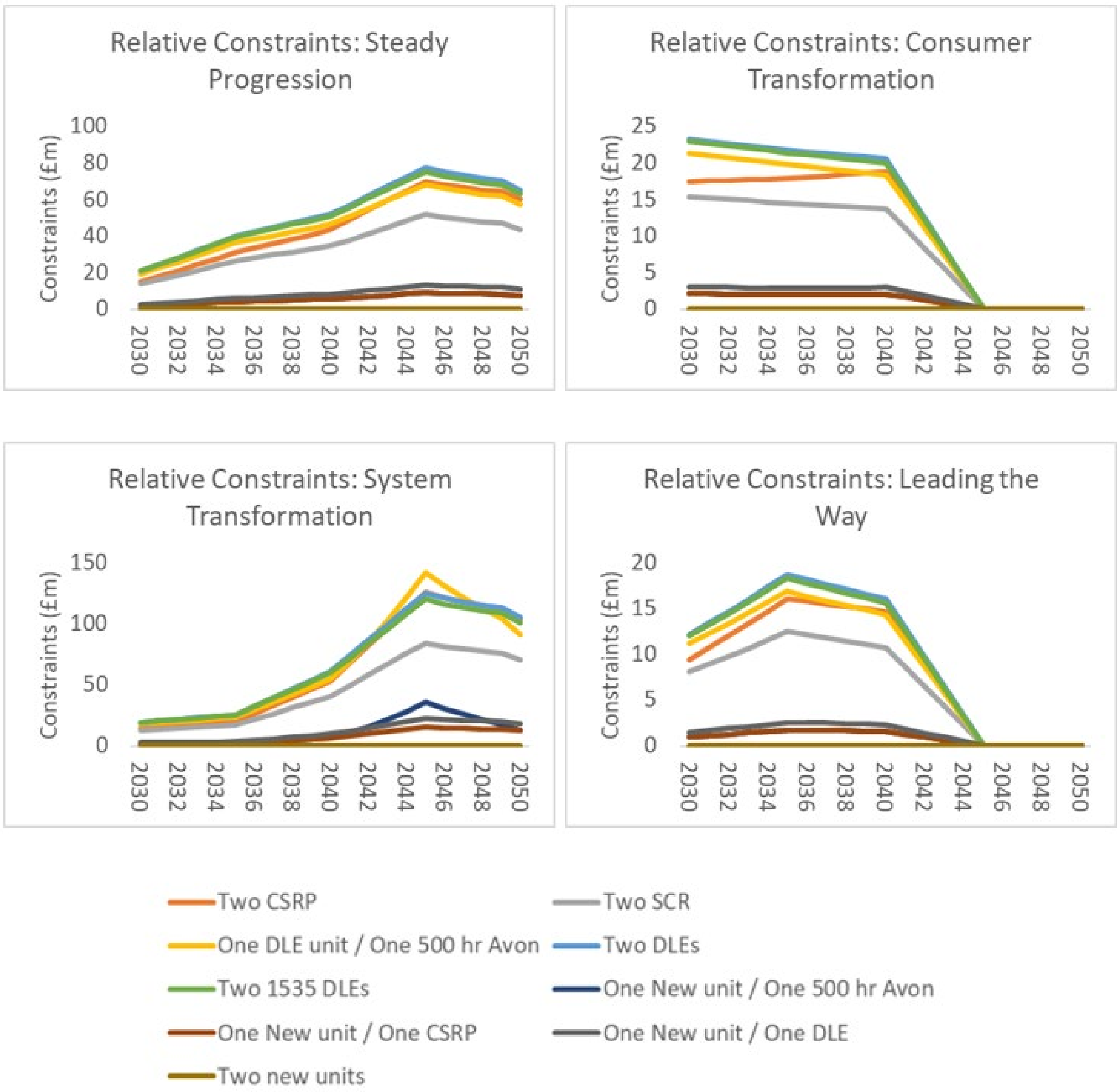


Figure 19 - Relative Annual Constraints

464. The relative performance of the options is similar in most scenarios with constraints based on the capability of each option along with the level of availability. The only difference is where there remains a unit limited to 500 hours of operation, as is the case in Options 4 and 7 which both retain a derogated Avon. For both of these options there is an increase in constraints in 2045 as the 500 limit impacts availability.

Cost Breakdown

465. **Figure 20** and **Figure 21** show the breakdown of the costs included in the CBA. This is split into the investment costs and compressor running costs. This allows a comparison over the relative costs in each of the options.

466. As would be expected, Option 10 – Two New units, has the highest investment costs, followed by the other options with new units. The options which retain the Avons and mitigate the emissions by retrofitting DLE or installing CSRP have lower investment costs but slightly higher ongoing asset health. These costs are covered in more detail in **Section 6.1** & **6.2.**

[redacted]

Figure 20 - Asset Costs included in the CBA

[redacted]

Figure 21 - Operational Costs included in the CBA

Operating Costs

467. While there are differences in fuel costs across the options these are not significant. The Emissions are more significant with the newer units emitting less CO_2 and incurring less damage costs.

468. The counterfactual sees the lowest fuel and emissions costs, this is due to the units being limited to 500-hours with the other options running significantly more. These

savings in fuel and emissions are more than outweighed by the increase in constraints by limiting the running of the compressors.

7.2. CBA Summary

CBA Assessment

469. **Table 44** shows the results of our CBA in our base case of System Transformation. All options had a positive NPV compared to the counterfactual, with the constraint costs outweighing the lower investment costs of this option.

Option	Relative NPV	Absolute NPV	Rank
1 – Counterfactual	£0 m	[redacted]	10
2 - 2 x CSRP	£3846 m		6
3 - 2 x SCR	£4057 m		5
4 – 1533 DLE + 500 Hr	£3832 m		7
5 - 2 x 1533 DLE	£3780 m		9
6 - 2 x 1535 DLE	£3796 m		8
7 - New GT + 500	£4531 m		3
8 - New GT + CSRP	£4560 m		2
9 - New GT + DLE	£4509 m		4
10 - 2 x New GT	£4639 m		1

Table 44 - NPVs System Transformation

470. Our lead option is to install two new units to replace both existing Avons. This option has the highest level of availability, highest capability and achieves the lowest level of emissions. This minimises the constraint risk by ensuring we have enough capability to meet the flow requirements and by achieving a high level of availability.

