Re-opener Report

MSIP - SF_6 Asset Intervention

January 2022

nationalgrid

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1. Executive summary

This document proposes funding for National Grid Electricity Transmission (NGET) to deliver interventions to abate SF_6 emissions, in addition to existing RIIO-2 funding. These interventions are required to meet established emissions reduction targets, consistent with achieving Net Zero by 2050.

Science-based targets (SBT) provide companies with a clearly defined path to reduce emissions in line with the 1.5 degrees Celsius, *Paris Agreement* goals. Our SBT is extremely challenging, requiring NGET to achieve a 33% reduction in SF_6 emissions by 2026 from a 2018/19 baseline. This equates to an average leakage rate across our asset base of not more than ~0.9% by 2026, compared to the ~1.27% rate reported at the end of RIIO-1. Based upon our forecasting this equates to a total abatement of 12,471kg of SF_6 emissions from 2022 to 2026 between the SBT and the do-nothing scenario.

Our Responsible Business Charter (RBC) sets out our commitments to be Net Zero by 2050 and to reduce SF_6 emissions by 50% by 2030. SF_6 inventory reduction will be a key contributor to achieving these commitments and we have set the ambition to eliminate SF_6 from our operations by 2050.

SF_6 emissions accounts for 92% of NGET's scope 1 carbon emissions. The global warming potential for SF_6 is 23,500 (IPCC AR5, 2014). The rising trend of SF_6 emissions requires reversing to achieve NGET's Net Zero, RBC commitments and ambitions.

Our RIIO-2 submission requested for the funding of defined interventions at 18 sites, a palliative coating application and a flexible funding mechanism to apply to assets that would be required for intervention funding to meet the SBT. The RIIO-2 outputs approved is for defined intervention at 10 sites and funding for a palliative coating application.

The baseline allowances provided in RIIO-2, which contribute to SF_6 leak abatement, are insufficient to achieve the required emission reduction requirements to be on track for the 2026, 2030 or 2050 milestones.

This re-opener proposes the additional funding and interventions required to achieve the 2026 SBT milestone for SF_6 emission abatement. More work is required to establish the additional requirements to achieve the SBT in 2030 and further proposals will be detailed in future submissions. This paper will not add additional SF_6 to the existing asset base and the proposals for inventory reduction will be factored into future submissions in line with updated timescales for alternative technology. The investments in this paper will reduce the SF_6 inventory by 29,455kg on the NGET network.

Where other NGET projects during RIIO-T2 demonstrate a clear requirement to invest ahead of alternative solutions being available, the volume of installed SF_6 will be kept to an absolute minimum. We have very low leak rate (0.25%) expectations for new equipment and any SF_6 inventory increase during RIIO-T2 is very unlikely to impact our commitment to achieve a 33% reduction in emissions by 2026. For example, if we were to install new SF_6 in other projects up to the volume of inventory removed in this reopener (29,455kg), this could result in additional leakage (at 0.25%) of 74kg per annum which equates to a 1% increase on our forecasted 2026 position. All other things being equal, we would have to install 400,000kg of new SF_6 equipment resulting in an additional 1,000kg leakage from this new equipment to adversely impact our forecast 2026 position.

The forecast emissions graph below shows the relationship between our SBT and three key forecast scenarios: no intervention, existing T2 outputs and T2 outputs + reopener.

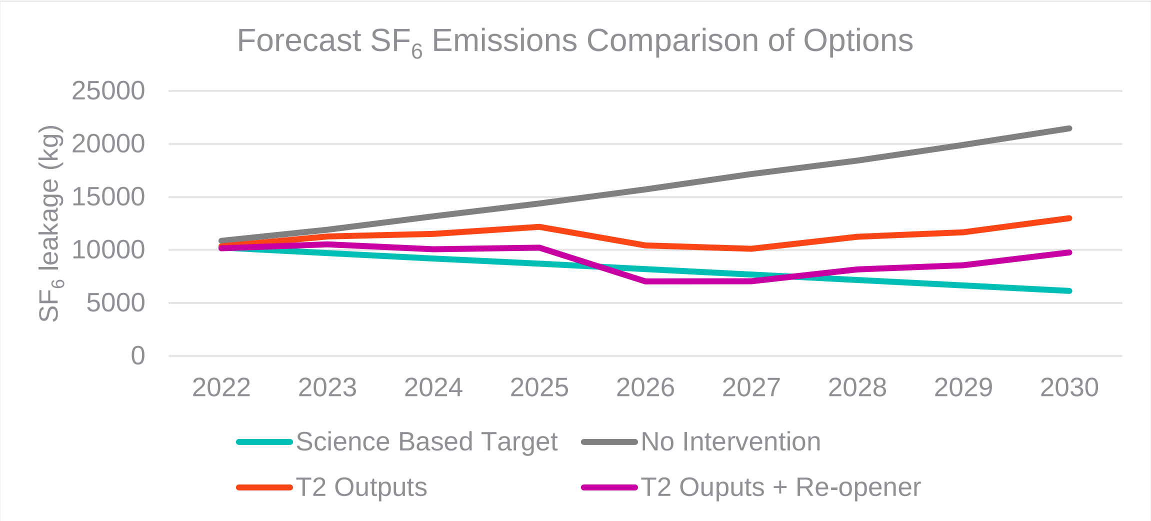


Figure 1.1: A comparison of the science-based target with forecast SF_6 emissions of the different investment options

The following funding requirements are required to achieve the 2026 SBT trajectory (T2+re-opener) shown on the graph above.

Intervention	Detail	Cost (£k 18/19)	SF_6 emission (kg) reduction to 2030	Carbon emission reduction (tCO2e)
[redacted]	GIB replacement with HV cable	[redacted]	431	10,128
[redacted]	Multiple GIS interventions*	[redacted]	2,393	56,235
[redacted]	Multiple GIS interventions*	[redacted]	3,125	73,437
[redacted]	Multiple GIS interventions*	[redacted]	5,420	127,370
[redacted]	Multiple GIS interventions*	[redacted]	1,422	33,417
SF_6 filled current transformers	427 current transformer replacement	[redacted]	4,808	112,988
275kV & 400kV Air insulated substation – SF_6 gas circuit breaker	167 SF_6 leak repairs	[redacted]	4,249	99,854
Total		**£54,294**	**21,848kg**	**513,429 tCO2e**

Table 1.1: A summary of the proposed outputs
**Multiple GIS interventions can include repair works (e.g. encapsulation wrap), refurbishment and/or bushing replacement*

Taken together these elements result in a proposed funding limit of:

[redacted] + [redacted] + [redacted] + [redacted] + [redacted] + [redacted] + [redacted] = **£54,294k**

The total emissions reduction is achieved by a diverse portfolio of investments across multiple sites and technology types. We need to deliver all of the proposed interventions if we are to achieve our 2026 emissions target.

Each of the deliverables have been assessed through a cost benefit analysis. Societal benefits of the forecast abated SF_6 emissions are based on a carbon price in each year provided by the Department for Business, Energy and Industrial Strategy.

The cost benefit analysis graph in Figure 1.2 highlights the intervention spend and the societal benefit together to indicate a value payback of the spend for the additional re-opener interventions. It provides the view that the spend within RIIO-2 would payback in benefits by 2028 with an increased growth in long term benefits from the interventions completed.

The economic assessment outlined by the CBA shows that the preferred solution of SF_6 interventions presents the best value to consumers, considering all investment costs, societal benefits and discounted using the Spackman method.

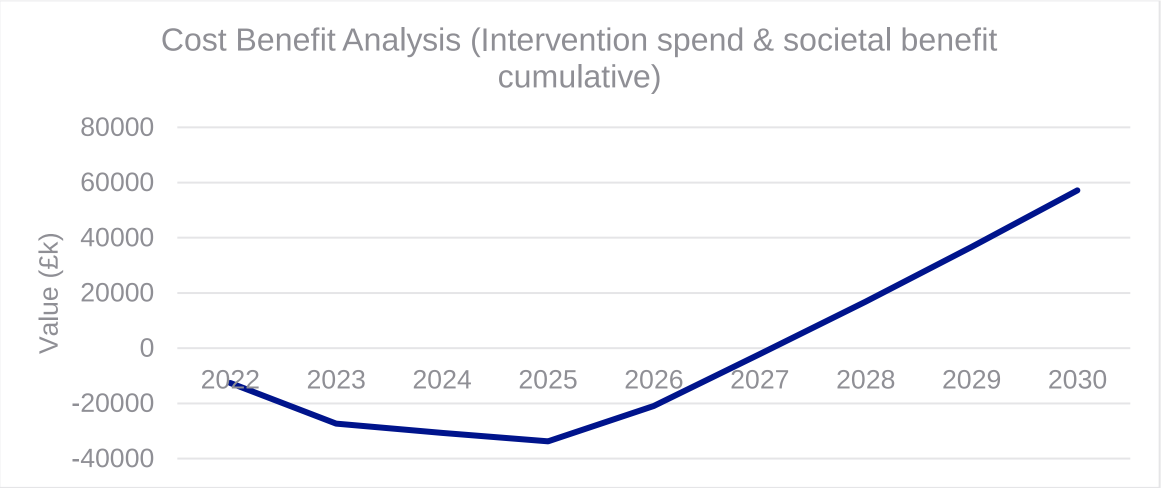


Figure 1.2 Cost benefit analysis – cumulative intervention spend & societal benefit (avoided forecast emissions)

Proposed PCD Definition

	2022 (£m)	2023 (£m)	2024 (£m)	2025 (£m)	Total Allowance (£m)
SF_6 re-opener spend	**9.83**	**15.00**	**10.95**	**18.51**	**54.29**

Table 1.2 Proposed PCD spend profile (18/19 prices)

Site	Output	Delivery Date	Total Allowance (£m 18/19)
[redacted]	GIB replacement with HV cable	2024	[redacted]
[redacted]	GIS Repair & Refurbishment	2025	[redacted]
[redacted]	GIS Repair, Replacement & Refurbishment	2025	[redacted]
[redacted]	Targeted GIS Repairs	2026	[redacted]
[redacted]	GIS Repair & Refurbishment	2025	[redacted]
SF_6 filled current transformers	427 current transformer replacements	2025	[redacted]
275kV & 400kV Air insulated substation – SF_6 gas circuit breaker	167 SF_6 leak repairs	2025	[redacted]

Table 1.3 Proposed PCD Outputs

For further information please contact:

Sarah Kenny-Levick, Regulatory Submission Manager
+44 (0) 7500 987785
sarah.kenny-levick@nationalgrid.com

2. Summary Table

Name of scheme	MSIP SF_6 Asset Intervention Re-opener
Primary driver	SF_6 emission abatement
Scheme reference / mechanism of category	Price Control Deliverable
Output references/type	
Cost	**£54,294k**
Delivery year	2022-2025
Reporting table	
Outputs included in previous RIIO Business plan	
Spend apportionment	

Version Control

Version Number	Summary of Changes	Name	Date
1.0		Bradley Kent	31st January 2022

3. Introduction

In line with the UK government's net zero carbon target, it is our strategy to reduce our SF_6 emissions & inventory progressing towards a net zero position by 2050. As part of this trajectory, we have set a verified science-based target (SBT) of 50% emission reduction from a 2018/19 baseline by 2030. For the RIIO-2 period, as part of our Environmental Action Plan, we have also set a commitment to reduce our scope 1 and 2 emissions by 34% by 2026. This equates to a 33% reduction in SF_6 emissions by 2026 (i.e. the end of RIIO-2) and amounts to a fixed target of no more than 8,180kg of emissions in 2026. Assuming no significant change of inventory this equates to an aggregate leak rate across our asset fleet of not more than ~ 0.9% compared to end of T1 leak rate of 1.27%; a very challenging target.

The current RIIO-2 outputs and all baseline SF_6 interventions, including the SF_6 asset intervention price control deliverable, are forecast to be insufficient to meet the 2026 emission reduction target and subsequent milestones in 2030 and 2050.

This paper sets out the basis for the additional funding to undertake additional interventions beyond existing T2 funding to achieve our SF_6 emission abatement targets for T2, establish an emission reduction trajectory consistent with our SBT and take early steps to deliver inventory reduction (e.g. [redacted] GIB replacement to cable).

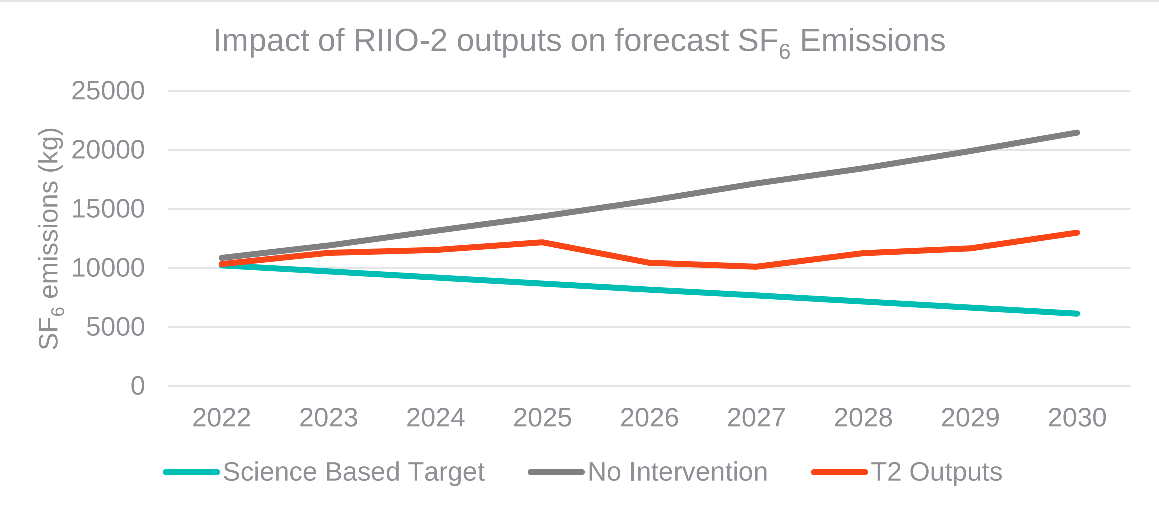


Figure 3.1: Impact of RIIO-2 outputs on forecast SF_6 emissions

We have refined our SF_6 leak forecasting capabilities since the initial RIIO-2 submission to investigate multiple scenarios and different intervention plans to ensure we have a deliverable plan in place to achieve our target We also use the forecast to predict progress in emissions reduction during delivery. Our latest forecasting indicates that, without intervention, our SF_6 emissions could be ~15,000kg per year by 2026 compared to the SBT level of not more than 8,180kg per year in the same year. The difference between these values defines the forecast abatement of actual & forecast leakage that we need to achieve by 2026, i.e. we must plan to have abated ~7,000 kg per year of actual and forecast leakage by 2026 to meet our long-term target.

This paper proposes additional funding to the SF_6 asset intervention deliverables listed below:

	2022 (£k)	2023 (£k)	2024 (£k)	2025 (£k)
[redacted] GIB to cable replacement	[redacted]	[redacted]	[redacted]	
[redacted] SF_6 Interventions	[redacted]			[redacted]
[redacted] SF_6 interventions		[redacted]		[redacted]
[redacted] SF_6 interventions	[redacted]	[redacted]	[redacted]	[redacted]
[redacted] SF_6 interventions	[redacted]	[redacted]	[redacted]	[redacted]
Current Transformer replacements	[redacted]	[redacted]	[redacted]	[redacted]
AIS Gas Circuit Breaker Interventions	[redacted]	[redacted]	[redacted]	[redacted]
Total	**£9,831**	**£14,999**	**£10,954**	**£18,510**

Table 3.1: Spend Profile

**Multiple GIS interventions can include repair works (e.g. encapsulation wrap), refurbishment and/or bushing replacement*

We have used the latest HMRC Greenbook figures for carbon price to assess the benefits of SF_6 emissions reduction whilst discounting these according to the societal time preference rate. It means that the timing of our interventions influences the size of the societal benefits forecast from SF_6 emissions, just as investment expenditure is also influenced by the cost of capital over time.

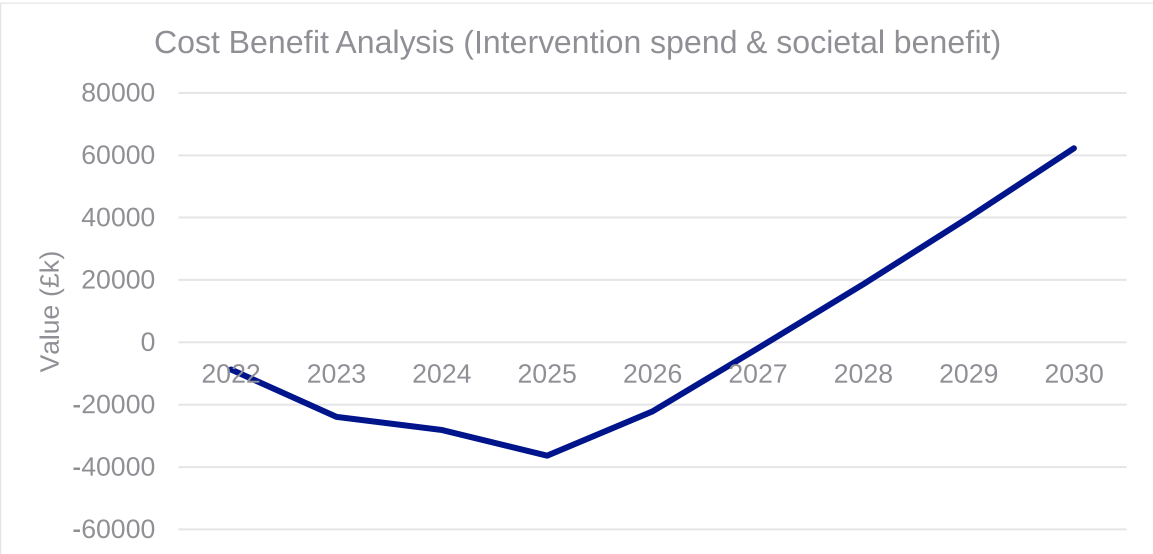


Figure 3.2: Combined value of intervention spend and forecast emissions reduction 2022-2030

Besides the quantity of interventions, our strategy also considers the quality and efficiency of interventions. To achieve the SBT, we need to move progressively from repairing leaks that have already occurred, to a combined programme of leak repair, proactive leak prevention and ultimately to an inventory reduction programme. This proposal delivers the investments necessary for us to achieve our 2026 science-based emissions target as the first phase of our trajectory towards our 2030 SBT and a net zero position by 2050. These investments deliver the required RIIO-2 performance improvements in a manner which is consistent with achieving long term value for consumers.

4. Structure of the re-opener submission

This Medium Sized Investment Portfolio (MSIP) Re-opener submission is structured into sections shown in the table below.

The Table signposts the structure of the document, sets out the purposes of each of the sections and demonstrates alignment to the re-opener guidance requirements.

This submission is based on the below licence special condition.

Reference: ET Licence Special Condition 3.14 MSIP.
3.14.6 (k) *– SF_6 asset interventions, where the licensee can demonstrate a well-justified intervention plan*

3.14.7(a) *– licensee may apply to the authority for an adjustment between: 25/01/22 – 31/01/2022*

The options through this submission are aligned to the long-term business strategy and net zero targets with the analysis performed on the historic performance of SF_6 leakage determining correlations linked to other asset factors. It then uses the data forecast model for SF_6 leakage to support the historic analysis and uses forecasted SF_6 leakage to predict future carbon emissions and the societal impact costs using the non-traded carbon cost aligned with the Ofgem CBA methodology.

The need for intervention is assessed at the individual asset level. A range of intervention options are then developed and assessed to determine the optimum intervention strategy for individual or groups of assets, considering both short-term benefits and long-term outlook. The intervention is assessed for deliverability against the outage plans on the transmission system and possible opportunities to bundle with other works (e.g. other NARM or PCD outputs) to determine confidence levels of delivery. The cost of intervention is assessed against the cumulative forecast leakage to determine over what period the cost of intervention would be outweighed by the benefits to consumers in the form of abated future carbon emissions.

The forecast emission reduction delivered by each intervention option is assessed in terms of the contribution to achieving our established emission reduction targets and consistency with achieving Net Zero.

The alternative technology to SF_6 and the SF_6 inventory reduction methodology required to achieve Net Zero is rapidly evolving and the initial steps to its development are detailed with how it aligns to future submissions.

The SF_6 emission and inventory reduction strategy and plans are regularly discussed and checked across stakeholders, suppliers, and technical working groups to receive and act on feedback as well as understand the wider industry progress on the same challenge.

All of the proposed options have also been assessed against existing outputs within RIIO-T2 to ensure no duplication, justify where changes to funding are required and show where bundling with other outputs can provide a delivery opportunity. These aspects are detailed fully in each of the relevant engineering justification reports.

	Content	Summary
Executive Summary		A high-level summary of the submission.
Introduction		A summary of the information presented across the submission to give an overview of the project.
Business Strategy & Commitments *Re-opener guidance section 3.10*	• Scientific basis • Responsible business charter • Environmental action plan • F-Gas regulations • Policy statement	Introduces the strategic importance of the project, environmental commitments and Net Zero ambition.
Needs Case *Re-opener guidance section 3.11 & 3.12*	• Emissions & inventory • Asset health • Failure mechanisms and condition • Forecasting	Sets out the current state, drivers for the project including: Asset health, SF_6 leakage, carbon emissions & forecasted SF_6 leakage.
Options *Re-opener guidance section 3.13*	• Intervention options • Intervention strategies • Portfolio funding options • Cost assessment • Option details	Describes the different types of interventions at an asset level, the strategy for choosing optimal asset intervention type and the different portfolio options considered.
Methodology for preferred option *Re-opener guidance section 3.13*	• Intervention prioritisation • Intervention strategies • Cost Benefit Analysis •	Describes the method of options considered to address the driver, how the options were appraised and how listed options were shortlisted for CBA.
The preferred option *Re-opener guidance section 3.14*	• Preferred option • Cost details • Risks & contingencies	Summarises the cost of the portfolio. Sets out the assumptions and the methodology used to arrive at a cost and dates.
Project delivery *Re-opener guidance section 3.15*	• Plan Alignment • Reactive nature for SF_6 • Future submissions • Phased Net Zero development	Describes the timing for the re-opener and how the deliverables are timed, and project managed. including how it aligns with future submissions.
Price Control deliverables *Re-opener guidance section 3.15*	• T2 Current position	Summarises the existing allowances in RIIO T2.
Stakeholder Engagement *Re-opener guidance section 3.16 – 3.18*	• Stakeholder informed strategy • Other TO engagement • CIGRE • Innovation/EIC engagement	Describes the stakeholder engagement to date and how we work with stakeholders to progress the project.

	• Independent user group • OEM Engagement • Ofgem Engagement	
Annexes *Re-opener guidance section 3.19 – 3.22*	• Engineering justification reports • Cost benefit analysis • Top-up methodology • T2 Existing Outputs • T1 Condition and performance	Details the list of annexes supporting the re-opener

Table 4.1: Structure of the Document

5. Alignment with overall business strategy and commitments

This re-opener submission proposes the work required to meet RIIO-2 environmental commitments towards achieving Net Zero. The below sections detail how the re-opener aligns to NGET's strategy in reducing carbon emissions. There is more information on how our strategy aligns with stakeholders' views and priorities in the section "stakeholder engagement".

NGET's strategy and commitments are to continue from RIIO-2 through into future regulatory submissions to achieve a 2050 Net Zero target. The longer-term commitments and ambitions are listed under the responsible business charter section and cover SF_6 emission and inventory reduction.

The Scientific Basis section sets out the primary driver for the re-opener which is focused on the reduction of our emissions footprint. The other sections detail how NGET are aligning to this primary driver and setting up the policy, strategy, action plans and commitments to achieve this.

The current T2 allowances and deliverables do not meet the RIIO-2 targets to be on track for Net Zero. This re-opener proposes the works required on top of the existing deliverables to meet the business targets and commitments.

The analysis conducted is detailed in the needs case section using the historic performance to inform scenarios to be assessed against the forecast leakage output. The outputs from these different scenarios are modelled in the Ofgem CBA to determine the societal benefit based on the abated SF_6 emissions and its cost derived from the equivalent carbon emissions and the price of carbon, in line with stakeholders' priorities and expectations.

As the reduction of SF_6 inventory is a strategic ambition for National Grid the CBA focuses on the next 10 years which aligns to the minimum effectiveness of interventions and when the SF_6 alternative technology will be fully available.

Summary of Key Messages:

Responsible Business Charter:

National Grid's responsible business charter sets out the following commitments and ambitions relevant to SF_6:

Commitment:

- Achieve Net Zero by 2050
- Reduce SF_6 emissions from our operations by 50% by 2030 from 2019 baseline

Ambition:

- Accelerate our Net Zero target wherever possible
- Eliminate SF_6 gas from our assets by 2050

Scientific Basis

SF_6 is a particularly potent greenhouse gas. It has a global warming potential (GWP) 23,500 times stronger (according to the latest IPCC data) than CO_2. SF_6 is the largest controllable element of our direct emissions at ~280,500tCO2e in 2018/19 it is 92% of NGET scope 1 emissions, and therefore the primary candidate for us to reduce our emissions footprint.

The RIIO-2 business plan guidance mandates a SBT, which externally verifies targets to limit global warming by 1.5 degrees Celsius. As Figure 1 below shows, the SBT Institute has confirmed that, for NGET, this equates to a 50% abatement by 2030, from a 2018/19 baseline. Our interim target for 2026 is calculated as 34% emission abatement assuming a linear pathway. To confirm achievement of the SBT milestone, the emissions target must be reached by scope 1 (Fleet + SF_6) and scope 2 (energy in buildings) independently, with no trading between the two categories. SF_6 is within scope 1 and fleet accounts for only 1.6% of scope 1 therefore SF_6 alone must be reduced by at least 33%.

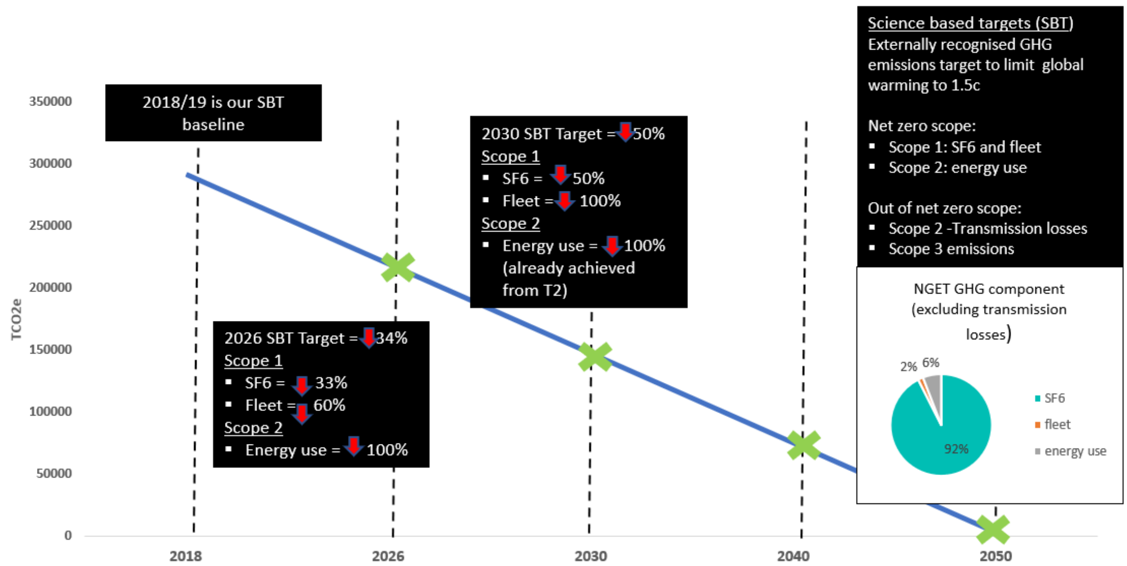


Figure 5.1: Details of the emissions included in the SBT Net Zero pathway milestones

Responsible Business Charter

National Grid Group have produced the Responsible Business Charter to articulate what responsibility means to us and identify where it will have the most impact on society, environment, communities, people, economy and governance.

The environmental charter represents the next stage of our commitments, setting out a significant change in what we will achieve. It includes specific commitments/ambitions on SF_6.

Commitments

Achieve net zero by 2050.
We will reduce Scope 1 and 2 greenhouse gas (GHG) emissions by 80% by 2030, 90% by 2040, and to net zero by 2050 *from a 1990 baseline*.
This aligns to a well-below two degrees pathway consistent with the ambition requirements of the Paris Agreement and SBT initiative.

Reduce SF_6 emissions from our operations 50% by 2030
from a 2019 baseline

Ambitions

Accelerate our net zero target wherever possible
We will work to achieve net zero in each part of our business as fast as we can.

Eliminate all SF_6 gas from our assets by 2050
Technology and solutions are not yet available to achieve this. Therefore, we will work with partners from across the sector to identify, develop and implement SF_6-free solutions at the earliest opportunity.

Environmental Action Plan

We play a leading role in enabling and accelerating the transition to a clean energy system. Whilst doing this, we must also reduce our own carbon emissions and environmental impact.

NGET have created an Environmental Action Plan outlining our vision and commitments for environmental sustainability improvements to 2026. It is our handbook to reduce our carbon emissions, reduce our resource use, improve our natural environment and demonstrate leadership for change. These goals align to the Responsible Business Charter commitments set up by Group.

The Environmental Action Plan has 25 commitments rooted within four environmental priorities, the SF_6 focused environmental priority is listed below :

- **Net zero carbon emissions:** By 2026 we will be reducing scope 1 and 2 emissions by 34% from a 2018 baseline in line with SBTs and all construction undertaken will be carbon neutral.

SF_6 commitments:

- By 2026 we will be reducing scope 1 and 2 emissions by 34% from a 2018 baseline in line with SBT. SF_6 is our biggest contributor to greenhouse gas emissions so we need to concentrate on this for our net zero commitment. We need to achieve a 33% reduction in SF_6 emissions from a 2018/19 baseline
- Take bold steps to tackle our SF_6 emissions and stimulate the market to more rapidly meet our stakeholders' needs

F-gas Regulation from 2015

The current Regulation strengthened the previous measures and introduced far-reaching changes by:

- **Limiting the total amount** of the most important F-gases that can be sold in the EU from 2015 onwards and phasing them down in steps to one-fifth of 2014 sales in 2030.
- **Banning the use** of F-gases in many new types of equipment where less harmful alternatives are widely available, such as fridges in homes or supermarkets, air conditioning and foams and aerosols.
- **Preventing emissions** of F-gases from existing equipment by requiring checks, proper servicing and recovery of the gases at the end of the equipment's life.

SF_6 Gas Policy Statement: PS(T) 005

NGET has an SF_6 Policy Statement setting out the ambition to minimise the environmental impact related to the use and emission of SF_6.

Key Elements of the Framework

Technology knowledge and technical leadership will be developed and maintained to ensure timely, risk-managed, development and adoption of SF_6-free technologies. Proactive engagement will be maintained with stakeholders including manufacturers, utilities, regulators, academia & research organisations, industry representative bodies, and consumer representative bodies. Collaboration through organisations such as IEC, CIGRE, IEEE, ENA will be used to advance and exploit collective knowledge.

Opportunities for pilot projects of SF_6-free technology will be proactively pursued where they contribute to understanding and/or accelerated market availability of technically and commercially viable solutions.

SF_6-free technologies will be progressively adopted and installed as they become technically and commercially viable in the context of utility asset management. Competing SF_6 technologies will be excluded from procurement activities when two or more technically and commercially viable SF_6-free solutions are available and offered.

A robust, transparent, and fair mechanism will be developed to take proper account of the differing costs and environmental impacts of competing technology solutions (both SF_6 and SF_6 free) in procurement and commercial activities. The mechanism is expected to take account of factors including Global Warming Potential of dielectric fluids, mass of dielectric fluids, total environmental impact, technology availability/maturity, total cost of ownership.

Asset interventions will be planned both reactively to repair leaks, and proactively to prevent leaks, based upon best available predictions of asset deterioration. Palliative measures will be applied to non-leaking assets to reduce deterioration rate where these measures are proven to be effective and efficient.

SF_6 leak repair techniques (short-term and long term) will be developed and/or assessed for deployment as part of a portfolio of emission reduction techniques.

Leak repair will be deployed to align and optimise the strategic replacement of SF_6 assets which are leaking or are predicted to leak.

Implementation Summary:

The policy establishes a set of key technology milestones:

- No further procurement of new assets containing SF_6 for use on the 132kV, 66kV and 13kV (tertiary) systems. Due to the very small volumes of SF_6 involved, procurement of equipment at other sub-transmission voltages such as 33kV and 11kV shall also conform to this requirement unless the cost and complexity exceed the benefit.
- No further procurement of new gas insulated busbar and gas insulated line containing SF_6 at any voltage. The integrated busbar sections of gas insulated substations are excluded from this requirement however all outgoing circuit-connections are included.
- No further procurement of 275kV or 400kV gas insulated switchgear containing SF_6 (excluding circuit-breakers) from 2024.
- No further procurement of 275kV or 400kV circuit-breaker containing SF_6 (AIS & GIS) from 2026.

Policy timeline table:

2021/22	2022/23	2023/24	2024/25	2025/26
No further procurement of new assets containing SF_6 for use on the 132kV, 66kV and 13kV (tertiary) systems				
No further procurement of new gas insulated busbar (GIB) and gas insulated line containing SF6 at any voltage				
			No further procurement of 275kV or 400kV gas insulated switchgear containing SF_6 (excluding circuit-breakers) from 2024.	No further procurement of 275kV or 400kV circuit-breaker containing SF_6 (AIS & GIS) from 2026.

Table 5.1: Policy timeline

ET Performance Contract

On an annual basis, NGET enters a Performance Contract with National Grid Group. The Contract consists of c.20 Key Performance Indicators (KPIs) (with a target for the current year and indicative targets for future years), transformation initiatives and milestones across NGET's strategic priorities. Performance against this contract is monitored by the NGET executive at a monthly Performance Dialogue meeting.

Reporting includes both the current and forecast year-end position and each KPI, milestone and transformation initiative is owned by a member of the executive. Group monitors performance against the commitments in the Performance Contract through a Monthly Business Review meeting (MBR), which is attended by the NGET President, NGET Chief Financial Officer, Group Chief Executive Officer, Group Chief Financial Officer and other members on an ad-hoc basis.

Both the FY22 and draft FY23 Performance Contracts contain an SF_6 leakage KPI. The leakage target in the FY22 and draft FY23 Performance Contracts reduces annually, reflecting NGET's ambition to reduce SF_6 emissions from the network by 50% by 2030 (based on the 2019 baseline). The draft FY23 Performance Contract also contains a transformation initiative on the inventory reduction of SF_6 assets with alternative gases. Both the FY22 and draft FY23 Performance Contracts also contained KPIs on delivery of asset interventions, including replacement/repair/refurbishment of leaking SF_6 assets.

6. Demonstration of the Needs Case

This section presents the needs case for doing the proposed work. It shows the impact of SF_6 leakage in terms of CO2e emissions based on historic performance, and how past performance is used to forecast future performance. Alignment with business strategy and with the targets and performance expectations detailed under the stakeholder section is also addressed.

This document focuses on emissions reduction requirements and details a do-nothing position alongside the forecast emission position from existing funding and deliverables within RIIO-2. Neither of these scenarios is able to deliver the established targets for emission reduction performance. Proposals are set out for the additional interventions, and associated funding, necessary to achieve 2026 targets and to establish an acceptable emissions reduction trajectory on which to build future performance improvements.

The start of this section highlights the current SF_6 asset health, failure mechanisms and NGET inventory/emissions position, the SF_6 inventory reduction strategy is mentioned in the project delivery section and is proposed to form a 2^{nd} re-opener with specifically focussing on the inventory reduction strategy.

<u>**Summary of Key Messages:**</u>

Leak rate & Inventory:

The current transformer portfolio has the highest leakage rate which is similar to the rate for circuit-breakers. Whilst GIS gas zones exhibit a lower leakage rate (%), their very large SF_6 inventory and rising emissions trend in recent years make them the largest contributor to total mass (kg) of SF_6 emitted to atmosphere. The emitted mass from gas zones is forecast to rise further without suitable interventions.