7.3. Supply and Demand Scenario Sensitivities

Key Assumptions

471. The key assumptions behind the Wormington case are detailed in **Table 45** below.

Category	Assumption	Base Assumption	Rationale
CBA parameters	WACC	2.81%	Defined in RIIO-T2
	Social Time Preference Rate	3.5% (Years 0 – 30) / 3.0 % (30+)	Defined in Green Book
	Regulated Asset Life	45 years	Defined in RIIO-T2
	Assessment Period	25 years	Based on lifetime of asset
	Depreciation	SOTYD	Defined in RIIO-T2
	Capitalisation	75.00%	Defined in RIIO-T2
Constraints and Fuel	Gas Price	Annual price 50 – 64 p/th	BEIS reference scenario
	Compressor Fuel Costs	Gas Price	
	Constraint management pricing	[redacted]	As defined by Commercial Constraint Price Methodology
	Constraint management method	50% buybacks/50% locational actions	Reflective of tools available to manage constraints
Emissions	CO2 cost	Annual price 241 – 378 £/tonne	BEIS Valuation of greenhouse gas emissions: for policy appraisal and evaluation : Central Case
	NOx price	£6,199 £/tonne	DEFRA damage costs

Table 45 - Key Assumptions and Sensitivities

Scenario Sensitivities

472. To test the sensitivity of the Wormington case to different supply and demand scenarios we have tested the case against all four FES scenarios. The relative and absolute NPVs of these can be seen in **Table 46** and **Table 47** respectively.

473. Our lead option in both the Steady Progression and System Transformation scenarios was Option 10 – Two new units. This option provides both the highest capability and highest level of availability minimising the constraint costs. With significant flows of LNG using the South Wales route the reduction in constraints outweighs the lower investment in the other options.

474. While Option 7 – One New Unit/One 500hr Avon is the lead option in the Leading the Way and Consumer Transformation scenarios, this is dependent on a rapid transition away from gas as a heating source with little utilisation of Hydrogen.

Option	Steady Progression	Consumer Transformation	Leading the Way	System Transformation
1 – Counterfactual	£0 m	£0 m	£0 m	£0 m
2 - 2 x CSRP	£2829 m	£196 m	£141 m	£3846 m
3 - 2 x SCR	£2933 m	£200 m	£139 m	£4057 m
4 – 1533 DLE + 500 Hr	£2802 m	£181 m	£136 m	£3832 m
5 - 2 x 1533 DLE	£2719 m	£153 m	£113 m	£3780 m
6 - 2 x 1535 DLE	£2722 m	£144 m	£104 m	£3796 m
7 - New GT + 500	£3334 m	£327 m	£233 m	£4531 m
8 - New GT + CSRP	£3326 m	£315 m	£220 m	£4560 m
9 - New GT + 1533 DLE	£3287 m	£303 m	£211 m	£4509 m
10 - 2 x New GT	£3377 m	£309 m	£209 m	£4639 m

Table 46 - CBA Results vs. FES 2021 - Relative NPV

Option	Steady Progression	Consumer Transformation	Leading the Way	System Transformation
1 – Counterfactual	[redacted]	[redacted]	[redacted]	[redacted]
2 - 2 x CSRP	[redacted]	[redacted]	[redacted]	[redacted]
3 - 2 x SCR	[redacted]	[redacted]	[redacted]	[redacted]
4 – 1533 DLE + 500 Hr	[redacted]	[redacted]	[redacted]	[redacted]
5 - 2 x 1533 DLE	[redacted]	[redacted]	[redacted]	[redacted]
6 - 2 x 1535 DLE	[redacted]	[redacted]	[redacted]	[redacted]
7 - New GT + 500	[redacted]	[redacted]	[redacted]	[redacted]
8 - New GT + CSRP	[redacted]	[redacted]	[redacted]	[redacted]
9 - New GT + 1533 DLE	[redacted]	[redacted]	[redacted]	[redacted]
10 - 2 x New GT	[redacted]	[redacted]	[redacted]	[redacted]

Table 47 - CBA Results vs. FES 2021 - Absolute NPV

Price and Market Sensitivities

475. Given the current volatility in energy markets it is key to understand the impact of prices on our investments. Our central CBA is based on the BEIS reference case for gas prices, these prices are broadly aligned to historic levels. They do not account for the levels seen over the last year or so, with first tight global LNG markets and then the conflict in Ukraine driving prices to historic levels.

476. To understand the impact of long-term higher prices we have modelled several different potential prices:

- BEIS High Price (80 – 90p/th)
- Low (P5) from last 12 months (114p/th)
- Average from last 12 months (219p/th)

477. In all three price levels our selected option remains unchanged, which is to be expected given it has the lowest constraints. This does significantly increase the difference between our lead option of installing two new units and the option to install One New unit and retain one on 500 hours. In our base case this is [redacted], however this increases to [redacted] when considering the BEIS high price, up to [redacted] when

considering the low price from the last 12 months and up to [redacted] when considering the average price from the last 12 months. Price sensitivities can be seen in **Table 48** below.

Option	BEIS High Price	P5 last 12 Months	Average Last 12 Months
1 – Counterfactual	£0 m	£0 m	£0 m
2 - 2 x CSRP	£5297 m	£6850 m	£13279 m
3 - 2 x SCR	£5599 m	£7248 m	£14075 m
4 – 1533 DLE + 500 Hr	£5277 m	£6822 m	£13221 m
5 - 2 x 1533 DLE	£5208 m	£6734 m	£13059 m
6 - 2 x 1535 DLE	£5235 m	£6772 m	£13144 m
7 - New GT + 500	£6251 m	£8094 m	£15709 m
8 - New GT + CSRP	£6294 m	£8152 m	£15830 m
9 - New GT + 1533 DLE	£6224 m	£8063 m	£15659 m
10 - 2 x New GT	£6412 m	£8314 m	£16165 m

Table 48 - Price Sensitivities System Transformation – Relative NPV

478. Another key sensitivity is to understand how changes in the global gas market could impact the investment. In both the UK and across Europe gas demand is being met increasingly by LNG with imports of Russian gas declining. In the UK this has seen much higher utilisation of Milford Haven with decreased imports through both the Interconnector and BBL pipelines. To model the impact if these changes persist in the long term, we have run the CBA only considering the high LNG case from the future energy scenarios. This maximises the use of LNG to meet flexible supply, with lower levels of imports from the continent.

479. The lead option in each scenario doesn't change in this sensitivity but the difference between our lead option to install two new units and the option to install one new unit and retain one Avon on 500 hours is reduced in the Consumer Transformation and Leading the Way scenario. **Table 49** shows the high LNG sensitivity results.