Inventory size & SF_6 Mass:

Improvements in SF_6 technology in recent years have reduced the SF_6 inventory required to deliver the same functionality e.g. the move from double-break to single-break 420kV GIS circuit-breakers. Consequently recent and ongoing installations of SF_6 filled GIS contribute proportionally less to SF_6 inventory growth than earlier installations

Forecast capabilities:

Our forecast in not able to predict accurately the future performance of individual assets e.g. the occurrence of single, new, large leaks. We use historic performance to forecast the aggregate emission behaviour of defined asset groups and apply this aggregate performance across the group population. This forecast information is used as decision support for our asset health assessment and to assess the impact of proposed intervention.

Asset Health

Leaks occur on all SF_6-filled equipment. Closed pressure systems such as those used for high voltage switchgear typically have design leak rates in the range 0.1% to 1.0% per annum depending primarily upon when they were designed and manufactured. All in-service leak rates in-excess of the design value warrant intervention given the environmental impact of SF_6. The average leak rate across our portfolio in 2018/19 (the benchmark year) was 1.4%. This average is made up of many assets that are performing well within design limits, as well as a population of assets and asset families that performs poorly against the same limits and which require early intervention.

The key measured parameter which we use to assess SF_6 leakage is the top-up mass over time. Single top-up events cannot be used to indicate unacceptable leakage as they provide no information on the leakage rate over time. Two or more top-ups on a single asset over time allow a leakage rate to be estimated. Assets with measured leakage rates significantly above the design value are candidates for intervention. For indicative purposes, we presently have approximately 880 functional positions (three phase asset locations) with leakage more than 1% per annum, which rises to approximately 1,100 if the border is set to 0.5% pa. All these locations are candidates for intervention if we are to achieve our long-term targets.

We record, via top-up data, all emissions of SF_6 from our assets so we have a good picture of present-day performance down to the individual asset level. Since the RIIO-1 period, we have continued to accumulate performance data that allows us to better understand evolving emission performance of SF_6-filled assets considering factors such as manufacturer, design type, installed location/environment, age, etc.

The Network Output Measures' Network Asset Risk Metric (NARM) framework includes a reactive, end-of-life scoring mechanism for SF_6 leakage for lead assets (circuit-breakers). Whilst not yet addressed by the NARM framework a similar approach has been applied to non-lead instrument transformers.

The scoring mechanism for these assets includes the following factors: mass of leakage (kg), leak rate (mass of leak per mass of asset SF_6 inventory) and a combined score which incorporates both the leak mass and leak rate if both exceed defined criteria. Further, a leakage duration score, based upon whether the asset has been leaking in the last two or five years (depending on the severity) is also assigned. These scores are combined to produce an overall index which will determine whether an intervention is required on the equipment within two years or five years. The type of intervention is cost justified and appropriate to the level of risk. It may not necessarily involve full replacement of the asset.

$$EOLmod = \max\left(AGE_{FACTOR}, DUTY_{FACTOR}, SF6_{FACTOR}, DEFECT_{FACTOR}, FAMILY_{FACTOR}\right)$$
$$SF6_{FACTOR} = Max(Leak_{Mass}, Leak_{Rate}, Leak_{Combined}) + Leak_{Duration} * Leaking_{time}$$

Formula: Extract from Network Asset Risk Annex

Using the example of circuit-breakers, NARM categorises SF_6 leakage of <10kg per annum or <5% leakage per annum as “insignificant” for asset health scoring. “Major leakage” thresholds are set at >50kg per annum or >10% leakage per annum. These categories remain appropriate when considering the ability of the asset to perform its intended function however they are not entirely effective for the purposes of minimising SF_6 emissions over time.

The NARM framework is effective for addressing gross leakage from discrete assets such as AIS circuit-breakers where interventions can be planned and delivered in isolation from interventions upon associated assets. Interventions triggered in this way are reactive and rely on there already having been significant loss of SF_6. As such they will not contribute to a year-on-year reduction in emissions. Such reductions require a more pro-active approach based on early detection of leakage / potential leakage, early intervention on leaking assets and pre-emptive interventions on assets with a high likelihood of developing similar leaks. This likelihood is influenced by factors such as operating environment (indoor/outdoor), design type/family and age.

Going forward, we intend to develop a monetised risk process for prioritising interventions on gas insulated switchgear (GIS) assets in line with the NARM Framework. This will involve developing a scoring methodology which incorporates condition, performance information, family type information and leak forecasting, to understand the probability of failure (PoF) and consequence of failure (CoF) which will feed into a risk model that will help determine which interventions are to be undertaken on the assets. We anticipate that the monetised risk will most likely be monitored at a bay/site level rather than an individual asset level within the GIS system due to the integrated nature of the assets. A diagram showing the interaction between the gas zone diagram and schematic of a GIS asset is shown in the annex.

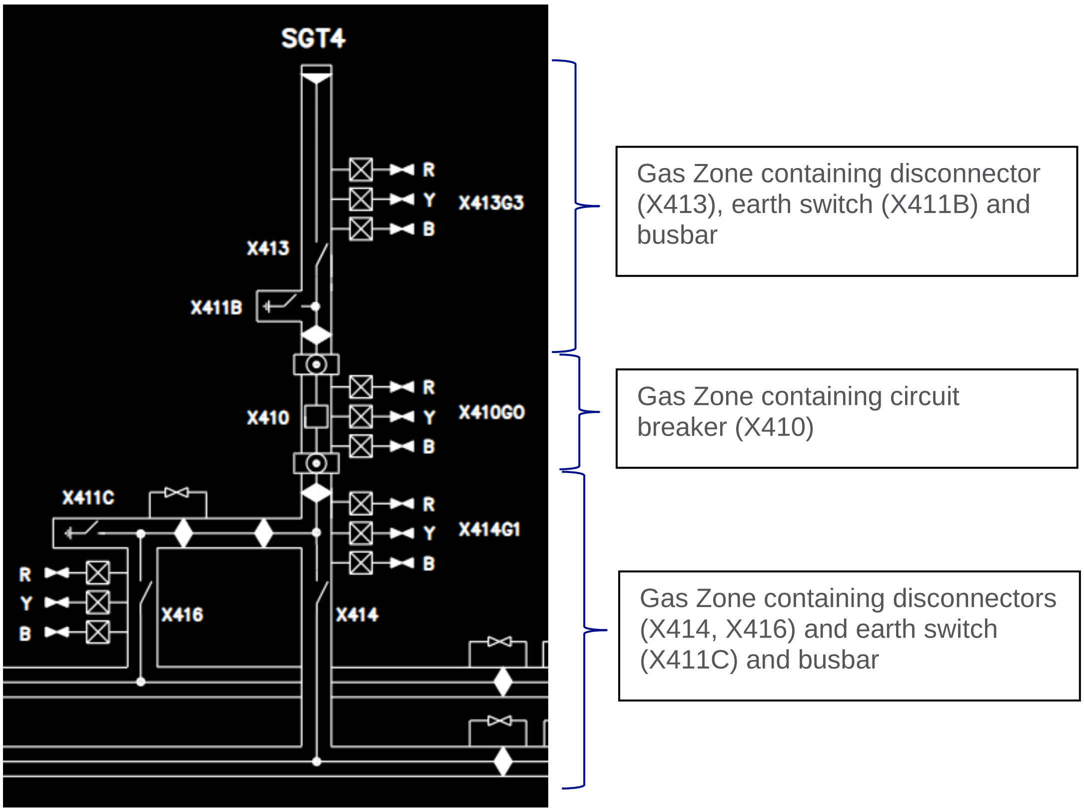


Figure 6.1: Gas diagram of Seabank SGT4 bay and interconnected assets within integrated gas zones.

Because interventions upon closely-integrated assets such as GIS have to be considered in the context of the actual and forecast performance of the associated assets, discrete asset interventions may be disproportionately costly or disruptive, so strategic interventions at the bay or site level must be considered. For example, if the outdoor GIS flanges of a particular asset design start to exhibit leakage and our forecasting predicts further evolution of leaks (number and magnitude) we would target the optimum cost-efficient intervention to mitigate existing emissions and prevent the development of further emissions for the remaining life of the installation.

Our forecasting has been updated to account for known high risk equipment design family types which have known issues and poor emissions performance. For GIS, design family and geographical location correlate strongly with the risk of excessive leakage and are key factors in our asset heath assessments. Improvements are being made to the accuracy and completeness of relevant asset data in Ellipse which will further improve the specificity of our forecasting.

The table 6.1 shows a clear linkage between leakage performance and asset design type, where three asset families dominate excessive historic leak performance: T155/1, YG and GMS41.

Row Labels	Sum of Total IIG Inventory (kg)	Average of 3 Year Leak Rate	Count of Plant Number FP	Average of Asset Age	Family Risk Category
250-SFMT-50F GIS GAS ZONE	6,115	0.0%	55	11	Low
400-SFMT-63F GAS ZONE	14,395	0.2%	103	11	Low
8DA10 GAS ZONE	1,247	0.1%	28	23	Low

8DN8-2 GAS ZONE	4,92	0.0%	20	17	Low
8DQ1-1 GAS ZONE	36,151	0.2%	196	11	Low
8DQ1-6 GAS ZONE	10,710	0.1%	110	10	Low
BBBC ELK-AN GAS ZONE	8,782	0.3%	167	23	Low
ELK14 GAS ZONE	12,216	0.0%	146	14	Low
ELK2 GAS ZONE	5,918	0.6%	73	29	Med
ELK-3 GAS ZONE	110,944	0.1%	1,003	9	Low
F35-2 GAS ZONE	567	0.0%	26	11	Low
GMS41 GAS ZONE	60,459	3.6%	313	32	High
GMT11 GAS ZONE	3,106	0.6%	40	32	High
NEI YG GAS ZONE	2,474	0.9%	27	24	Med
T155/1 GAS ZONE	68,693	1.7%	197	25	High
T155/1 GAS ZONE_GIL*	4,140	0.6%	15	16	Med
T155/2 GAS ZONE	188,336	0.1%	808	9	Low
T155/3 GAS ZONE	12,114	0.0%	157	3	Low
YG1 GAS ZONE	39,043	7.4%	180	40	High
YG2 GAS ZONE	74,078	4.4%	411	22	High
YG3 GAS ZONE	40,175	1.7%	217	16	High
Various family types	87,985	0.3%	1,715	10	Low

Table 6.1: Table of gas zone (GIS) family risk categorisation
**Mixed gas installation of 20% SF_6 – inventory shown is the total SF_6 mass*

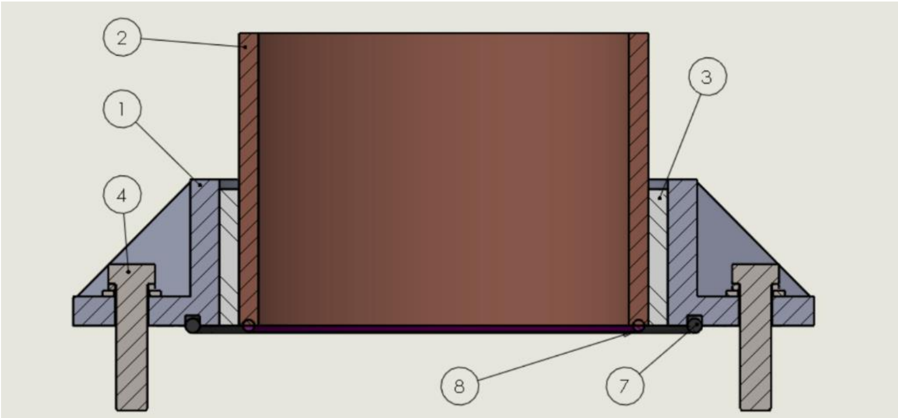
During the RIIO-2 period and beyond, we will continue to gather relevant data and use it to identify developing trends in emissions performance that will allow us to take proactive action to prevent most potential leaks developing into real emissions. For example, if our data indicated that a small percentage of a particular asset type, under particular environmental stresses, had developed significant leakage after 20 years in service, we would look to develop a cost-effective intervention both to repair those assets and to prevent all similar assets degrading to the same state in the same way. Our aim is to maximise the emission-free performance of our assets over the long term at minimum equivalent annual cost. As can be seen in the failure mechanism section, environmental corrosion is a key factor in SF_6 leakage. By taking actions to prevent the ingress of moisture and pollution the onset of such leakage can be deferred or prevented.

Failure Mechanisms

The failure mechanisms that lead to SF_6 emissions can be broadly categorised as being directly associated with the primary gas volume (e.g. GIS enclosure flanges, bursting disks) or with ancillary parts (e.g. SF_6 connecting pipework). When excessive leak rates are detected through top-up information, site surveys are used to identify the specific location of the leak and inform the choice of the most appropriate intervention.

The corrosion of outdoor sealing arrangements is the dominant factor in SF_6 emissions, with the deterioration of flanges being the precursor to leaks. There are two elements for this failure mode: metal to metal flanges and porcelain to metal flanges. Due to the presence of cement as a bonding agent within porcelain assets, these tend to deteriorate more quickly than the metal-to-metal flanges.

A cross sectional drawing of a simplified version of this joint is shown below:



ITEM NO.	PART NUMBER	QTY.
1	Metal flange	1
2	Porcelain section base	1
3	Cement Joint	1
4	BS EN 28765 - M16x1.5 x 65 x 38-N	12
5	Black washer BS 4320 - M16 (Form E)	12
6	Square section spring washer BS 4464 - 16 (Type A)	12
7	Outer O-Ring	1
8	Inner O-Ring	1

Figure 6.2: Cross section of bushing flange assembly

The SF_6 containment failures occur when rainwater enters the top of the cement joint (item 3 above) and permeates down through the joint to the bottom, in between the two O-Rings and between the porcelain section and the joining plate (not shown in the diagram). As the water runs through the cement joint, it picks up some of the water-soluble salts within the cement mixture. This forms an alkaline solution that will then form a reaction with the aluminium plates it is mounted to. A similar reaction occurs within steel components.

This reaction creates aluminium salts, which are white powdery substances that will defeat the sealing elements of the asset as they sit over the O-Rings. The pressure differential between the interior of the asset and atmosphere then exploits the weak point within the joint and the leak occurs. In doing so, it is possible for the flow path of gas to dislodge the aluminium particulate leading to secondary leaks. The SF_6 gas will then take the path of least resistance to atmosphere – this could be back through the cement joint or out over the outer O-Ring if it has been compromised – either through corrosion, compression set or other mechanisms.

The photos below are taken from some of our assets showing this issue. These are a mixture of AIS & GIS assets.

The photos below show an AIS Gas Circuit Breaker (GCB) – [redacted] (CB180). This was the sole leak site on the GCB, and the asset leaked 217.16 kg in 2018/19 prior to being repaired. The asset is now not leaking. The photo on the right demonstrates the low level of corrosion that can lead to SF_6 leaks.

Figure 6.3: Photos of leaking [redacted] circuit-breaker

The photo below shows the same type of deterioration, this time oxn an [redacted] This contamination is made more complicated by the addition of grease within the flanges.

Figure 6.4: Photos of leaking [redacted] circuit-breaker

A final example shows corrosion on an FE type GCB.

Figure 6.5: Photos of leaking FE circuit-breaker

Figure 6.5 photo (right) shows the location of the SF_6 leak after being sprayed with leak detection solution:

In terms of GIS assets with porcelain sections, the photos below show a [redacted] bushing that had exhibited SF_6 leakage. There is extensive corrosion on the key sealing areas. The asset was around 20 years old.

Figure 6.6: Photos of leaking [redacted] bushing

The photos below indicate the condition of outdoor GIS assets.

Figure 6.7 (Left): [redacted] GIS at [redacted] showing evidence of corrosion

Figure 6.8 (Right): [redacted] at [redacted] showing evidence of corrosion

The orientation of GIB flanges has an impact on the onset of failure. A flange in a horizontal orientation has flat surfaces on the flange face and on the top of bolts. These flat surfaces allow water to pool which gradually seeps through split washers (where used) and the bolt threads, which over-time causes corrosion in the joints which in turn eventually causes an SF_6 leak. Flanges in a vertical orientation don't have these upward-facing flat surfaces and therefore rainwater runs off these joints without pooling. For this reason, leaks from flanges across the network are significantly more likely to be from a horizontally-oriented flange. Figure 6.9 shows an example of the two orientations of flanges and shows an example of a previous repair on the horizontal flange at the top of the GIB section.

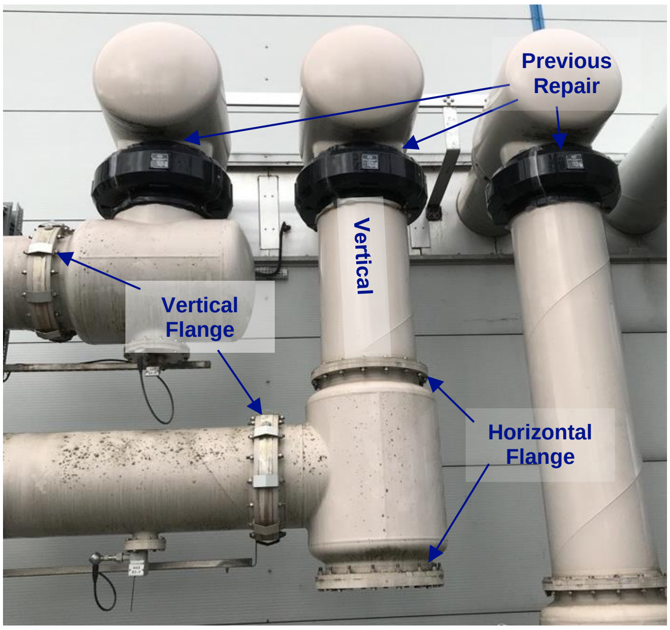


Figure 6.9: Example Flange Layouts - [redacted]

The below photos show the use of leak detection spray applied to small bore pipework components to indicate whether leakage is occurring by the formation of bubbles in the spray solution from the escaping SF_6.