Option	Steady Progression	Consumer Transformation	Leading the Way	System Transformation
1 – Counterfactual	£0 m	£0 m	£0 m	£0 m
2 - 2 x CSRP	£4376 m	£276 m	£171 m	£5524 m
3 - 2 x SCR	£4593 m	£292 m	£176 m	£5889 m
4 – 1533 DLE + 500 Hr	£4387 m	£251 m	£165 m	£5560 m
5 - 2 x 1533 DLE	£4253 m	£215 m	£139 m	£5483 m
6 - 2 x 1535 DLE	£4269 m	£208 m	£130 m	£5517 m
7 - New GT + 500	£5199 m	£471 m	£287 m	£6556 m
8 - New GT + CSRP	£5190 m	£458 m	£274 m	£6607 m
9 - New GT + 1533 DLE	£5128 m	£443 m	£263 m	£6531 m
10 - 2 x New GT	£5290 m	£462 m	£266 m	£6739 m

Table 49 - High LNG Sensitivity

Other Sensitivities

480. To stress test our lead option we have looked to change key elements of the CBA to understand what it would take to change our option. It required an increase of 220% (multiply by 320%) to investment costs to change our lead option. In this case Option 8 – One New Unit / One CSRP became the new lead option. We do not believe cost increases of this magnitude are likely. We also tested the impact of changing Ongoing Asset Health costs, however increasing/decreasing these did not result in any changes to the results.

481. In addition to the costs, we also tested the impact of reducing constraints. In this case it required an 80% decrease in constraints to result in a change in option, in this case to Option 7 – One New Unit / One 500 hour Avon. **Table 50** shows the stress test.

Element	Change	New Lead Option
Investment Cost	Increase 220%	Option 8 – One New unit / One CSRP
Ongoing Asset Health Costs	No sensitivity changed the results.	N/A
Constraints	Decrease 80%	Option 7 – One New unit / One 500hr Avon

Table 50 - Stress Test

482. To test the performance of the options if the PARCA at Milford Haven does not proceed we have run a sensitivity without the increased capability and flows which would be delivered by the PARCA.

483. This sensitivity does not fundamentally change the outcome of the CBA when compared to our main case. While flows are reduced without the PARCA so is the capability of the network. The lead option in each of the scenarios remain the same. When assessing the full period constraints are lower which does reduce the relative NPV but overall, this does show our recommended option remains the same even without the PARCA. The relative and absolute NPVs can be seen in **Table 51** and **Table 52** below.

Option	Steady Progression	Consumer Transformation	Leading the Way	System Transformation
1 – Counterfactual	£0 m	£0 m	£0 m	£0 m
2 - 2 x CSRP	£1929 m	£136 m	£2 m	£2997 m
3 - 2 x SCR	£1909 m	£95 m	-£41 m	£2931 m
4 – 1533 DLE + 500 Hr	£1890 m	£149 m	£19 m	£2740 m
5 - 2 x 1533 DLE	£1829 m	£96 m	-£32 m	£2813 m
6 - 2 x 1535 DLE	£1817 m	£84 m	-£44 m	£2800 m
7 - New GT + 500	£2032 m	£193 m	£53 m	£3015 m
8 - New GT + CSRP	£2014 m	£135 m	-£8 m	£3082 m
9 - New GT + 1533 DLE	£1979 m	£126 m	-£15 m	£3034 m
10 - 2 x New GT	£2068 m	£147 m	£0 m	£3170 m

Table 51 - Relative NPV – Without PARCA

Option	Steady Progression	Consumer Transformation	Leading the Way	System Transformation
1 – Counterfactual	[redacted]	[redacted]	[redacted]	[redacted]
2 - 2 x CSRP	[redacted]	[redacted]	[redacted]	[redacted]
3 - 2 x SCR	[redacted]	[redacted]	[redacted]	[redacted]
4 – 1533 DLE + 500 Hr	[redacted]	[redacted]	[redacted]	[redacted]
5 - 2 x 1533 DLE	[redacted]	[redacted]	[redacted]	[redacted]
6 - 2 x 1535 DLE	[redacted]	[redacted]	[redacted]	[redacted]
7 - New GT + 500	[redacted]	[redacted]	[redacted]	[redacted]
8 - New GT + CSRP	[redacted]	[redacted]	[redacted]	[redacted]
9 - New GT + 1533 DLE	[redacted]	[redacted]	[redacted]	[redacted]
10 - 2 x New GT	[redacted]	[redacted]	[redacted]	[redacted]

Table 52 - Absolute NPV - Without PARCA

7.4. Investment Deferral Analysis

Scope Assumptions

484. To assess deferring our investment, we have considered Option 7. This option involves installation of one new unit on a greenfield area of NGGT owned land to the south of the existing plot with one existing Avon retained on 500 run hours per year. This option would progress with a similar programme duration to the preferred option but with additional outages required for the asset health works associated with the retained Avon. No pre-investment costs have been included within the cost estimate for a second new unit so that the discounting effect of investment deferral is maximised.

485. Should network capability requirements dictate additional compression requirements at Wormington in the future then a second new unit would be installed adjacent to the new unit installed as part of the initial MCPD investment. Other than allocation of sufficient plot space, no pre-investment is included in the initial MCPD investment so that the discounting effect of investment deferral is maximised in the CBA. However, this minimal pre-investment philosophy would create constructability challenges for the installation of a second new unit due to the scope of construction works that would need to be conducted close to the operational unit. These issues have not been accounted for in the CBA and it has been assumed that the second unit can be installed efficiently with a single site outage for tie-in and commissioning.

486. For the purpose of the CBA it has been assumed that the second new unit would be delivered under completely separate contract arrangements to the initial investment due to the programme and scope uncertainty. The cost of tendering these additional contracts and the fixed costs associated with each contract offer potential efficiencies which would need to be reviewed alongside potential design efficiencies through the development of a pre-investment philosophy. This pre-investment philosophy would need to be produced in the pre-FEED stage and developed alongside development of the engineering design and delivery strategy of the initial MCPD investment.

487. The deferral option assessed would require an investment decision on the second unit to be made by the end of 2030 to allow operational acceptance of the second unit before 2035. This is based on a similar delivery approach to the first unit with pre-FEED followed by FEED and EPC. It may be possible to shorten the delivery period between investment decision and operational acceptance through refinement of the delivery and pre-investment strategies. On balance the assumptions regarding delivery strategy and pre-investment used to support CAPEX estimates and spend profiles are considered appropriate to allow fair assessment via CBA at this stage.

Real Option Analysis

Two Units

Single Unit

One Unit Now / Option to Expand in 2035

[redacted]

Weighted NPV -694.3

Two Units Now

Value of Delay £5.0 m

[redacted]

Weighted NPV -699.3

Figure 22 - Real Option Analysis Delay until 2035

488. When assessing all the scenarios equally this delay seems beneficial overall with the risk of overinvestment outweighing the increased constraint risk. If we consider two of the key sensitivities, higher gas prices and higher LNG flows, these benefits are lost with little benefit to delaying the investment in either sensitivity. The results for the sensitivity and the central case can be seen in **Table 53** below.