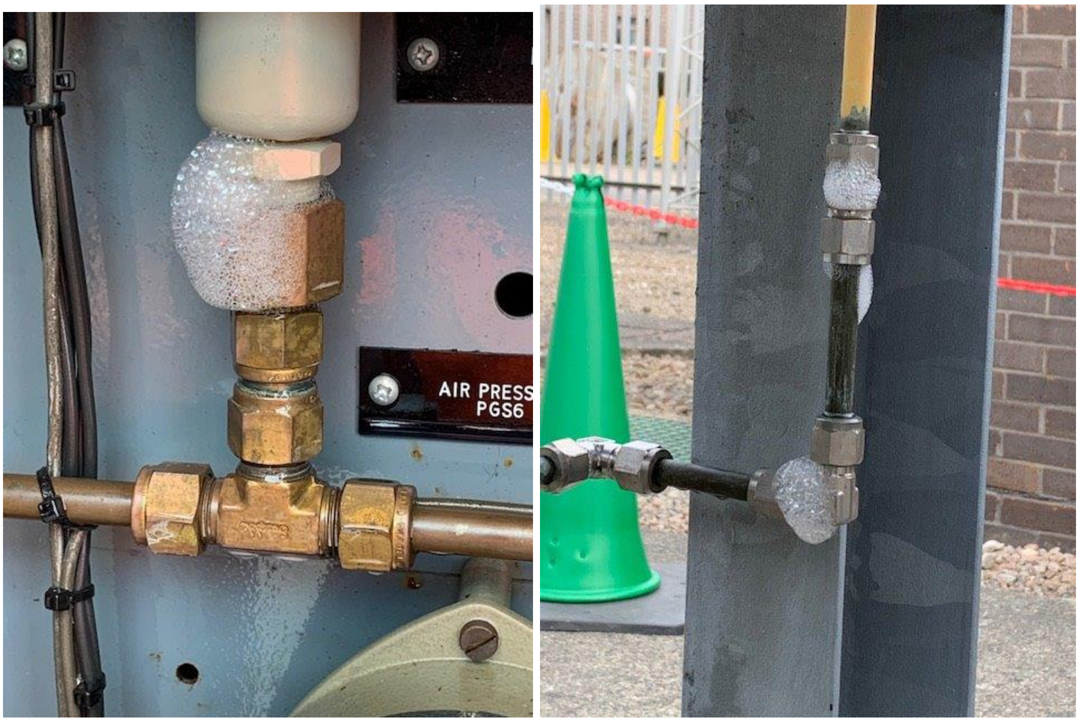


Figure 6.10: Use of leak detection spray

These photos illustrate the nature and location of the corrosion that can be found on the SF_6 assets. The condition survey information for specified interventions is presented in greater detail in the relevant engineering justification reports.

Inventory & Emissions

Inventory

There are currently 7,958 sets of assets (functional positions) containing SF_6 installed as part of NGET network, with each set made up of between 1 and 3 individual assets depending on the number of phases and design

Asset Category	No. of Functional Position Assets	SF_6 Inventory (kg)	% of SF_6 inventory
Gas Zones (GIS)	6,123	790,634	85.8%
AIS Circuit Breakers	1,469	88,717	9.6%
AIS Instrument Transformers	252	41,640	4.5%
Other**	97	821	0.1%

Table 6.2: Inventory details

**Based on November 2021 inventory data*
*** under "Other" asset categories include: Bushings, Earth switches, Disconnectors, Voltage Transformers*

The asset type and voltage of the inventory is shown in the Figure6.11.

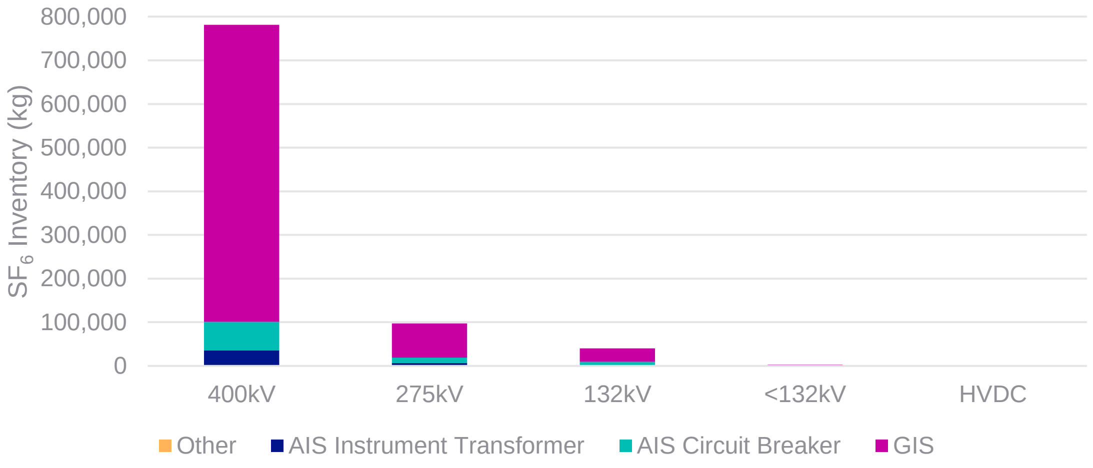


Figure 6.11: Asset type and voltage distribution of SF_6-filled assets

During the RIIO-T1 period there was net increase of 169,966kg in the SF_6 inventory, with 44,559kg removed from the network and 239,370kg added.

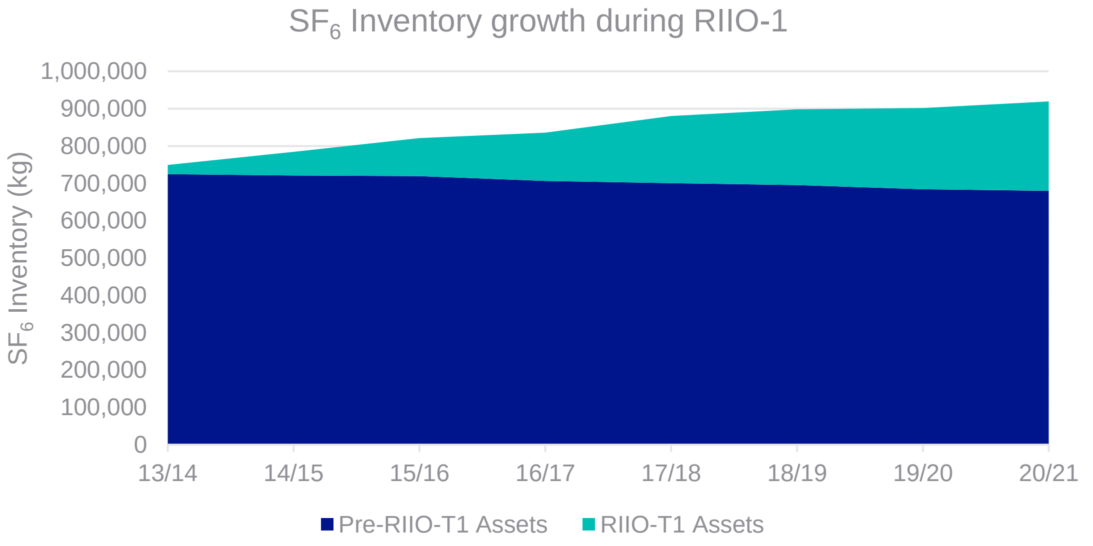


Figure 6.12 SF_6 Inventory growth during RIIO-1

The map visualisation in figure 6.13 provides a representation of where SF_6 inventory is regionally installed across the transmission system and also shows the location of GIS family risks as defined in the asset health section above.

There is a significant amount of SF_6 installed around the London region due to the smaller physical footprint from GIS assets compared to equivalent AIS assets.

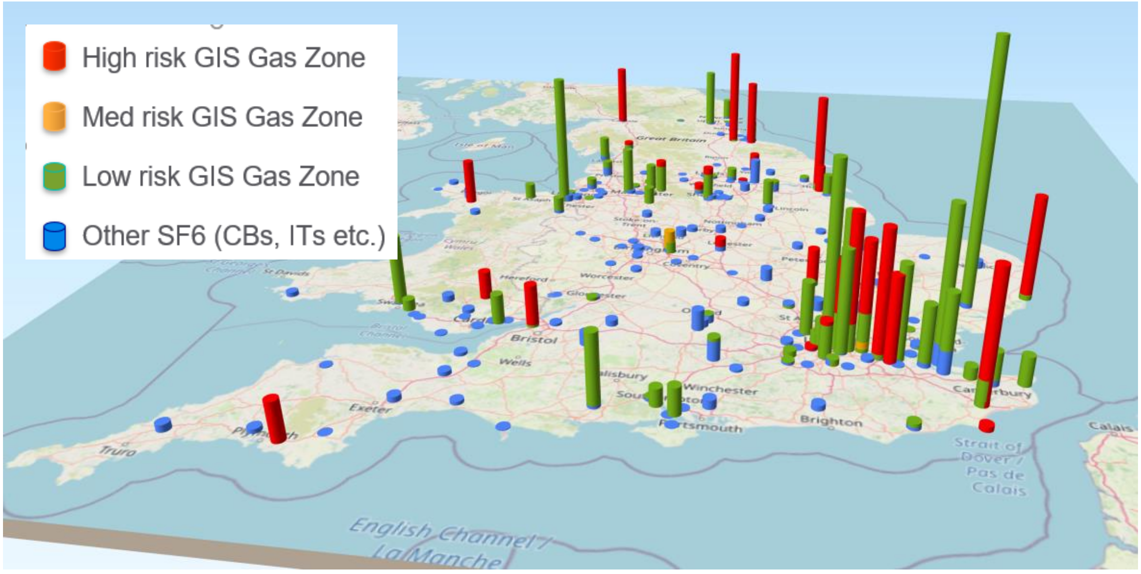


Figure 6.13: Geospatial depiction of SF_6 inventory

The below graph shows the annual SF_6 emissions during the RIIO-1 period

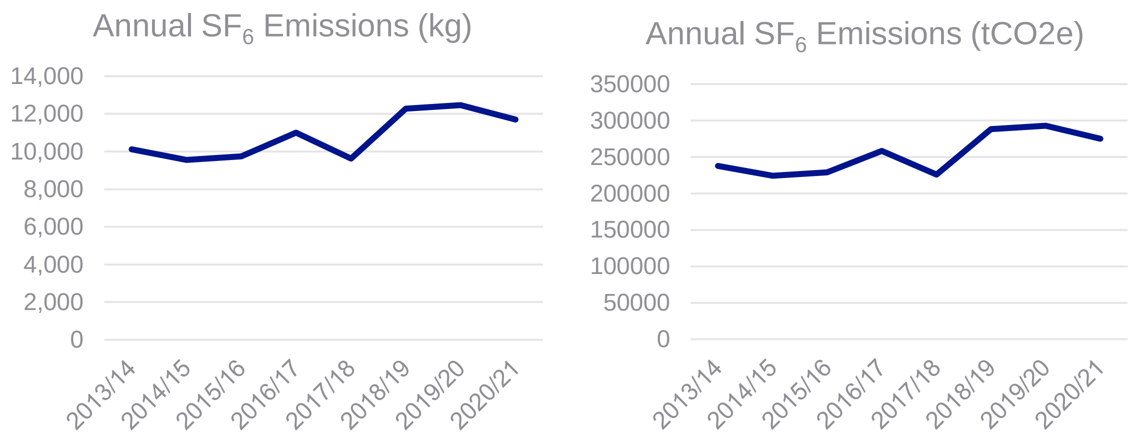


Figure 6.14 Annual SF_6 emissions during the RIIO-1 period (SF_6 and CO_2 mass)

The annual SF_6 emissions rate over time for the three main categories of assets is shown in the graph below.

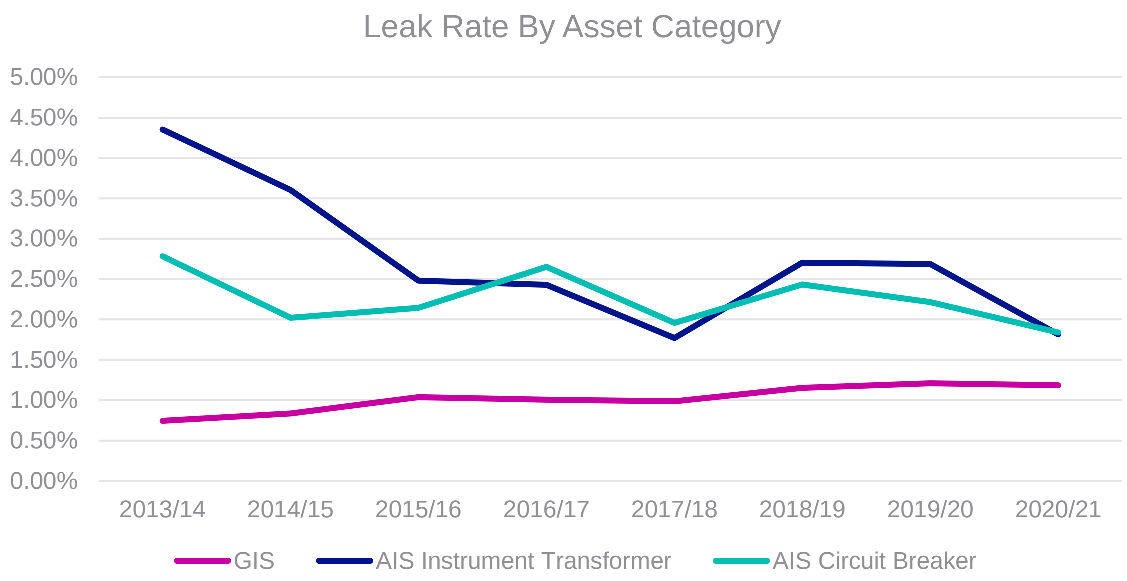


Figure 6.15: Leak rate by asset category

The leak rate in figure 6.15 shows that the current transformer portfolio has the highest leakage rate which is similar to the AIS circuit breaker rate. Figure 6.15 shows that the current transformer portfolio has the highest leakage rate which is similar to the rate for circuit-breakers. Whilst GIS gas zones exhibit a lower leakage rate (%), their very large SF_6 inventory (see figure 6.11) and rising emissions trend in recent years make them the largest contributor to total mass (kg) of SF_6 emitted to atmosphere. The emitted mass from gas zones is forecast to rise further without suitable interventions.

Leakage from assets is not distributed evenly across the asset population, nor is it distributed evenly across an individual asset's life. All SF_6 filled assets leak to some extent with established benchmarks of 0.005 (0.5%, IEC Standard requirement referred to by manufacturers) and 0.0025 (0.25%, NGET SF_6 methodology and present minimum standard for new assets). These compare to an NGET SF_6 leakage rate for pre-RIIO-2 assets of 0.0118 (1.18%).

All leakage, including leakage less than 0.5% is undesirable and has to be addressed in the medium term as we progress towards Net Zero. Initially we need to reduce our network wide emission rate towards this 0.5% value by addressing those assets which leak, or will leak, far in excess of the 0.5% benchmark.

645 (8%) of the above mentioned 7958 assets have been topped up in the financial year 2020/21. For these 645 assets, figure 6.16 shows proportion of the asset inventory added in 20/21 plotted against the total mass of top-ups.

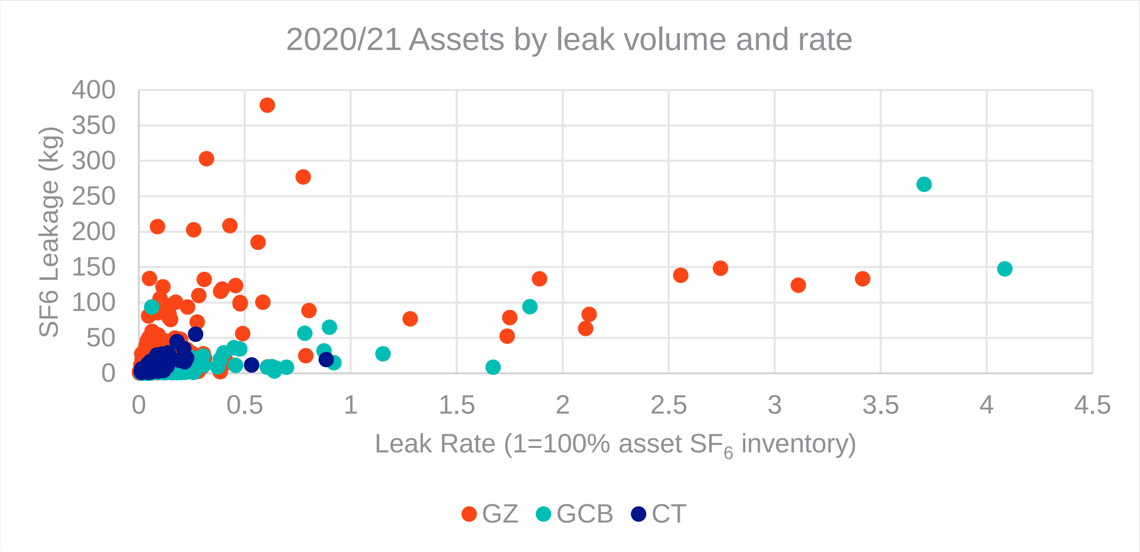


Figure 6.16: 2020/21 emissions - assets by leak volume and rate

Considering the proportion of asset inventory added (x axis) the data can be considered in two broad categories.

Annual top ups of less than 0.1- 0.15 (15% of inventory) require more detailed analysis than can be derived from a one-year top-up snapshot. This is due to the design margin between rated pressure and alarm pressure being in the range of 10-15% for most SF_6-filled assets which is further detailed in the SF_6 leakage detectability section. Taking the example of a 10% design margin, a single top up of 10% of inventory may represent a leak rate of approaching 10% in a single year but might equally represent a leak rate of 0.5% over the preceding 20 years.

Top-up data analysed over multiple years can be used to refine the analysis where annual top-ups fall within the <0.15 (<15%) range.

Annual top-ups in excess of this range are a clear indicator that assets are leaking excessively. The graph above represents a total leakage of approximately 12 tonnes, approximately half of which is emitted from the 74 assets leaking >0.25 (>25%) with the other half being spread across the remaining 571 assets.

For reference the figure 6.17 present the same data progressively focussing in upon the smaller volume/rate values in the bottom left of the above graph.

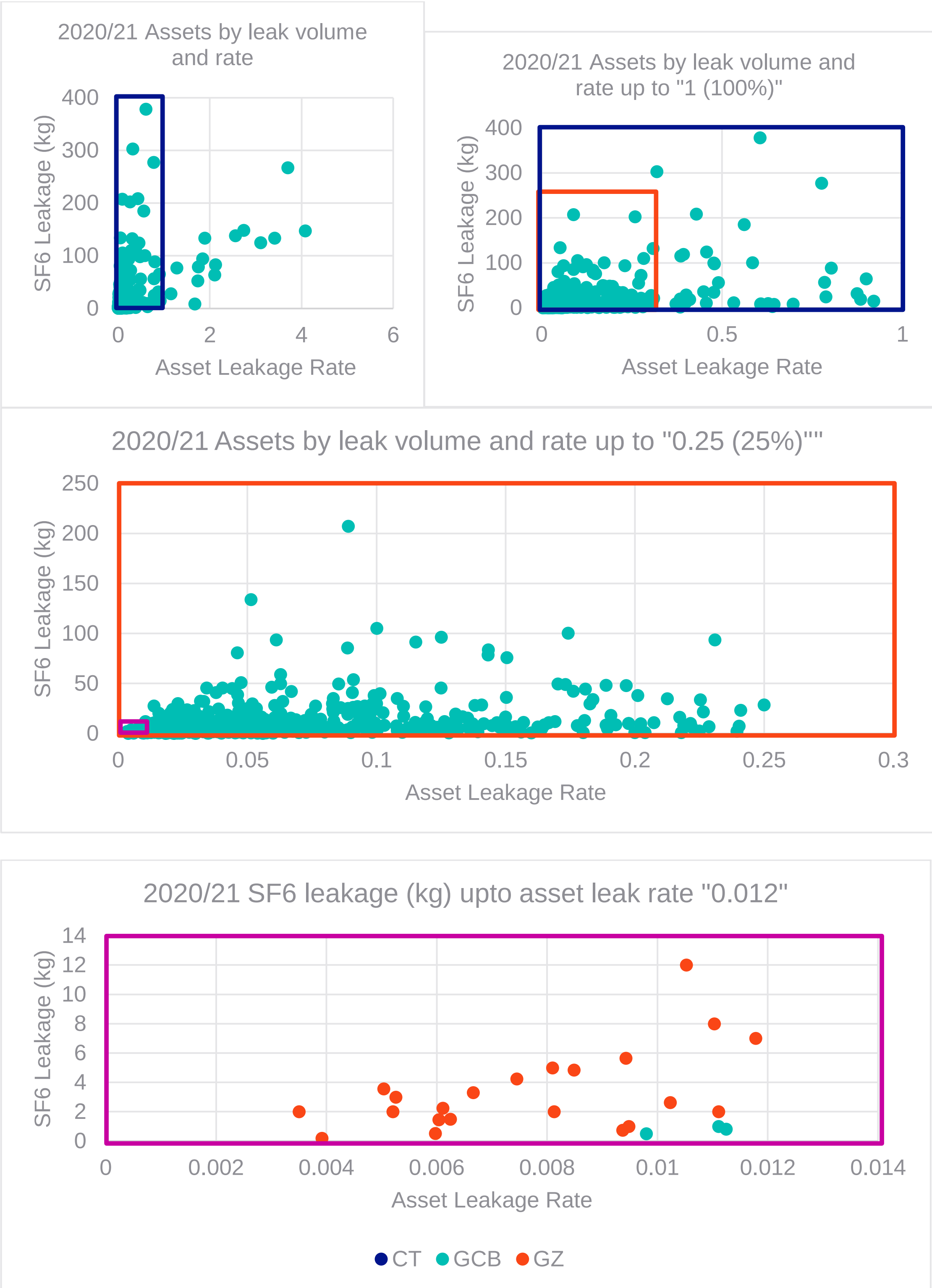


Figure 6.17: Assets by leak mass and rate – alternative views

Analysis of this type allows us to quickly identify those assets that are performing particularly poorly and build intervention scenarios to address the worst leakage and hence substantially reduce our aggregate leakage rate towards 0.5%.

To date, we have taken a largely granular, reactive approach to how we use this data, i.e. we have targeted leaks for intervention on an individual asset basis as-and-when they occur. If we are to deliver the step-change that we need to migrate from a reactive to a proactive emission abatement approach, making best use of all available intervention techniques: prevention, repair, refurbishment, and replacement. Due in large part to the installation profile, shown in Figure 6.19, a concerted programme of interventions in the RIIO-2 period and beyond is essential if we are to deliver our environmental commitments.

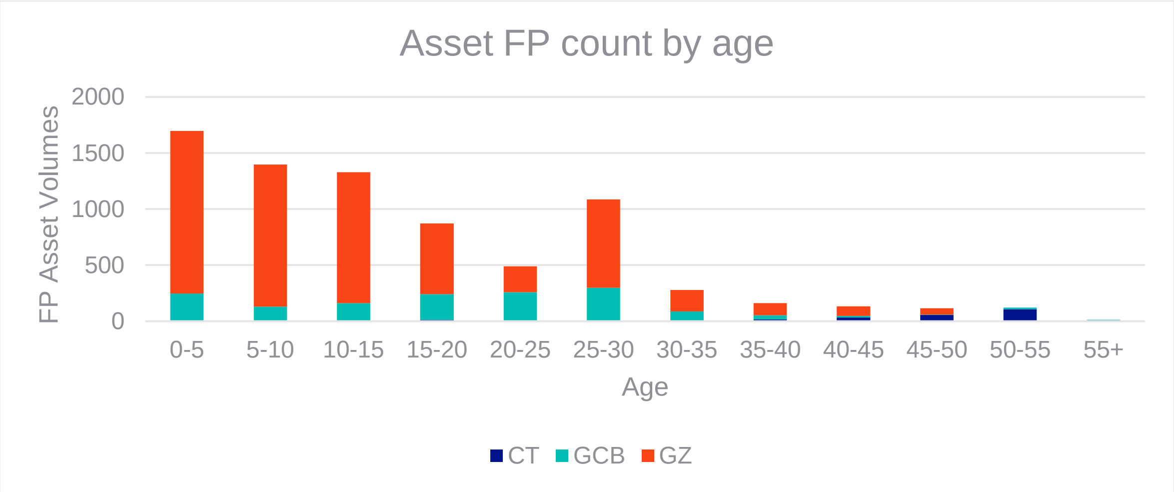


Figure 6.18: Asset count by age

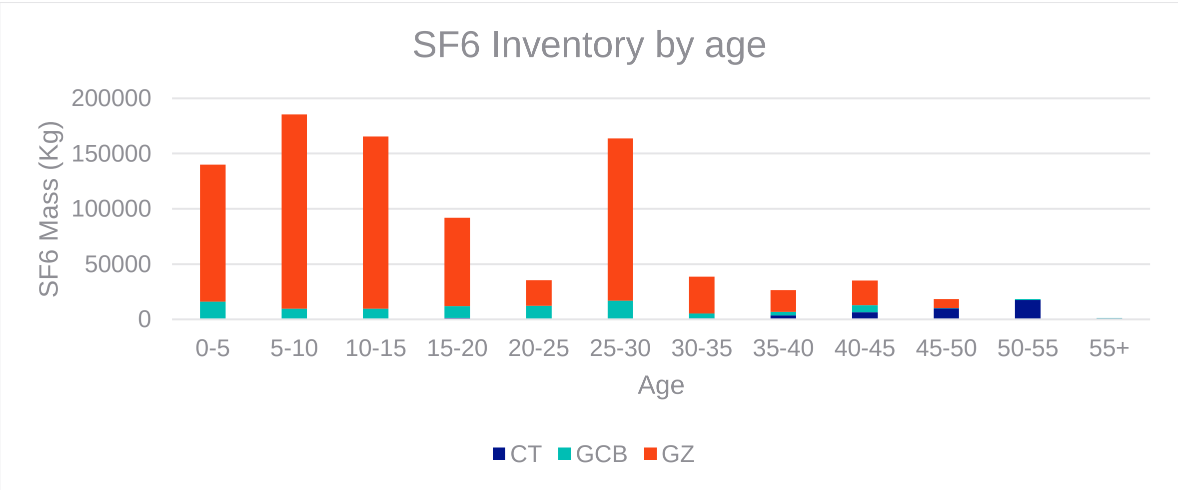


Figure 6.19: SF_6 inventory count by age

Figure 6.20 normalises emissions with respect to inventory and shows the strong correlation between age and emission rate where emission rate is given by the mass of leakage per mass of inventory in five-year age groupings. The falling trend beyond 50 years results from “survivor bias” (i.e. the tendency for only the best performing assets to have survived) and the fact that the most leaking assets have already been replaced.

These graphs taken together show indicators such as a significant SF_6 inventory in younger assets (<25 years) with low leak rates that require the application of preventive palliative coatings and a large inventory of 25+ year assets with potential for high leakage requiring larger interventions whether repair, refurbishment, retro-fill or replacement.

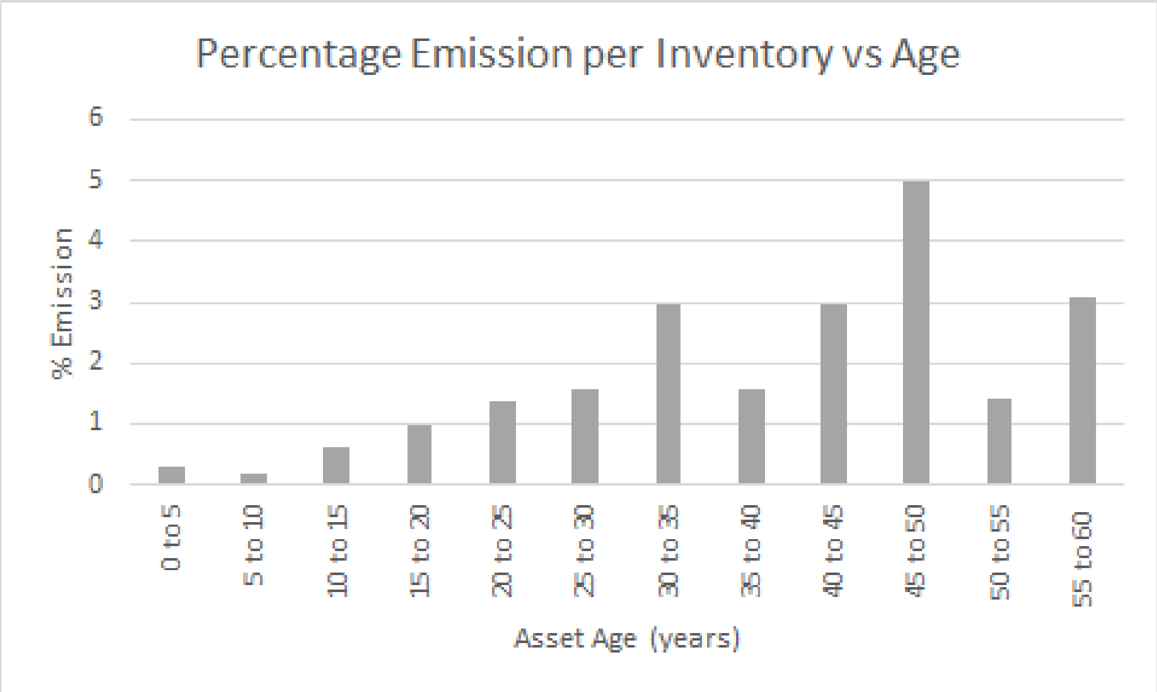


Figure 6.20: Percentage emissions by age

We have used our granular, per-asset/per-functional position SF_6 leakage and forecast data to categorise assets requiring intervention. We have identified several relevant categorisations related to age, operating environment, and design/installed location.

Excluding the assets & sites already aligned to other funding mechanisms we are providing further details on 4 major GIS sites/assets with excessive leakage affecting a significant number of individual assets that require strategic interventions in RIIO-2 if we are to achieve our abatement targets.

From the original asset group strategy investment plan that was based upon T1 leak performance the table 6.3 summarises the position of the 18 top leaking sites:

These sites and a summary of key SF_6 emission related metrics are detailed in Table 6.3.

Site	Inventory (kg)	Indoor Inventory (kg)	Outdoor Inventory (kg)	Transitional Inventory (kg)	T1 average leakage (kg)	T1 Leakage (%)	T1 Average of Funct'l Pos'ns Leaking >1% (%)	Asset Design Family	T2 Position
[redacted]	22310	10295	6404	5611	143	1	8	[redacted]	T2 Re-opener
[redacted]	10622	10622	0	0	144	1	33	[redacted]	T2 LOTI
[redacted]	7165	0	7165	0	106	1	28	[redacted]	T2 SF_6 Asset Intervention
[redacted]	833	683	72	78	77	9	25	[redacted]	T2 SF_6 Asset Intervention
[redacted]	16365	15513	852	0	343	2	28	[redacted]	T2 LOTI
[redacted]	17406	10570	3341	3495	332	2	16	[redacted]	T2 SF_6 Asset Intervention
[redacted]	24868	0	24868	0	1067	4	67	[redacted]	T2 SF_6 Asset Intervention
[redacted]	8086	0	8086	0	667	8	68	[redacted]	Site under replacement
[redacted]	17582	14495	3087	0	213	1	16	[redacted]	T2 SF_6 Asset Intervention
[redacted]	25612	13687	11925	0	476	2	24	[redacted]	T2 SF_6 Asset Intervention
[redacted]	4731	0	4731	0	98	2	50	[redacted]	T2 SF_6 Asset Intervention
[redacted]	5834	0	5834	0	266	5	10	[redacted]	T2 SF_6 Asset Intervention
[redacted]	8833	5483	462	2888	290	3	13	[redacted]	T2 Re-opener
[redacted]	26267	19588	5668	1011	734	3	22	[redacted]	T2 Re-opener
[redacted]	22213	19432	2781	0	471	2	39	[redacted]	T2 SF_6 Asset Intervention
[redacted]	2445	0	2445	0	204	8	69	[redacted]	Site repaired in 2020
[redacted]	27640	20910	6730	0	126	0	13	[redacted]	T2 Re-opener
[redacted]	852	780	72	0	156	18	53	[redacted]	Site decommissioning

Table 6.3: Summarised emission performance of selected sites

Table 6.3 demonstrates the poor emission performance of the targeted sites in terms of absolute leakage rates, percentage leakage rates and percentages of assets leaking excessively. For sites with both indoor and outdoor assets we can also distinguish the relative performance, and intervention driver for these asset subsets. The sites listed for the RIIO-2 re-opener are still critical in addressing the existing leakage and reducing the leakage position for the SBT and Net Zero target.

The contrasting indoor and outdoor performance at these specific sites aligns with the broader, network-wide performance comparison shown in the following Figure 6.21.

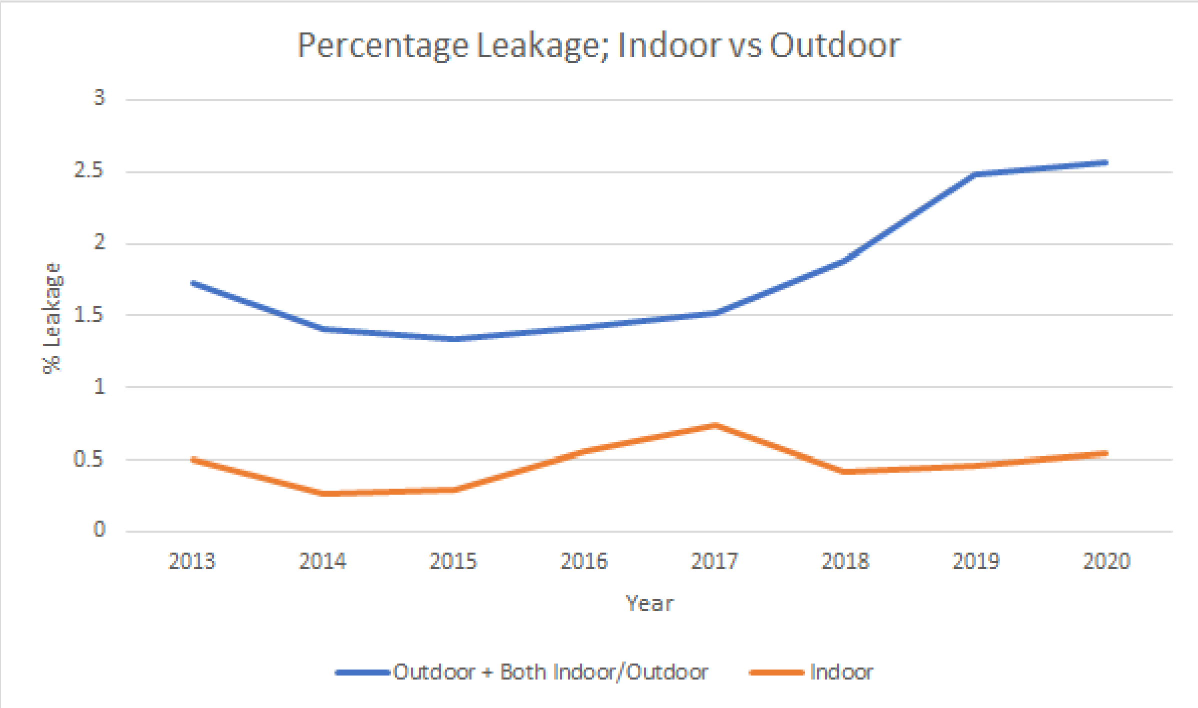


Figure 6.21: ***Comparison of indoor vs outdoor leakage rates***

Whilst only a proportion of the relevant assets at each site are presently leaking, we predict that similar, non-leaking assets of the same design types at the same sites will develop similar leaks within the short-term. As such we are targeting these sites for focussed, defined, strategic interventions for leaking assets & highlighting the risks associated to the non-leaking assets. Further details are presented in site-specific annexes to this document.

These are not the only sites that are exhibiting unacceptable leak rates from several assets, requiring strategic intervention in RIIO-2. A summary of the site level situation is shown in Table 6.4 with the sites being intervened on or having existing allowances under the RIIO-2 deal colours grey or considered in this reopener highlighted blue in the list. Yellow sites are the next top 5 sites from RIIO-1 total leakage which is considered as part of the options and scenarios. This list is ranked by RIIO-1 average leakage. The optimum investments to mitigate excessive leakage at these sites requires site and/or asset specific scheme development which need detailed development and aligned with site strategies and the SF_6 reduction strategy. We expect to plan and deliver interventions on a proportion of these sites. The selection of these sites will be prioritised based on leakage performance (actual and forecast) and contribution to achieving the SBT.