Investment Delay & Sensitivity Analysis	Central Case	Price Sensitivity (BEIS High Case)	Flow Sensitivity (High LNG)
Steady Progression	[redacted]	[redacted]	[redacted]
Consumer Transformation	[redacted]	[redacted]	[redacted]
Leading the Way	[redacted]	[redacted]	[redacted]
System Transformation	[redacted]	[redacted]	[redacted]
Overall Delay Value	£5.0m	£0.2m	-£0.9m

Table 53 - Delay analysis and sensitivity results

489. Delaying the investment does risk exposing consumers to increased risk if supply and demand is closer to Steady Progression and System Transformation, even in the short term. The risk to consumers in these scenarios is around [redacted] in our base case, but this could be as high as [redacted] in the High LNG scenario.

490. Given the lack of progress towards both Leading the Way and Consumer Transformation as detailed CE-AMP, delaying the investment could limit the UK's ability to access LNG supplies. These flows contribute significantly to UK security of supply, both by providing access to global gas markets and acting as a source of flexible supplies to respond rapidly to changes in supply and demand. Any disruptions which limit the capability of Milford Haven could pose a significant risk to Security of Supply and increase the chances of serious disruptions to the UK gas market.

7.5. Business Case Summary

491. The preferred option in our central scenario is Option 10 – install two new units. This significantly reduces the constraint risk, both compared to the counterfactual and Option 8. Overall, the relative NPV is £4639m and almost £80m higher than Option 8 with a relative NPV of £4560. Relative NPV can be seen in **Table 54.**

492. When we consider all four scenarios Option 10 – install two new units is positive against all scenarios. While this is not the lead option in all scenarios, with Option 7 – One New unit / One 500 hour Avon the lead in both Leading the Way and Consumer Transformation. However, when considering all four scenarios together Option 10 – Two New units performs best on balance, with the highest average NPV across the four scenarios.

Option	Steady Progression	Consumer Transformation	Leading the Way	System Transformation	Average
1 – Counterfactual	£0 m	£0 m	£0 m	£0 m	**£0 m**
2 - 2 x CSRP	£2829 m	£196 m	£141 m	£3846 m	**£1753 m**
3 - 2 x SCR	£2933 m	£200 m	£139 m	£4057 m	**£1832 m**
4 – 1533 DLE + 500 Hr	£2802 m	£181 m	£136 m	£3832 m	**£1738 m**
5 - 2 x 1533 DLE	£2719 m	£153 m	£113 m	£3780 m	**£1691 m**
6 - 2 x 1535 DLE	£2722 m	£144 m	£104 m	£3796 m	**£1692 m**
7 - New GT + 500	£3334 m	£327 m	£233 m	£4531 m	**£2106 m**
8 - New GT + CSRP	£3326 m	£315 m	£220 m	£4560 m	**£2105 m**
9 - New GT + 1533 DLE	£3287 m	£303 m	£211 m	£4509 m	**£2078 m**
10 - 2 x New GT	£3377 m	£309 m	£209 m	£4639 m	**£2134 m**

Table 54 - Relative NPV with average across scenarios

493. Several sensitivities were carried out and when stress testing against both investment costs and constraints our recommended option proved to be robust against changes to these elements, with cost increases of 220% and constraint decreases of 80% needed to change the option. In addition to the stress tests, we also assessed sensitivities which tested our proposals against the impact of higher prices and increased LNG flows. In these sensitivities Option 10 – Two New Units continued to have the highest NPV against our central case.

494. When assessing the potential to delay the decision to install a second unit there was a potential value £5m in this delay. When assessing the High LNG and High Price sensitivities this value is reduced to £0m. The delay to the investment would also expose consumers to increased risk in both the Steady Progression and System Transformation scenarios. These risks would be around £10m and could increase to £15-20m in our High LNG and high Price sensitivities.

8. Preferred Option Detail

8.1. Preferred Option for the request

What is the Driver for this Investment?

495. The primary driver for future investment at Wormington Compressor Station is to ensure compliance with Medium Combustion Plant Directive (MCPD) emissions legislation. Failure to invest in emissions reduction or replacement with new MCPD compliant units will place the existing Avon Units A & B onto reduced running hours which reduces site availability. The implication of this, given high future compression requirements at Wormington, is significant constraint costs for consumers, potentially higher gas costs for consumers and reduced security of supply.

496. In addition to ensuring compliance to the aforementioned emissions legislation, NGGT must also ensure the right level of network capability is maintained in order to fulfil our customer's needs and our operational requirements, efficiently minimising network constraints and meeting the 1-in-20 peak day demand. We must ensure that our network is safe, reliable and that it delivers value for our consumers and stakeholders, while minimising impact on the environment.

Our Investment Recommendation

497. Our Final Preferred Option decision was driven by a robust option selection process where a range of emission reduction solutions were evaluated by CBA and BAT assessment; including derogation, abatement, new build and availability enhancement. Our CBA utilised [redacted] CAPEX estimates to determine the whole life cost for each short-listed option. Unit capability was assessed using network capability modelling while availability estimates were based on NTS operational data and site-specific RAM models as described in **Appendix B** and **Appendix K**. These CBA inputs combined to determine the highest NPV option based on projected network capability requirements outlined across the four Future Energy Scenario's. The BAT assessment, which is an Industrial Emissions Directive requirement, supported decision making through qualitative scoring of options based on an operational and environmental perspective.

498. Based on the outcome of the CBA, BAT assessment and considering the criticality of Wormington Compressor Station to the UK's security of supply, the installation of two new gas–driven compressor units is our Final Preferred Option. These units will be located on a greenfield site which is outside the existing site footprint but within the National Grid land ownership boundary at Wormington Compressor Station. For cost evaluation purposes, unit size was determined to be approximately 15 MW each but following Final Preferred Option approval each new unit will be appropriately sized to meet capability requirements. This option provides long-term emissions compliant compression capability that is needed to meet forecast future requirements across the Future Energy Scenarios.

Justification for New Build Investment

499. Two new units is one of the highest performing solutions (alongside SCR) from an emissions reduction perspective. New GT compressors offer efficient operation, long-

term reliability and low emission compression. In comparison to the counterfactual, two new units provide an 87%[53] reduction in NO_x emissions until 2050 (in the scenario where VSD is unavailable). New units also feature the most up-to-date technology which protects this investment from future changes in energy legislation ahead of the UK's aspiration to achieve Net Zero by 2050.

500. While new build units incur the highest capital investment cost, this is offset against reductions in future constraints. Overall, this option provides the best return on investment for consumers considering the impact of constraint costs until 2050. Relative NPV is expected to turn positive from 2032 based on projections from the System Transformation scenario.

501. From a technical perspective, Option 10 received the highest overall technical rating with the BAT assessment compared to the alternative investment options. New units scored highest in terms of network versatility, future proofing against changes in energy legislation, maintainability and environmental hazard control.

502. The Final Preferred Option ensures the highest unit availability of all shortlisted options. When comparing the unit availability values for retrofit Avons against new build units we can expect a decrease of 11% (90% vs. 79%), which will reduce site resilience. Given the critical function of Wormington this will have a significant impact on network capability, and continuity of supply into the NTS. Increased new unit availability also ensures that units are more capable of meeting projected future flow requirements. GTs are required to provide backup compression capability when the VSD is not available due to planned or unplanned outages as well as primary duty for capability requirements that cannot be achieved by Unit C (VSD) alone (i.e. high flow and high head conditions). The improved availability of new GTs compared to the existing Avons has a significant impact on network constraints and security of supply.

503. Required outages during construction and commissioning are a key consideration which have a significant impact on the short-term availability of Wormington to the NTS. The Final Preferred Option, involving installation of two new units on an area of NGGT owned land outside the current site plot, allows the majority of construction works to be completed away from operational plant with minimal outages required for tie-in and commissioning of the new units. Conversely options which involve retaining Units A and/or B involve significant amounts of brownfield scope which would require more outages to allow construction and commissioning activities to progress safely. This presents construction challenges and impacts site availability through the construction period. Due to the location of Wormington on the NTS and its criticality, outages during the construction phase may result in network constraints with an associated cost to consumers which has not been included in the CBA. More detail on the Level 2 programme for the preferred option can be found in **Section 8.2**.

504. It should be noted that while Option 10 was highlighted as the most cost-effective option within the Steady Progression and System Transformation future scenarios, it was not the lead option in Consumer Transformation and Leading the Way. These scenarios

[53] Investment summary table – NO_x emissions: 1897 tonnes NO_x (counterfactual) vs. 256 tonnes NO_x (two new units) – See also BAT Report within Appendix G

see immediate reductions in annual gas demand with consumers changing their behaviour and making significant investment in thermal insulation and heat pumps. There are currently no incentives in place to drive this behaviour making the predicted reductions seen in the Customer Transformation and Leading the Way scenarios ambitious and unlikely to occur. A strong reliance on gas is likely beyond 2030, a more detailed assessment of the scenarios and what is driving the change is detailed in CE-AMP. It should be noted that any delay to a mass electrification of heating by 2030, as seen in the Customer Transformation and Leading the Way scenarios, would increase the risks to consumers if we have not installed two new units. NGGT continue to monitor these scenarios against real world demand to inform our other investment decisions.

505. Wormington is critical in supporting LNG imports through the Milford Haven terminal. These flows contribute significantly to UK security of supply, both by providing access to global gas markets and acting as a source of flexible supplies to respond rapidly to changes in supply and demand. Any disruptions which limit the capability of Milford Haven could pose a significant risk to Security of Supply and increase the chances of serious disruptions to the UK gas market. Our recommended option provides significant resilience at Wormington to minimise these risks.

506. Deferral of the decision on the second unit has been considered by evaluating the impact of delaying second new unit installation until after 2030. This would necessitate maintaining an existing Avon during the first construction phase to provide sufficient resiliency, thereby incurring the site outages and cost associated with the necessary asset health investment. Second unit installation adjacent to the initial new unit would also have an impact on site operations which is not considered within our CBA. Real Option Analysis has been conducted to define the potential value of the deferral across our four Future Energy Scenarios. When the scenarios are weighted equally this analysis shows that delaying the decision provides a potential value of £5.0m. However, when assessing the deferral in our high price and high LNG sensitivities this potential is reduced to almost nothing.

507. The delay to investment does pose a risk to consumers in both the Steady Progression and System Transformation scenarios. This is because we would have lower availability on the network due to the delay to the investment. In these scenarios the risk of delaying the investment five years would be around £10m. This risk increases in both our high price and high LNG sensitivities to between £15-20m. Given the lack of progress towards both Leading the Way and Customer Transformation as detailed in CE-AMP, delaying the investment could expose consumers to significant risk, along with limiting the UK's ability to access LNG supplies.

508. For the selected option, operational acceptance is forecast for 2028, aligned to our RIIO-T2 and RIIO-T3 outage plans. Decommissioning of the non-compliant units could take place from 2029, once the new units are operational, but this decision will not form part of the MCPD Uncertainty Mechanism. An NTS-wide assessment of units to be decommissioned will be undertaken under a separate decommissioning investment plan within our RIIO-T3 submission. This will ensure targeted decommissioning

investment can be undertaken to provide maximum value in terms of risk reduction and capability enhancement across the NTS.

509. Various planned investments are expected to interface with this Final Preferred Option, these are detailed within Section 4.2. With particular reference to WGN and the control system cyber and asset health projects are targeted to be completed by early 2025 with the MCPD project construction of two new units forecast to start at the end of 2025. There is potential for delivery efficiencies by bundling scope with these projects but there is no significant impact on the deliverability of the MCPD scope. Based on these programmes the schedule risk associated with achieving operational acceptance prior to the MCPD deadline of 1 January 2030 is considered low. Further detail on the risk associated with the preferred option and other shortlisted options is included in **Appendix F**.

510. Specific project risks relating to the Final Preferred Option are covered within **Section 8.3**.

8.2. Option Programme

511. Project delivery programmes for all shortlisted investment options have been developed to confirm the feasibility of delivery prior to the 1 January 2030 MCPD legislative deadline and to identify notable schedule related risks. These programmes have not been used to derive any elements of the CAPEX estimates, but they have been used to determine basic spend profiles.

512. The delivery programme for the preferred option including the key assumptions and constraints is described below. Delivery programmes for the other shortlisted option are provided in **Appendix E**.

513. The project delivery programme is based on a standard EPC delivery approach including the following main contracts:

- Pre-FEED
- FEED
- Compressor machinery train equipment supply
- Engineering, Procurement, Construction and Commissioning

514. Pre-FEED stage will be initiated immediately following confirmation/approval of the Final Preferred Option via the Re-opener planned for completion February 2023. During this pre-FEED stage the delivery strategy will be confirmed and tender documentation for the FEED stage produced.

515. During the subsequent FEED phase the selected investment option will be defined to an appropriate level of detail to support the Re-opener to confirm remaining project costs and to allow the EPC phase to be contracted on a lump sum or target price basis.