Row Labels	Count of Asset Plant Number (FP)	Sum of SF6 FP Holding (kg)	Average Annual T1 Leak %	Average Annual T1 Leakage
[redacted]	94	24867.5	4%	1119
[redacted]	125	26267	3%	838
[redacted]	71	25611.8	2%	526
[redacted]	116	22213	2%	478
[redacted]	56	8086	6%	474
[redacted]	62	17406.23	3%	442
[redacted]	107	16239	2%	392
[redacted]	30	8832.5	3%	288
[redacted]	21	5833.5	5%	267
[redacted]	9	1626.8	14%	224
[redacted]	98	17582	1%	211

[redacted]	73	22310	1%	204
[redacted]	15	780	19%	147
[redacted]	27	10622	1%	142
[redacted]	130	27640	0%	125
[redacted]	2	78	154%	120
[redacted]	2	4351	3%	114
[redacted]	49	7770	1%	107
[redacted]	51	8041.46	1%	104
[redacted]	27	4908	2%	88
[redacted]	7	4525	1%	54.5
[redacted]	121	24223	0%	51.3
[redacted]	53	13921	0%	34.1
[redacted]	15	4140	1%	32.9
[redacted]	15	11353	0%	30.5
[redacted]	37	6625	0%	30.5
[redacted]	73	9236.47	0%	29.7
[redacted]	7	2176.9	1%	25.3
[redacted]	142	16629.3	0%	22.8
[redacted]	20	2152	1%	20.4
[redacted]	6	1008.5	2%	20.3
[redacted]	73	15875.9	0%	19
[redacted]	44	5904.33	0%	18.8
[redacted]	16	2556	1%	18.5
[redacted]	38	5040.5	0%	18.3
[redacted]	218	53422.7	0%	17.2
[redacted]	73	6104.34	0%	16.3
[redacted]	40	1523.29	1%	16.1
[redacted]	16	1246	1%	14.8
[redacted]	73	5917.9	0%	13.9
[redacted]	28	2509.24	1%	13.7
[redacted]	51	5801.91	0%	13.6
[redacted]	49	2315	1%	12.4
[redacted]	23	3153	0%	11.7
[redacted]	247	37254	0%	10.5
[redacted]	241	30930.9	0%	10.5

Table 6.4 – Sites with excessive SF_6 emissions ranked by RIIO-1 average emissions; extract of full list for indicative purposes
**** Asset with leakage repaired in 2020***

We also have comprehensive leakage data for discrete non-GIS assets which is already used within the NARM framework and Instrument Transformer asset group strategy to prioritise interventions that mitigate gross leakage. Where early interventions upon discrete circuit breaker assets or families of assets are required we have demonstrated this within the circuit breaker EJR to show its contribution to achieving our SBT cost-efficiently. For Current Transformers that are at end of life we have proposed the replacement of these for SF_6 alternatives to reduce the inventory and abate and mitigate any leakage from the portfolio

Forecasting

Using the detailed top-up data that we accumulated during RIIO-1 we developed forecasting techniques to allow us to better understand the need for asset interventions to both address and prevent leaks. As part of the RIIO-2 submission the forecast of network-wide SF_6 emissions in the form shown in Figure 6.22 was published. This forecast represents the hypothetical case where we cease all current efforts (refurbishment, replacement, repair) to mitigate leakage from SF_6 filled assets. However, the methodology used in that submission did not work effectively at an asset level, and so we were unable to provide scenario analysis to vary our intervention strategy

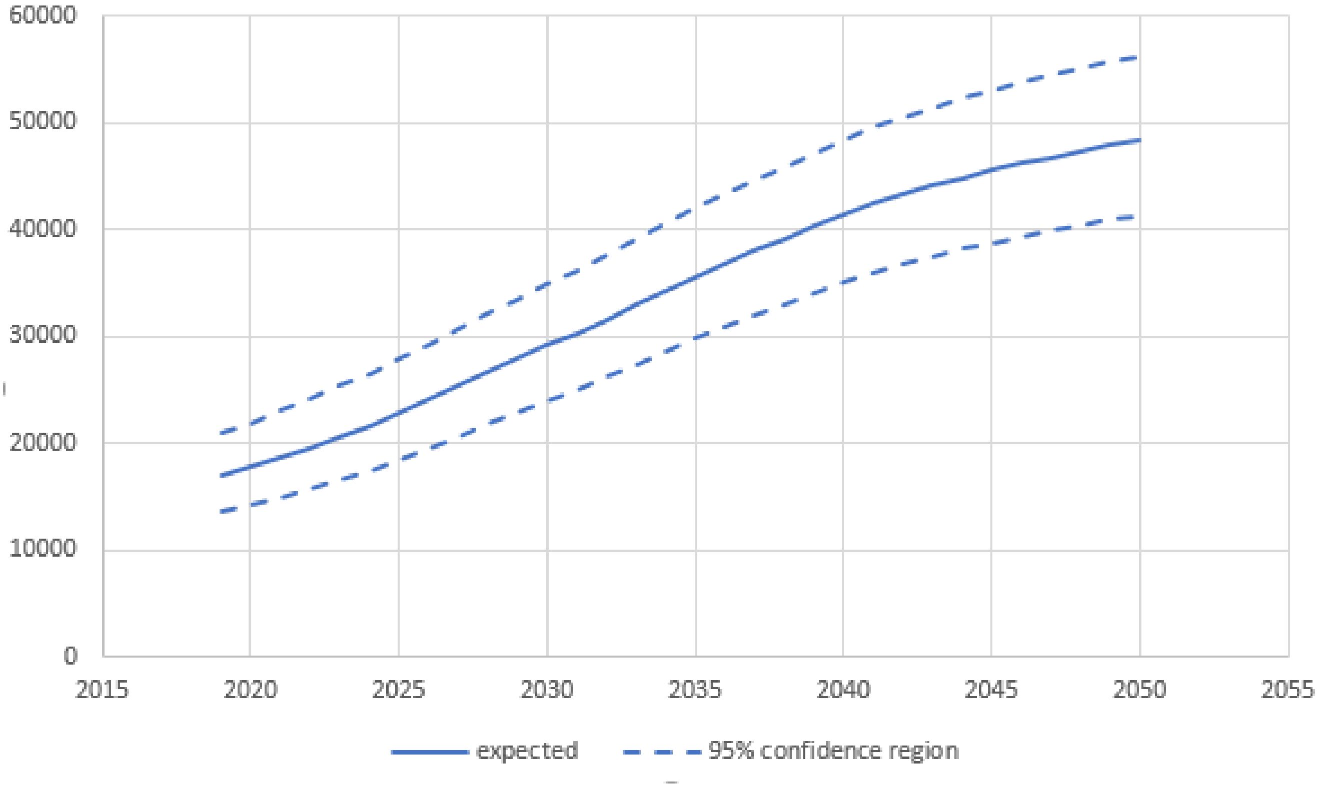


Figure 6.22: SF_6 leak rate forecast included as part of RIIO-2 submission

To enable scenario analyses and explicitly include interventions in our modelling, a new methodology was developed, details of which are presented in the forecasting annex. The network-wide emissions from the new forecast methodology are shown in Figure 6.23 and show a similar trajectory to the forecast submitted previously. Note that the start point is lower, as some assets have been repaired or removed from the network since the previous forecast was submitted. The figure shows kg SF_6 on the primary axis and the greenhouse gas impact as million tonnes of CO2 equivalent on the secondary (right) axis.

The new methodology uses a Monte Carlo simulation which enables the simple calculation of a range of outcomes for a particular scenario. In the following charts the 5% and 95% lines represent the values for which 5% or 95% of samples have total leakage lower than the value plotted respectively. This gives the range of likely outcomes for the set of assets considered. Note that for a small number of assets (e.g. the 'Other assets' category in figure 4) there are a wide range of outcomes so the uncertainty is large, compared to the expected forecast. When there are many assets, the relative range of outcomes is smaller as there are fewer outliers.

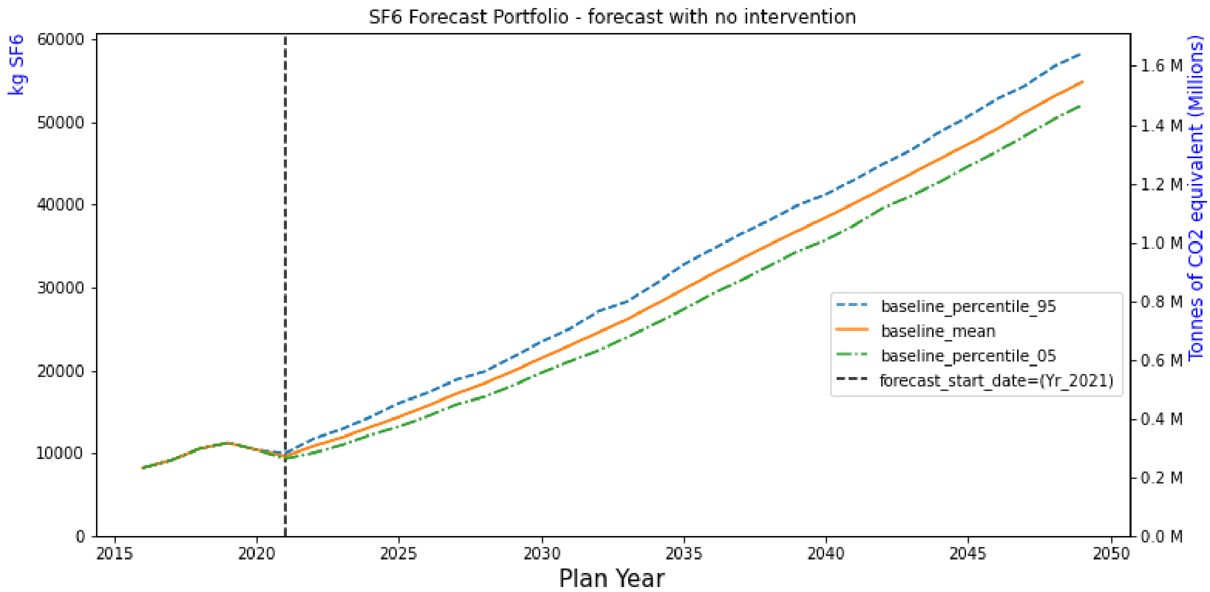
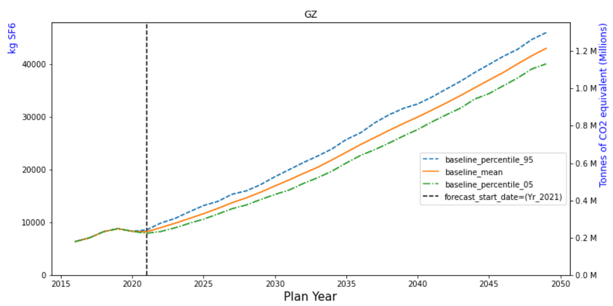


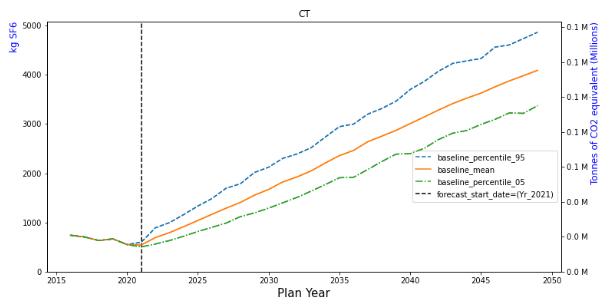
Figure *6.21*: Revised forecast allowing asset level interventions to be considered

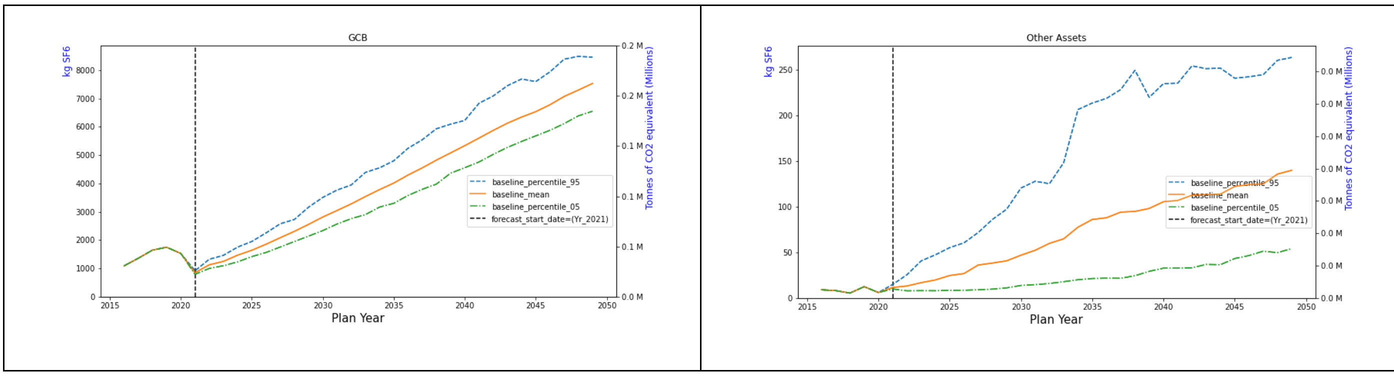
Figure 6.24 shows the breakdown between leaks from the three categories of assets with the largest total inventory: current transformers (CT), AIS gas circuit breakers (GCB) and gas zones (GZ), other assets make a small fraction of the inventory and thus do not contribute substantially towards NGET's forecast leaks. The mass of leaks in each category is largely driven by the inventory size, separating the assets like this emphasises a need to reduce inventory and focus on reducing the number of SF_6 Gas Zones on our network.

Gas Zones



Current Transformers





AIS Gas Circuit Breakers

Other asset types

Figure *6.22*: SF_6 leak forecast separated by asset category

Indoor Outdoor split:

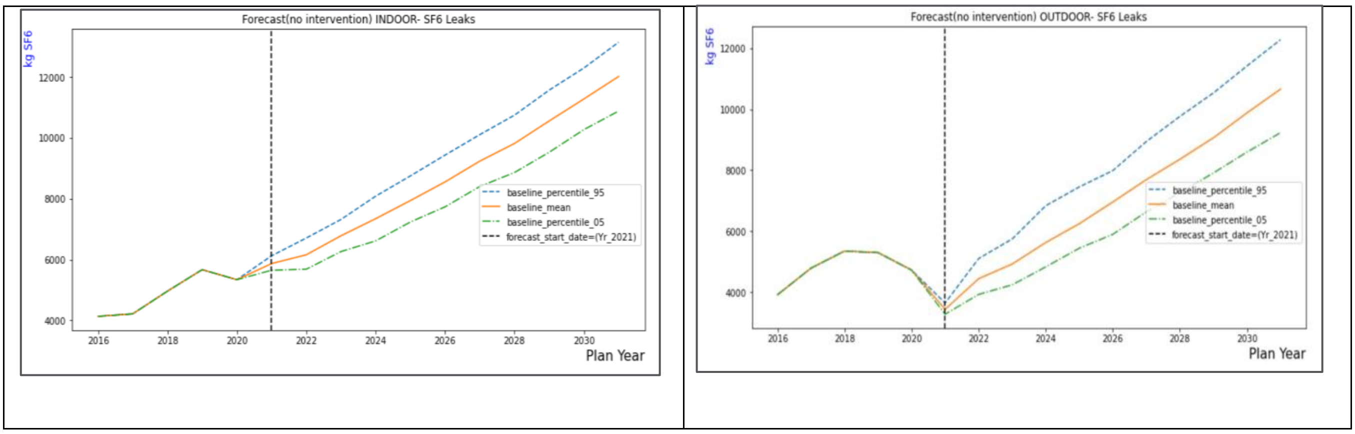


Figure *6.25*: SF_6 leak forecast separated by indoor/ outdoor

Table 6.5 below details the top leaking sites based on the gas zone inventory sorted in order of the highest cumulative forecasted SF_6 leakage between 2022 – 2026.

The following colour coding has been used to highlight the alignment to the earlier T1 leaking table:

Existing Output in RIIO-2/ delivered in T1
T2 original submission site with no current allowance
Next Top 5 RIIO-1 leaking site

This shows that the previous sites from the original submission are also forecasted to be in the highest leaking sites to 2026 & 2030.

However, the next top 5 leaking sites that weren't included in the original submission are forecasted to be lower/greater than other sites. A significant factor of the difference in forecast leakage is the fraction of leakage based on the inventory size at different sites. As an example, BRFO4B has little leakage but it has the largest inventory size of all sites which would forecast a larger amount of leakage over time even with a smaller leak rate.