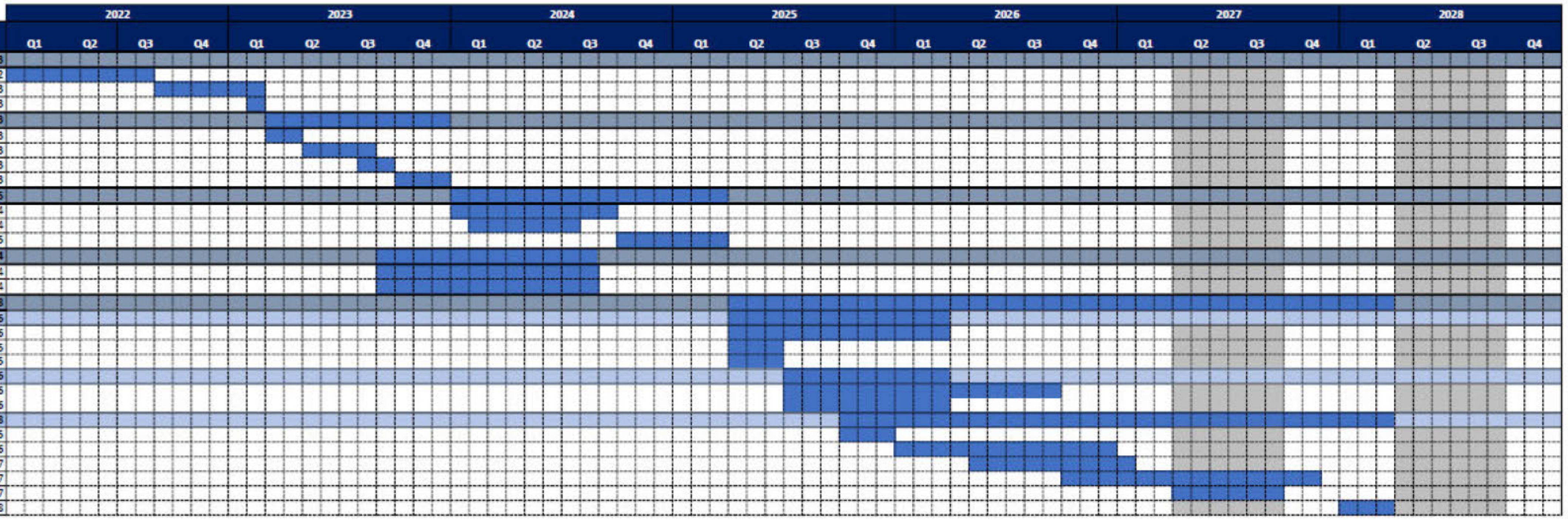
516. The EPC phase will include development of tender package for the compressor machinery train equipment which will be purchased by National Grid and free issued to the EPC contractor. Site works will commence once detailed design has been sufficiently progressed and three years has been allowed for all site works up to

operational acceptance. The selected greenfield location will allow a significant amount of site works to be conducted in a separate CDM area segregated from the operational site thus reducing the impact on operations. However, a summer station outage will be required to allow tie-in and commissioning of the new units.

517. Tie-in and commissioning of both units will be conducted in the same outage window. Due to the criticality of Wormington Compressor Station to support gas supply from Milford Haven ASEP, attaining appropriate outages has been identified as a schedule risk. For this reason an extended window for construction works has been allowed for. Potential optimisation will be reviewed in the FEED stage once the scope has been refined and delivery approach confirmed. The preferred option requires fewer outages than options which retain one or more Avon's which will require outages for brownfield asset health work.

518. After operational acceptance a winter running period has been allowed to operationally prove the new unit prior to the 2030 legislative deadline when any non-compliant units will be removed from service. **Figure** 24 shows Option 10's execution programme plan.

Option 10	Duration (wks)	Start	End
Select	66	01/11/2021	01/02/2023
Select Study	0	01/11/2021	31/08/2022
Ofgem Re-opener Window #1	22	31/08/2022	01/02/2023
Option Approved	0	01/02/2023	01/02/2023
Pre-FEED	44	02/02/2023	09/12/2023
Pre-FEED Study ITT and Award	12	02/02/2023	27/04/2023
Pre-FEED Study	16	28/04/2023	18/08/2023
FEED ITT Package	8	21/07/2023	15/09/2023
FEED ITT & Award	12	16/09/2023	09/12/2023
Define	65	10/12/2023	10/03/2025
FEED Study	39	10/12/2023	08/09/2024
Vendor Engagement	26	07/01/2024	07/07/2024
Execute ITT and Award	26	09/09/2024	10/03/2025
Consents	52	19/08/2023	17/08/2024
Environmental Assessments	52	19/08/2023	17/08/2024
Planning Consents and Approvals	52	19/08/2023	17/08/2024
Execute		11/03/2025	23/03/2028
Engineering	52	11/03/2025	10/03/2026
Detailed Engineering	52	11/03/2025	10/03/2026
Purchase Order Placement Compressor Machinery Train	12	11/03/2025	03/06/2025
Purchase Order Placement Piping/Structural etc	12	11/03/2025	03/06/2025
Procurement and Fabrication	39	04/06/2025	04/03/2026
Compressor Machinery Train Equipment	69	04/06/2025	30/09/2026
Piping/Structural/Asociated Equipment	39	04/06/2025	04/03/2026
Construction	131	23/09/2025	23/03/2028
Site Mobilisation	12	23/09/2025	16/12/2025
Civil Work for New Compressors	52	17/12/2025	16/12/2026
Piping/Structural Fabrication	40	07/04/2026	12/01/2027
Install New Compressors & Equipment	58	01/10/2026	11/11/2027
Station Outage - Tie in Works	26	01/04/2027	30/09/2027
Commissioning of New Compressors	16	02/12/2027	23/03/2028



Notes:

1 Refer to supporting report for full assumptions and schedule basis

2 Decommissioning of Avon to be removed from service not shown. This will be undertaken after commissioning, operational acceptance and winter proving period for the new units. Outage will be required for isolations

Figure 24 - Option 10 Execution Programme Plan

8.3. Option Risks and Opportunities

519. Key risks and opportunities for all shortlisted options have been reviewed using a semi-quantitative approach. This risk methodology is described fully in the Risk Report & Register contained within **Appendix F**. This particular section concerns risks & opportunities associated with the Final Preferred Option only.

520. For the preferred option much of the value erosion is associated with the risk of CAPEX increase and schedule delay which will therefore be a focus area for onward risk management.

521. The highest rated risks & opportunities associated with Option 10 are identified below. Significant, Minor and Negligible risks are summarised within **Appendix F**.

Key Option Risks & Mitigation

522. A critical risk has been identified regarding the lack of confirmed network outage periods during the execution phase of the option. Allowed outage may be shorter than anticipated or at less optimum time for construction of new build units. Risk mitigation is expected to take the form of a more detailed conversation with GNCC during pre-FEED and FEED phases once the final option is confirmed.

523. There is a critical risk associated with UK specific and worldwide geopolitical issues which has the potential to impact equipment supply and labour rates and availability leading to CAPEX increase and schedule delay. This risk will be a key focus area during development of the delivery strategy and lessons learnt from other similar projects will be applied appropriately.

524. The preferred option involves significant extension of the existing site footprint which will trigger permitting and consent requirements. Although this footprint extension is within the current NGGT land ownership boundary there is a significant risk of schedule delays associated with permitting and consenting activities. Liaison with local planning authorities and other stakeholders will be commenced as early as practicable during the FEED stage in order to mitigate potential delays.

525. Progression to the next phase of the project relies on agreement between National Grid and Ofgem on the preferred option. There is a critical risk that alignment will not be gained at the end of the 6-month Re-opener window allowed for in the project delivery programme causing schedule delays. To mitigate this risk we have held regular engagement meetings with Ofgem through the option selection phase. The output of these engagement sessions has informed this option selection process described in this submission.

526. There is a significant risk that the existing instrument air package is inadequately sized for the new equipment to be installed as part of the preferred option as no capacity assessment has been conducted to date. This will be reviewed as part of the design development during pre-FEED but there is potential for scope increase and associated CAPEX impact.

Option Opportunities Identified

527. A conservative approach to layout development has been applied and there is therefore an opportunity for optimisation which will be reviewed during the early stages of engineering development which has the potential for CAPEX reduction.

528. There is also an opportunity to coordinate with other projects and bundle scope to provide potential CAPEX savings across this and other investments. This will be reviewed with the development of the delivery strategy.

529. The opportunity to align the design to a future hydrogen strategy will also be reviewed early in the engineering design development process.

8.4. Efficient Cost

530. CBA and BAT assessments are based on [redacted] CAPEX estimates developed according to the methodology described in **Section 6.1**. These cost estimates were based on engineering inputs, including material quantities and equipment lists provided by [redacted] the engineering consultant used for the option selection phase. We applied in-house cost data developed from previous projects to the engineering inputs to produce CAPEX estimates for new build scope. Asset Health costs were based on relevant funding allowances agreed for RIIO-T2.

531. Following confirmation of the Final Preferred Option we will develop the delivery strategy, engineering design and cost estimates through pre-FEED and FEED stages ahead of the cost Re-opener currently forecast for 2024. As part of the development of the preferred option, value engineering and delivery efficiencies will be reviewed including consideration of opportunities identified during the option selection process including:

- Refinement of the proposed layout
- Alignment of project delivery with other planned investments at Wormington and across the wider NTS. This includes consideration of outage requirements for construction and commissioning and bundling opportunities which provide delivery efficiencies
- Refinement of the project delivery programme alongside the development of the delivery strategy for the project. This will incorporate relevant lessons learnt from the Hatton LCPD project which is being delivered to an accelerated programme using an EPCM contracting strategy

532. Cost efficiencies will be incorporated into the updated cost estimates which will form the basis of the funding allowance request to be submitted in our cost Re-opener submission in 2024.

533. As noted in the programme for the preferred option described in **Section 8.2**, we plan to defer placement of the purchase order for compressor machinery train equipment until after the cost Re-opener in 2024. This decision is based on lessons learnt from the Hatton LCPD project and improves the CAPEX spend profile by moving the significant cost associated with this equipment later in the delivery programme.

534. An investment decision regarding decommissioning of Avon Unit A and B at Wormington will be taken after operational acceptance and a winter proving period for the new units to be installed as part of the MCPD scope. This decommissioning investment will be reviewed alongside other similar scope on the wider NTS and will form part of a separate NTS wide decommissioning specific funding request in RIIO-T3. This will allow decommissioning scope to be assessed against the network capability requirements at the time and allow scope to be prioritised and bundled to ensure efficient spend.

8.5. Outputs and Allowances in RIIO-T2

535. In RIIO-T1 NGGT did not have any outputs related to Wormington Compressor Station emissions compliance. As detailed in the summary table, **Table 8**, we have spent [redacted] in RIIO-T1, which was to initiate the feasibility study and options selection process as well as the development of our RIIO-T2 business plan submission for MCPD compliance for Wormington Compressor Station. For further detail on RIIO-T1 outputs related to emissions compliance, please see CE-AMP.

536. In RIIO-T2 NGGT has a Compressor Emissions PCD detailed in Special Condition 3.11 Compressor emissions Re-opener and Price Control Deliverable, Appendix 2. The PCD is to ensure NGGT delivers a Final Options Selection Report, long lead items and a Re-opener submission for Wormington Compressor Station. Through pre-application engagement we agreed with Ofgem the most appropriate timing for submission of the Final Option Selection Report is August 2022 to ensure option selection is based upon results from all options under consideration and the Re-opener application window is in November 2024. The received Baseline allowances are [redacted] (excl. RPEs).

537. The PCD follows the GT Project Assessment Process (GTPAP), which is a two-step process whereby we submit the FOSR as part of the first step, and a cost submission once the project has gone through a full Front End Engineering and Design (FEED) for the preferred option and tender process, as a second step. The outcome of the second step (Re-opener submission in November 2024) will be to amend the licence to incorporate the PCD outputs associated with delivery of the selected option set by Ofgem's Final Determinations in December 2020.

538. NGGT's Baseline allowance covers development costs and deposits on long-lead items, subject to a true-up during the associated Re-opener (cost submission). In the first year of RIIO-T2 we have spent [redacted] of our Baseline allowance. Please see **Table 8** for further detail of spend to date. We are reporting on spend and progress against our Baseline allowance and PCD as part of our annual Regulatory Reporting Pack (RRP).

539. Following Ofgem's review and approval of our Proposed Final Option for Wormington Compressor Station MCPD compliance, we will continue working to develop our preferred option further in readiness for our Re-opener submission in November 2024 at which date we will propose a revised PCD to be included in the Gas Transporter Licence to reflect the delivery of our preferred option as detailed in **Section 8.2**.

9. Conclusions and Next Steps

540. Based on the outcome of the CBA, BAT assessment and considering the criticality of Wormington Compressor Station to the UK's security of supply, the installation of two new gas–driven compressor units is our Final Preferred Option. This recommendation is justified following comparison against a variety of key investment metrics:

- Two new units is one of the highest performing solutions (alongside SCR) from an emissions reduction perspective. New GT compressors offer efficient operation, long-term reliability and low emission compression.
- While new build units incur the highest capital investment cost, this is offset against reductions in future constraints. This option provides the best return on investment for consumers while relative NPV is expected to turn positive from 2032 based on projections from the System Transformation scenario.
- From a technical perspective, Option 10 received the highest overall technical rating compared to the alternative investment options. New units scored highest in terms of network versatility, future proofing against changes in energy legislation, maintainability and environmental hazard control.
- Two new units provide the highest unit availability of the shortlisted options. New unit availability of approximately 90% helps to ensure Wormington Compressor Station remains functional to meet the needs of the network. Reduced unit availability can have a significant impact on site resilience, network capability and continuity of supply on the NTS. Given Wormington's key role in supporting LNG flows from Milford Haven, maximising the resilience on site is vital in minimising the risks to Security of Supply any disruptions would cause.
- The greenfield location of the preferred option provides a significant benefit to Wormington site availability and ensures reduced impact on existing site during construction. This is because the majority of construction works will be completed away from operational plant with minimal outages required for tie-in and commissioning of the new units. Due to the location of Wormington on the NTS and its criticality, outages during the construction phase may result in network constraints with an associated cost to consumers which has not been included in the CBA. Outage planning at Wormington will be complicated by the fact that compression capability requirements is driven by supply rather than demand.