Row Labels	Count of Asset Plant Number (FP)	Sum of SF_6 FP Holding (kg)	Average Annual T1 Leak %	Average Annual T1 Leakage (kg)	Forecast SF_6 cumulative (kg) leakage (22 - 26)	Forecast SF_6 cumulative (kg) leakage (22 - 30)
[redacted]	94	24868	4%	1118.5	6767	13608.8
[redacted]	125	26267	3%	838.28	6724	12827.9
[redacted]	116	22213	2%	478.24	4221	8517.6
[redacted]	71	25612	2%	526.04	3350	7218.01
[redacted]	107	16239	2%	392	3274	6383.95
[redacted]	73	22310	1%	203.57	2621	4891.29
[redacted]	62	17406	3%	442.19	2484	4744.05
[redacted]	30	8832.5	3%	287.88	2275	4450.21
[redacted]	27	10622	1%	141.87	2021	4030.93
[redacted]	98	17582	1%	211.06	1708	3840.68
[redacted]	121	24223	0%	51.261	1411	3542.6
[redacted]	130	27640	0%	124.58	1289	3101.47
[redacted]	51	8041.5	1%	104.36	1101	2301.56
[redacted]	2	4351	3%	113.53	1088	1994.89
[redacted]	49	7770	1%	106.95	1063	2365.97
[redacted]	103	19277	0%	9.1169	938	2011.25
[redacted]	218	53423	0%	17.201	797	2168.8
[redacted]	21	5833.5	5%	267.25	758	1805.06
[redacted]	73	15876	0%	18.959	650	1482.29
[redacted]	27	4908	2%	87.954	564	1234.51
[redacted]	56	8086	6%	474.07	534	1096.65
[redacted]	73	9236.5	0%	29.665	497	1189.39
[redacted]	15	780	19%	147.3	395	698.83
[redacted]	11	1305.2	0%	2.1875	374	623.262
[redacted]	85	22088	0%	0.2178	359	975.224
[redacted]	37	6625	0%	30.496	343	846.309
[redacted]	119	27120	0%	3.3438	333	987.875
[redacted]	142	16629	0%	22.791	331	1091.6
[redacted]	2	78	154%	119.76	327	463.409
[redacted]	73	6104.3	0%	16.337	291	785.122
[redacted]	49	2315	1%	12.391	291	559.095
[redacted]	73	5917.9	0%	13.875	288	776.46
[redacted]	247	37254	0%	10.499	283	973.076
[redacted]	23	3153	0%	11.701	277	678.007
[redacted]	15	4140	1%	32.948	264	646.379
[redacted]	7	2176.9	1%	25.32	256	521.112
[redacted]	21	4057	0%	7.5	241	592.096
[redacted]	9	1626.8	14%	224.44	237	469.471
[redacted]	38	5040.5	0%	18.348	209	611.19
[redacted]	15	11353	0%	30.521	181	563.274
[redacted]	51	5801.9	0%	13.598	162	376.68
[redacted]	75	5224.8	0%	5.6925	161	344.286
[redacted]	159	20488	0%	9.4225	160	447.297
[redacted]	9	1538.8	1%	7.9506	148	334.022
[redacted]	20	2152	1%	20.36	125	325.198
[redacted]	16	1246	1%	14.754	124	288.428
[redacted]	120	11442	0%	5.03	119	370.242
[redacted]	241	30931	0%	10.475	104	425.215
[redacted]	40	1523.3	1%	16.064	93.1	209.256
[redacted]	103	14395	0%	3.8529	85	253.054
[redacted]	28	2509.2	1%	13.71	82.8	197.903
[redacted]	6	1008.5	2%	20.341	80.7	190.896
[redacted]	53	13921	0%	34.075	73.4	242.869
[redacted]	15	618	0%	1.27	71.9	163.967
[redacted]	12	1812.1	0%	0.4875	67	188.268

Table 6.5: top leaking sites based on the gas zone inventory sorted in order of the highest cumulative forecasted SF_6 leakage between 2022 – 2026

Societal costs from the forecast

The carbon price associated with the SF_6 leaks are shown in figure 6.26, the cost rises from £65m/year in 2021 to £180m/year in 2031. The cost of leaking greenhouse gases to the atmosphere will continue to increase, which reinforces the need to act urgently to reduce the leakage and begin removing SF_6 from the network and replace it with alternatives as soon as that is commercially feasible. The reduction of carbon emissions provides a societal benefit to consumers.

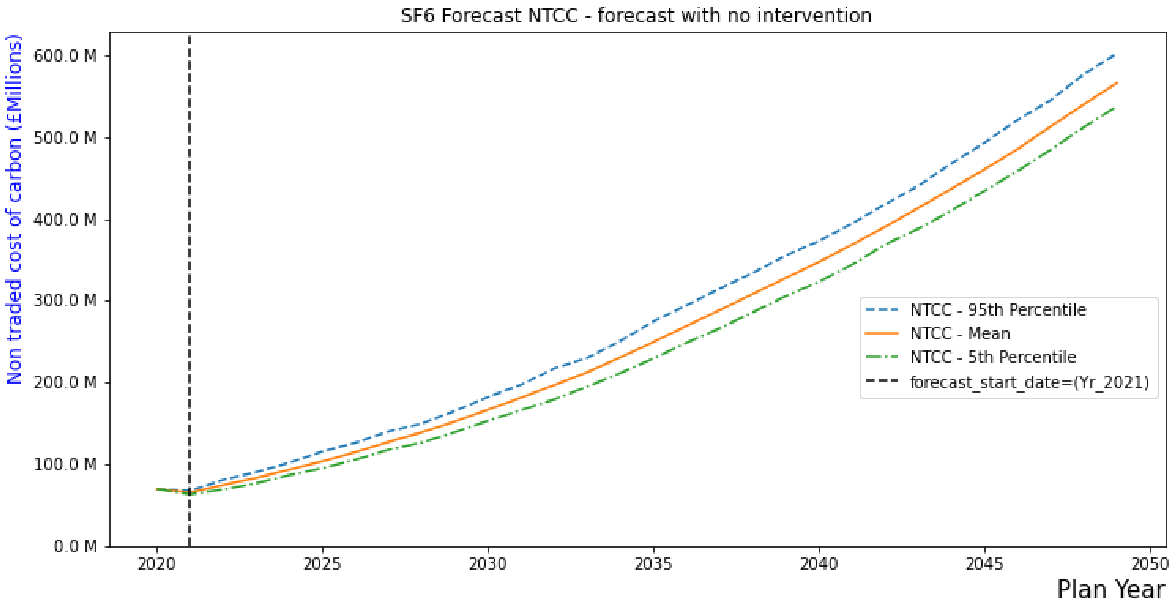


Figure *6.26*: Carbon price of forecast SF_6 leaks from 2020-2030

Forecasting the Portfolio leakage with and without RIIO-2 existing interventions

Using our asset level forecast we can apply the planned interventions to the forecast and can predict the abatement associated with different scenarios of intervention. Figure 6.27 is the forecast assuming we cease all work compared with the forecast if we follow the planned interventions sanctioned as part of RIIO-2. Any asset interventions that have not got a defined date or outage currently planned are assumed to be delivered by the end of RIIO-2 and are defaulted to a delivery year of 2026 in the intervention modelling. Our forecast predicts that following the RIIO-2 plan slightly reduces the current leak rate of SF_6, from an actual leak rate of 11,700 kg in 2020-21 to approximately 11,100 kg in 2026. However, this forecast value is substantially higher than the 2026 SBT of 8,180kg.

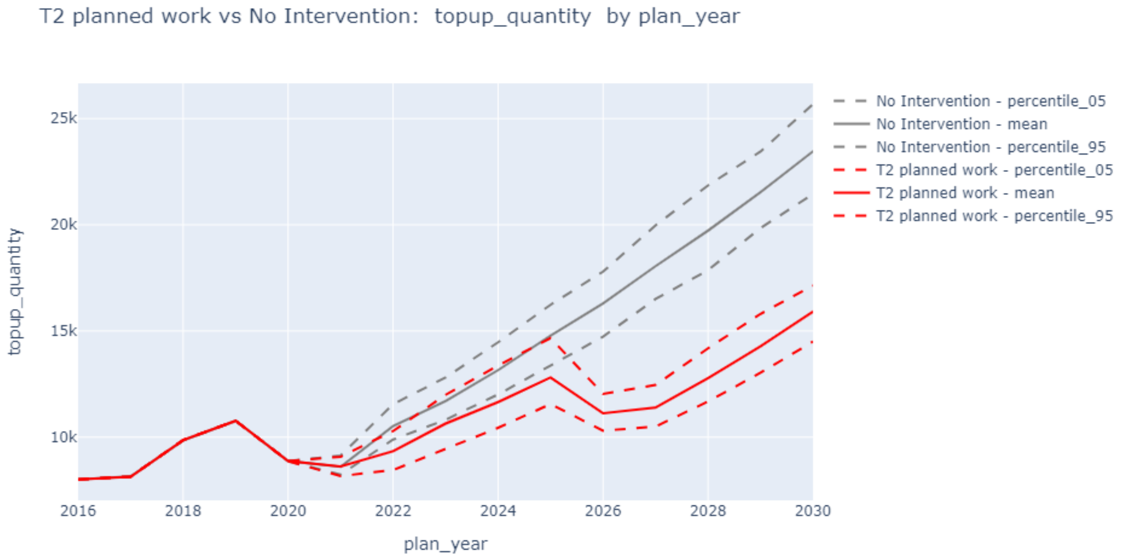


Figure 3.27*:* Comparison of the forecast SF_6 leak rate if no interventions are taken with the leak rate following work agreed in RIIO-2.

If we add the work recommended in this MSIP, the leak rate in 2026 reduces from 11,400 kg to 7,034 kg of SF_6. However as shown, assets are forecast to continue to leak and deteriorate meaning that additional work will be required in T3 and beyond if we are to meet our ongoing commitment to reaching net-zero carbon equivalent emissions by 2050.

Work included in this MSIP will move us closer to our SBT but additional work will be required during the RIIO-2 price control, and we need to continue to focus on SF_6 alternative solutions for insulating gas. Figure 6.28 shows the relationship between the forecast, the SBT and the RIIO-2 intervention scenarios presently being considered.

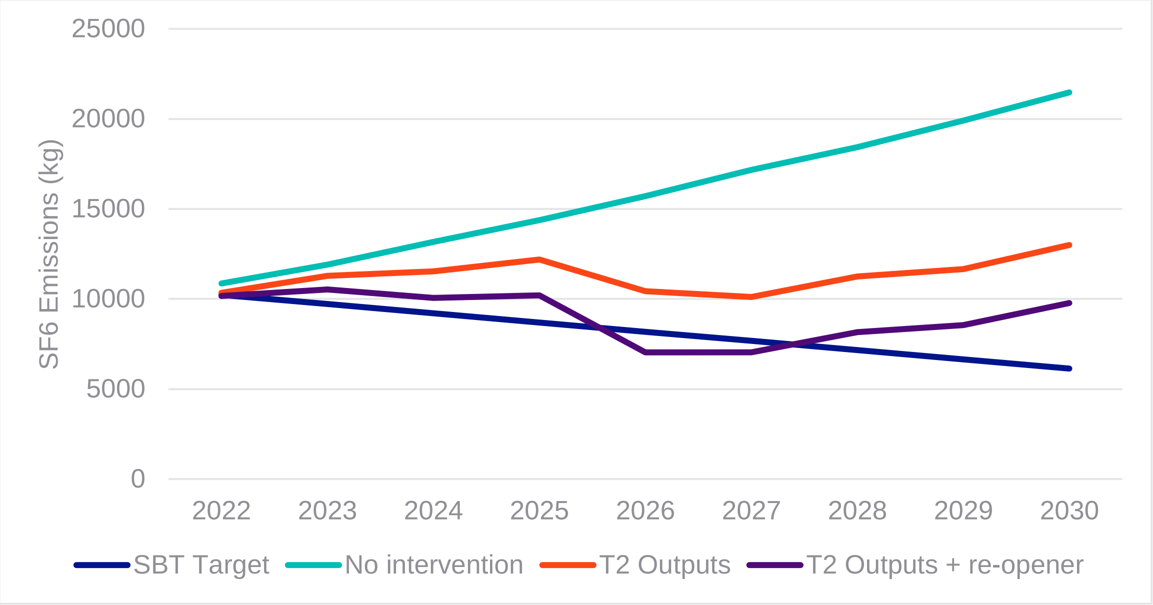


Figure 6.28: Comparison of forecast leak rate following RIIO-2 work and following RIIO-2 work and the work included in this MSIP and the SBT – demonstrating that this MSIP does not reach the SBT in 2026.

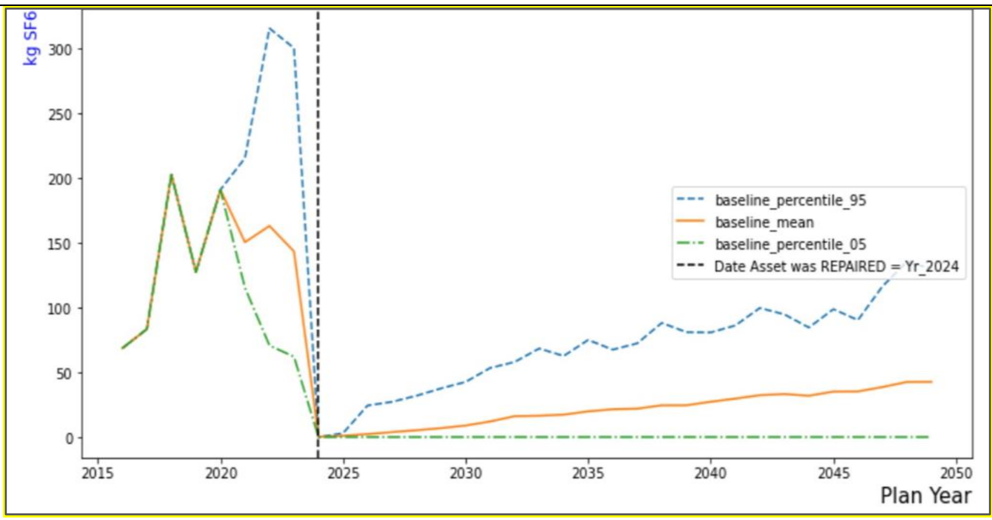
Modelling of Interventions on the forecast

Due to the limited data available on assets following an intervention, the modelling of interventions is implemented consistently on the basis of assumed outcomes. The forecast relies on age and recent leak history to predict the leak in the following month.

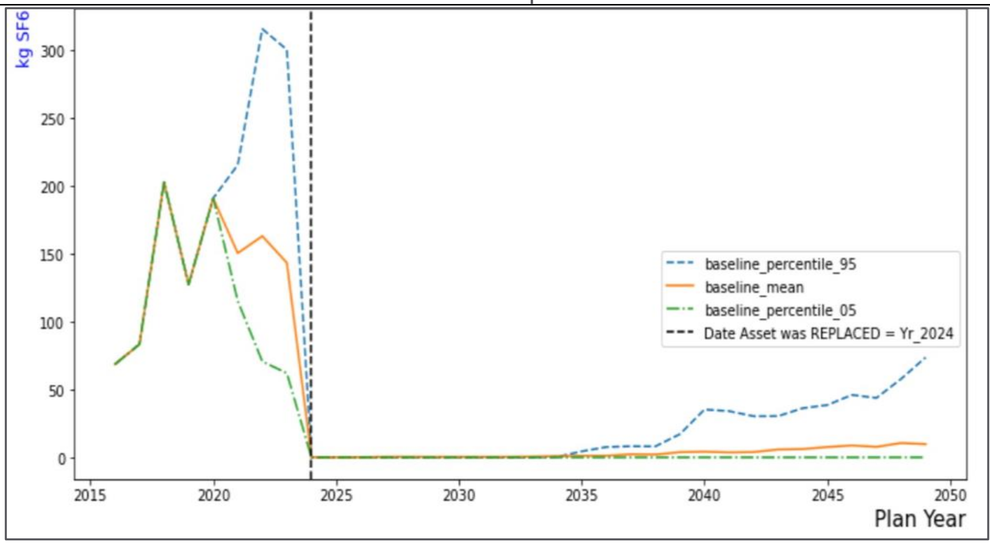
- Following a repair, the recent leak history for the modelled asset is set to 0.
- Following a replacement or refurbishment, the recent leak history is set to 0 and the age of the asset is set to 0.

Setting the leak rate to 0 is optimistic and there is an understanding that even new assets will have a very small but non-zero leak rate. The model may slightly underestimate the leak rate of the lowest leaking assets and slightly overestimate the leak rate of assets that are topped up for the first time. However, setting the leak rate to 0 is consistent with the other assumptions that have been made.

To demonstrate the impact of a replacement, refurbishment or repair on an asset, the forecast for a single asset that is currently leaking, [redacted] is shown below in Figure 6.29. The asset intervention is scheduled for 2024 in each case.



Asset Repair



Asset Replacement or Refurbishment

Figure 6.29: Comparison of leaks from [redacted] following repair or replacement

Forecast development improvement
The forecast developed during 2021 was designed to improve on our previous forecast methodology by allowing the modelling of individual assets and using historical leak rate of an asset as a predictor. This enabled us to include interventions in the modelling. The predicted future leaks are based on our observations of assets historically and includes the difference in leak rate of assets of different ages and location. The forecast is used in three main ways:

- to support decisions made based on the engineering assessment of asset condition and historical leaks
- to estimate the volume of interventions that are required to meet our net-zero commitments
- to support the cost-benefit analysis associated with the leak reduction following intervention.

NGET is committed to the reduction of SF_6 on the network. To best prioritise this work the forecasting methods will continue to be improved and updated. The quality and quantity of data available for SF_6 assets increases with time, and this new data will be used to improve the forecasting accuracy of the model. Old forecasts will be periodically reviewed to get a better understanding of the forecast's (short range) accuracy.

As new assets with alternative IIGs become available the forecast will be improved to allow interventions which update the quantity and type of IIG in an asset. This will enable NGET to predict the reduction in CO_2 equivalent following the transition to alternative IIGs and in doing so, demonstrate the environmental impact of this important next step to reducing NGET's carbon footprint.

Finally, a small number (<1%) of the assets that have the highest leak rate (as a proportion of the asset's inventory) show some regression to the mean in the forecast. The forecast leak increases to a point, and then starts to fall. NGET does not believe this to be realistic behaviour. However, these assets are always candidates for intervention and remain so, even after their leak rate is forecast to spontaneously reduce. As a result, the total forecast mass of SF_6 leaked from these assets is underestimated, and the benefit of performing those interventions is likely to be higher than reported in this MSIP. NGET is investigating alternative forecasting strategies for these assets.

7. Options and option costs

Summary of Key Messages:
Intervention Strategy – Technology:
The interventions selected take account of the available technology, particularly the availability of new SF_6-free technologies in place of SF_6-filled. The available portfolio of SF_6-free solutions will develop and increase throughout RIIO-2 and beyond and we have presented the technology outlook as it stand today. Where practical we aim to retain assets requiring intervention e.g. by deploying repairs) until such time that replacement can utilise SF_6-free technology.

Cost Assessment:
The cost assessment uses established unit costs in line with asset group strategy document submissions for RIIO-2 where these exist. Where we have no established unit costs, the costs have been collated from original engineering manufacturer (OEM) & 3rd party supplier quotes and previous costs for delivery of similar works.

Portfolio options
A comprehensive portfolio of intervention options has been established. Each engineering justification report demonstrates assessment against this portfolio, in conjunction with the actual and forecast emissions reduction delivered by each of the assessed options. This has allowed us to make robust and consistent proposals which are cost-effective and consistent with our commitments.