541. Following Ofgem's decision on the Final Preferred Option, NGGT will use the remaining baseline allowances confirmed in 2019 to develop our preferred option up to the cost Re-opener currently forecast for November 2024. We intend to initiate a pre-FEED stage immediately following preferred option confirmation where the delivery strategy will be confirmed, and tender documentation produced for the FEED stage. During the subsequent FEED phase, the selected investment option will be refined to support the cost Re-opener and confirmation of remaining project cost. The EPC phase will include development of tender package for the compressor machinery train equipment. Site works will commence once detailed design has been sufficiently progressed which allows for a maximum of three years for all site works up to operational acceptance. The selected greenfield for the new units will allow a significant amount of site works

to be conducted in a CDM area separate from the operational site thus reducing the impact on operations. After operational acceptance in 2028, a winter running period is provided for the new units prior to the 2030 legislative deadline when units A and B will be restricted to a maximum of 500 hours operation per year.

10. Appendices

- Appendix A – [redacted]
- Appendix B – [redacted]
- Appendix C – Engineering Report and Appendices
- Appendix D – Asset Health Report
- Appendix E – Project Programmes and Report
- Appendix F – Project Risk Register and Report
- Appendix G – Preliminary BAT Report Summary
- Appendix H – [redacted] Avon DLE Test Report
- Appendix I – [redacted] SCR Technical Feasibility Study
- Appendix J – [redacted] CSRP Performance Testing Report
- Appendix K – NG RAM Study Report
- Appendix L – [redacted]
- Appendix M – [redacted]
- Appendix N – [redacted]

Glossary	
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.
AGI	**Above Ground Installation:** 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
ASEP	**Aggregated System Entry Point:** 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.
Avon	Rolls Royce (Siemens) gas turbine engine which forms part of the compressor machinery train and is subject to MCPD.
Barg	Bar gauge
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.
BAT	**Best Available Technique:** 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.
Brownfield	Construction within the existing site perimeter fence.
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.
Carbon Dioxide (CO_2)	A naturally occurring chemical compound composed of two oxygen atoms and a single carbon atom. If there is not enough oxygen to produce CO_2 during combustion, carbon monoxide (CO) is formed.
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 (CO_2), such as when operating an internal combustion engine in an enclosed space.

Glossary	
CE-AMP	Compressor Emission Asset Management Plan
Compressor Unit	Equipment used to compress gas to high pressure for transport through the NTS. Each compressor station consists of one or more compressor units as well supporting equipment such as meters, filters, valves and pipework. Compressor units can be driven by gas turbines or electric drives.
CSRP	**Control System Restricted Performance:** Technology that restricts the performance of a gas-driven compressor to limit NO_x emissions.
CBA	**Cost Benefit Analysis:** 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.
DLE	**Dry Low Emissions:** An Avon DLE retrofit modifies the combustion system within the Avon engine so that air and fuel are premixed before combustion. This reduces the peak combustion temperature, which in turn reduces the amount of NOx produced
EUD	**Emergency Use Derogation:** Derogation provided under the MCPD for equipment used in emergencies and less than 500 hours per year on a rolling 5 year average, with a maximum limit of 750 hours in any one year.
Emission Limit Values (ELV)	Limits set for industrial installations by the LCP directive and IPPC under the umbrella of the IED and MCPD.
Emission Abatement	Includes technology that reduces the emissions from a gas-driven compressor.
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.
EA	**Environment Agency:** A non-departmental public body, sponsored by DEFRA, with responsibilities relating to the protection and enhancement of the environment in England.
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 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.
FOSR	Final Option Selection Report
FEED	**Front End Engineering Design:** The FEED is basic engineering which comes before the detailed design stage. The FEED design process focusses on the technical requirements as well as an approximate budget investment cost for the project.

Glossary	
FES	**Future Energy Scenarios:** 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 ESO and contains their latest scenarios.
DN	**Gas Distribution Network:** An administrative unit responsible for the operation and maintenance of the local transmission system and <7barg distribution networks within a defined geographical boundary.
Greenfield	Construction on land that is outside of the existing perimeter site boundary, where there is no need to demolish or rebuild any existing structures.
IED	**Industrial Emissions Directive:** An EU directive that came into force in January 2011.
Intrusive Outage	Significant outage works impacting the whole station and where the station cannot be returned to service until the scheduled works are completed.
LCPD	**Large Combustion Plant Directive:** 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 NO_x, CO, SO_2, and particles.
LNG	**Liquefied Natural Gas:** Natural gas that has been cooled to a liquid state (around -162^oC) and either stored and/or transported in this liquid form.
MCPD	**Medium Combustion Plant Directive:** A directive to reduce emissions from combustion plants with a net thermal input between 1-50 MW.
MTO	Material Take Offs
MWC	Main Works Contractor
NTS	**National Transmission System:** 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.
NPV	**Net Present Value:** NPV is the discounted sum of future cash flows, whether positive or negative, minus any initial investment.
NDP	**Network Development Process:** The process by which National Grid identifies and implements physical investment on the NTS.
NGGT	National Grid Gas Transmission
Nitrogen Oxide (NO_x)	Oxides of nitrogen which are a by-product of combustion of substances in the air, such as gas turbine compressors.

Glossary	
Ofgem	**Office of Gas and Electricity Markets:** 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.
PARCA	Planning and Advanced Reservation of Capacity Agreement
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.
RB211	A Rolls Royce (Siemens) gas turbine engine which forms part of the compressor machinery unit and is subject to LCPD.
Re-opener	Re-openers are a type of RIIO uncertainty mechanism. Depending on their design, they allow Ofgem to adjust a licensee's allowances (in some cases up and in some cases down), outputs and delivery dates in response to changing circumstances during the price control period.
Replacement	Installing a new unit to replace the capability provided; this may not be a like-for-like replacement.
RIIO	**Revenue = Incentives + Innovation + Outputs:** RIIO-T2 is the second 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.
RPE	Real Price Effects
SEPA	**Scottish Environment Protection Agency:** Scotland's environmental regulator and flood warning authority.
Selective Catalytic Reduction (SCR)	A means of converting nitrogen oxides (NO_x) with the aid of a catalyst into diatomic nitrogen, N_2, and water, H_2O. 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 (CO_2) is a reaction product when urea is used as the reductant.
UAP	Unallocated Provision

Glossary	
Uncertainty Mechanism	Uncertainty mechanisms exist to allow price control arrangements to respond to change. They protect both end consumers and licencees from unforecastable risk or changes in circumstances.
Unit Outage	Significant outage works impacting one or more compressor 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.