Intervention options

We have a wide range of possible interventions available (listed below) to reduce SF_6 emissions which form the basis of the options considered within the engineering justification reports. The options are:

- Do Nothing
- Prevention (Palliative Coatings & enhanced asset protection)
- Repair
- Refurbishment
  - Full Refurbishment
  - Targeted Refurbishment
- Replacement (full or partial)
  - SF_6
  - Alternative gas
  - Alternative equipment (e.g. GIB for cable)
- Retro-filling (substitution of SF_6 within existing equipment)
- Removal
- Addition

In addition to reducing SF_6 emissions the below interventions also contribute to reducing the inventory:
- Retro-filling
- Replacement
  - SF_6 (where inventory is smaller than original)
  - Alternative gas
  - Alternative equipment (e.g. GIB for cable)
- Removal

Considering our SBT and the UK 2050 net-zero target we do not consider “do-nothing” as a credible long-term option for assets which have, or which are forecast to have, excessive leakage.

This paper does not consider the “addition” intervention type regarding interventions on the existing asset base and to reduce emissions. However, additions outside of this submission need to adhere to the NG policy statement PS(T)005 and would be modelled in the leakage forecast when the details are known.

Prevention intervention was agreed in the "Palliative works" under the Network Operating Cost funding. We have not included any specific prevention/palliative works in this submission, however where repair, refurbishment or retro-filling interventions are proposed on gas zones, and the gas zone is not currently listed under the existing NOC funding for palliative works, the palliative coatings will be costed and included within the intervention.

SF_6 replacements are not considered in this paper given the commitments and ambitions in reducing the use of SF_6.

The application of interventions against asset type is listed below in the extract from NGET's technical guidance note 316 "Management & Guidance of SF_6 leaks":

Voltage / Insulation	Equipment	Intervention		
		Replace	Refurbish	Repair
400kV / 275kV / 132kV GIS	Bushings	OEM / Internal	OEM	
	Tube Sections			OEM / Internal / 3rd Party
	Support Cones	OEM		
	Ancillary Equipment	OEM / Internal		OEM / Internal
	Bursting disks	OEM / Internal		
	PD couplings	OEM		
	Transducers	OEM / Internal		
400kV / 275kV AIS GCB's	Interrupter heads		OEM / Internal	OEM / Internal
	Columns		OEM / Internal	OEM / Internal
	Pipework	OEM / Internal	OEM / Internal	OEM / Internal
	Gauges		OEM / Internal	OEM / Internal
	Bursting disks		OEM / Internal	OEM / Internal
	Transducers		OEM / Internal	OEM / Internal
132kV AIS GCB's	Interrupter heads	OEM / Internal		OEM / Internal
	Columns	OEM / Internal		OEM / Internal
	Pipework	OEM / Internal		OEM / Internal
	Gauges			
	Bursting disks			
	Transducers			

Table 7.1: Application of interventions versus asset type

For SF_6 Current Transformers the only intervention considered is replacement with a non- SF_6 filled current transformers.

For this paper, the interventions are defined as follows:

Prevention:
Interventions applied to non-abnormally leaking assets in order to mitigate a future risk of leakage. This may include the application of external palliative coatings to outdoor components of gas insulated substations to prevent pollution ingress and environmental degradation of SF_6 seals. These are typically low cost, minimal outage interventions with an effective duration of the order of 10-15 years and the ability to be re-applied. The SF_6 gas remains installed in this option. This option is most effective when first applied to younger assets (up to 20 years old).

Examples of preventative coating can be seen in the images below:

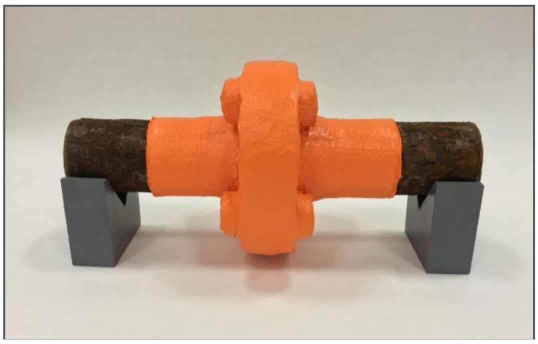


Figure 7.1: Preventive coating from [redacted]

Figure 7.2: Preventive coating from [redacted]

Repair:

Gas Zones:

Repairs on gas zones are generally externally applied encasement of leaking components such as collars or wraps provided by switchgear Original Equipment Manufacturers (OEMs) or third-party sealing specialists. Typically of medium cost and requiring limited outages, these have an effective duration of the order of 10 years. These could potentially be re-applied but are most likely to be applied in later life to manage equipment to its optimum condition-driven replacement window. The SF_6 remains installed in this option.

In some instances, the leaking components can be found on the bursting discs, small bore pipework or viewing windows such that the replacement of these sub-components would address the leak. The replacement of the components would be effective for the rest of the asset life. By targeting the repair based on the leaking component it enables a more cost and duration effective intervention to be carried out.

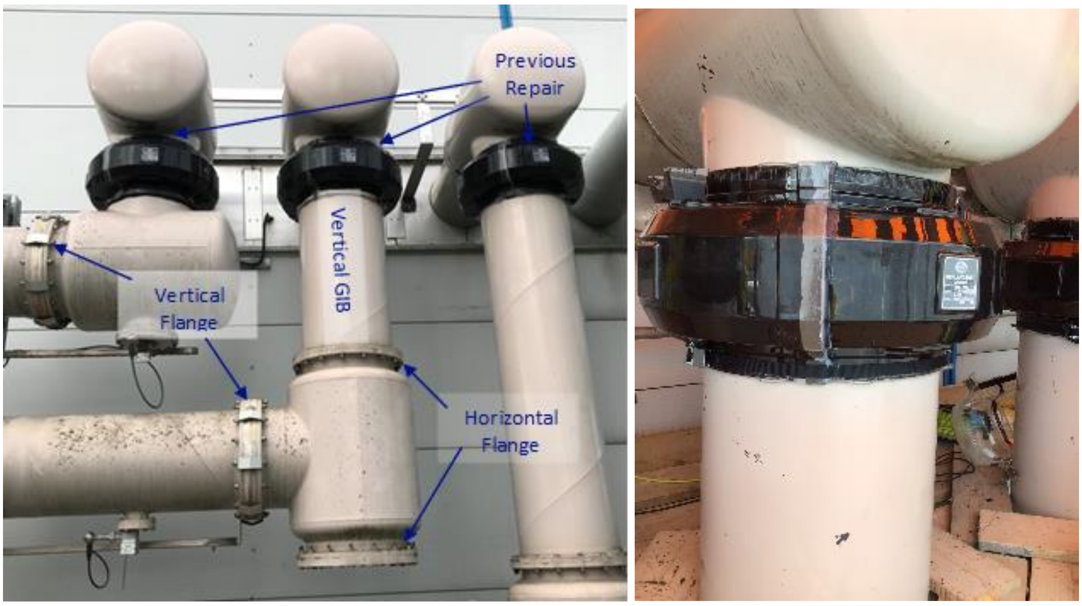


Figure 7.3: GIS arrangement with repairs

AIS Gas Circuit Breakers:

Repairs on air-insulated SF_6 Gas Circuit Breakers (GCB) at 66kV and above are predominantly applied to assets that are no longer fully supported by the Original Equipment Manufacturer (OEM) in terms of production and spares support.

Multiple interrupter GCBs at 275kV and 400kV are best managed by a refurbished traveller exchange programme due to their larger & more complex construction and to prevent undue environmental exposure of components. This method also limits outage and delivery duration as the refurbishment process is detached from the site delivery phase.

The scope includes the nominal head and column exchange with in-situ small bore pipework, fittings, and pressure gauge* replacements (*pending calibration and environment). The refurbishment process involves dismantling the circuit breakers, cleaning and refurbishing the sealing surfaces, application of an additional flange sealant outside of the original SF_6 seals to improved protection of the sealing surfaces against weather ingress and corrosion.

The circuit breaker is then rebuilt, replacing any out of specification parts and refreshing consumables and lubrication.

The scope is to achieve up to a 20yr intervention that intends to address every seal.

Figure 7.4: 400kV AIS Gas Circuit Breaker Refurbishment with new sealant applied

Figure 7.5: Site delivery phase of 400kV Air Insulated Substation Gas Circuit Breaker Repair

Small Bore Pipework Repair (Replacement)

Replacement of small-bore pipework involves removing rigid copper or brass pipes and joints and replacing with stainless steel, quick coupling flexible tubing.

The outage duration required for the works is heavily dependent upon the gas volumes as de-gassing of the system is required prior to the work commencing. The installation of flexible tubing typically reduces the installation time by a factor of four compared with using rigid pipework and joints.

The quick coupling flexible tubing also offers several leak performance advantages. Importantly the number of joints and potential leak points is approximately halved and provides the ability to seal individual gas zones so that de-gassing whole systems will not be required in the future.

Refurbishment:

Gas Zone Refurbishment:

Return of the critical SF_6 sealing components to "as-new" condition with an effective duration in-excess of 20 years. This activity includes physical dismantling of the equipment, cleaning & re-working damaged components and replacing seals and gaskets, etc. Costs are high and the work requires long outages. This activity may also include corrective activities on non-primary parts such as SF_6 pipework which is low cost but typically requires outages for de-gassing the equipment. The SF_6 gas is normally returned to the refurbished equipment although SF_6 free options will be incorporated if/when they become commercially available as detailed in the retro-fill section.

There are 2 options for gas zone refurbishments: full refurbishment or targeted refurbishment. Both options include the same activities, but the targeted refurbishment is only on specific areas of the equipment that are more prone to leakage. A targeted refurbishment significantly reduces the cost, delivery duration and system access requirements.

Figure 7.6: 400kV Gas Zone Refurbishment

Replacement:

Substitution of the leaking equipment for new equivalent equipment. This may be individual components (e.g. gas to air bushings), partial (e.g. outdoor gas-insulated busbar sections) or full (e.g. replacement of an entire gas-insulated substation). Costs and outage durations are high. Partial replacement needs careful analysis of the equivalent annual cost of the full installation to avoid non-optimal investment. The ambition is that SF_6 gas will not be installed in this option to avoid perpetuation of the SF_6 inventory and the risk of future emissions, but this will be assessed on a case by case basis pending full commercial availability of SF_6-free alternatives for all applications.

Replacement of SF_6 current transformers will be for the non- SF_6 filled option, oil impregnated paper (OIP) current transformer. The replacement outage delivery duration is dependent on the number of CT's to be replaced, up to 2 weeks for 3 phase CT replacement.

Replacement of AIS SF_6 circuit breakers for non- SF_6 alternatives is only currently available at 132kV and will be available at higher voltages through the RIIO-2 period. The replacement of AIS circuit breakers require a duration of 6 weeks for the disconnection, removal, installation, and commissioning of a new circuit breaker.

Figure 7.7: Gas to air bushing replacement

Retro-filling:
Retro-filling of existing installations with non-SF_6 insulating gases is becoming available for simple applications (e.g. gas-insulated busbar) within the RIIO-2 period however timelines are still uncertain and we cannot, at present, commit to an adoption timescale without further detail and assessment of the solution.

Retro-filling for the conversion of gas requires degassing of all gas zones and may require pressure tests to ensure chambers can withstand the higher gas pressure if these are required for the alternatives gases. Unsuitable gas zones would need to be replaced to comply with the new gas standards.

GIS circuit breakers which are designed to use SF_6 within the interrupter cannot be retro-filled with alternative gases. This will mean that that only GIB and passive switchgear gas zones are possible candidates to be considered.

We are keen to implement such solutions and will continue further work on this to align with the SF_6 reduction strategy and propose to submit an update as a further re-opener. NGET has led innovation projects during RIIO-1 and continued within RIIO-2 to facilitate the early adoption of such solutions.

Figure 7.8: Retro-fill of SF_6 with alternative gas.

Removal:
The removal of SF_6 equipment will reduce the inventory of SF_6 installed, prevent future leakage of SF_6 from the asset and abates any of the existing SF_6 leakage from the asset. The application for removal is very bespoke and normally associated to specific options or drivers unique to the asset or site.
We've been exploring the removal options more thoroughly to understand where and what applications could be considered. Currently removal interventions are mostly applied to the removal of a substation that is linked to a wider strategy, such as network design changes which may be linked with changes in new connections or disconnection of generators.
We have also identified other removal opportunities such as GIB removal where we can substitute the GIB for a cable or potentially an extension of the AIS busbars for an OHL connection.

Intervention Strategies

Identifying the optimum intervention on a case-by-case basis depends on factors such as:

- Contribution to total emissions
- Present leak status
- Extent and likelihood of potential emissions (Forecasting)
- Residual life of the assets (excluding SF_6 emission factors),
- Cost of intervention,
- Effective duration of intervention,
- Deliverability
- Technology availability
- Site strategy

The role of these factors in our decision making is described in more detail below:

Contribution to total emissions:
We will prioritise interventions that maximise cost-effective emissions abatement, i.e. seek to deliver the most beneficial interventions first. It is important that we meet year-on-year targets (as determined by the SBT) as well as our long-term commitments. All planned interventions will be assessed and prioritised on this basis.

Current leak status:
Assets with existing SF_6 emissions will be prioritised for early intervention since leak rates typically worsen over time. The condition and performance of these assets will be used to inform performance forecasts for similar assets.

Extent and likelihood of potential emissions (Forecasting):
Based on asset condition data, particularly from assets which are leaking/have leaked, we will develop future emission scenarios based on relevant factors such as design, age, operating environment, and previous interventions. These scenarios will be used to target cost-effective pre-emptive interventions in order to mitigate future emissions

Residual life of the assets (excluding SF_6 emission factors) and cost of intervention:
We will focus upon minimising equivalent annual cost in that any investment in emissions abatement applied to an asset is assessed in terms of the expected life of that intervention. For example, applying a costly refurbishment solution to a substation with only 5-10 years' residual life is unlikely to deliver value. Conversely, the repeated application of short-term repairs may prove non-optimal for an installation with decades of residual life where a more enduring approach may provide better lifetime benefit. If the effective duration of the intervention (see below), is less than the residual life of the installation, future interventions to achieve the residual life of the installation will also be included in the assessment.

Effective duration of intervention:
As mentioned above, the various intervention options have differing lifetime expectations. The use of equivalent annual costing takes due account of this factor as described above and mitigates against any bias towards low-cost, short-term solutions.

Deliverability:
Timescales for planning and delivering refurbishment and replacement interventions are measured in years depending upon factors such as outage availability, physical site constraints, and delivery resource availability. Hence, delivery of our ideal (unconstrained) SF_6 emission reduction plan is not possible and, to meet emission abatement targets, we will be forced to advance or postpone investments. For assets with significant existing/developing leakage, this may mean applying short-term, low-cost repairs pending the opportunity to undertake more significant interventions.

Technology availability:
Our intention is to avoid the installation of additional SF_6 where practicable. Thus, where we identify replacement as a preferred option for emission abatement, we will assess the benefit of timing the intervention to align with the availability of SF_6-free technology against the impact of any delay upon achieving our emissions targets. Where we can achieve targets and avoid the installation of additional SF_6, this will be our preferred option.

[redacted]

Manufacturer: Solution: Solution type:	[redacted]		[redacted]		[redacted]	
SF_6 Alternative Technology	**Market**	**Product**	**Market**	**Product**	**Market**	**Product**
400kV Gas Insulated Busbar (GIB)	Now	Now	Now	Now	Q2 2022	Q2 2023
400kV Gas Insulated Switchgear (GIS) – inc. CB	Q2 2022	Q4 2022	July 2025 [redacted]	Q4 2025	Q2 2026	Q3 2027
132kV Gas Insulated Switchgear (GIS)	Now	Now	Now	Now	Now	Now
Retro-fill (GIB only)	Bespoke to NG	Now	Bespoke to NG	Now	N/A	N/A

132kV Live tank Air Insulated Substation Gas Circuit Breaker (AIS-GCB)	Now	Now	Now	Now	Now	Now
400kV Live tank Air Insulated Substation Gas Circuit Breaker (AIS-GCB)	Q4 2023	Q4 2023	Q4 2025	Q4 2025	Q2 2026	Q3 2027
132kV Dead Tank Air Insulated Substation Gas Circuit Breaker (AIS-GCB)	Q4 2022	Q4 2022	Q2 2023	Q2 2023	Q4 2021	Q2 2022
400kV Dead Tank Air Insulated Substation Gas Circuit Breaker (AIS-GCB)	N/A	N/A	N/A	N/A	Q4 2029	Q2 2030
400kV Gas Insulated Switchgear with GWP=0	N/A	N/A	N/A	N/A	Q2 2026	Q3 2027

Table 7.2: Product availability timescales agreed with manufacturers

Market – available for tender/procurement

Product – available for install

** Year shown is financial year (e.g. 2022 = Apr'22 – Mar'23)*

Site Strategy:
We will review the wider Intervention strategies across the other assets on site as well as any additional key drivers such as future connections, network operation considerations and other legislative drivers to consider optimal alignment and cost options for delivering interventions at the same time or a consideration to replacing the site. Each site is unique though and needs thorough assessment to determine the optimal option across all assets. This will be specific to each site within its engineering justification report.

This can include but not limited to:
- Wider asset health (Civils, SGTs/Reactors, Disconnectors, Protection & Control etc.)
- Future connections
- Regional strategies
- 3rd party connected strategies (e.g. DNOs)
- NOA outputs
- Land Restrictions
- Legislative/Regulation requirements (e.g. PCB removal)

Cost assessment

Costing of work with an established technical scope and prior delivery experience (e.g. substation and asset replacements) has been quoted in accordance with the NGET cost-book and aligned with the cost details submitted in the RIIO-2 asset group strategy submission. Activities such as targeted refurbishment of outdoor GIB, partial replacement of outdoor GIB and encapsulation based repairs are relatively new solutions for which we have less established benchmarks for delivered cost. The costs on which these solutions have been developed are derived from supplier quotations and early applications.

- Encapsulation based repairs which are deployed selectively to address existing leaks for up to 10 years are costed on a per-flange basis with repair of a three-phase set of flanges costing approximately £[redacted] (21/22 prices). This cost includes the cost of internal NGET resource, the cost to develop the intervention (including survey costs), the cost of project management, the cost of 3rd party / contractor resource and the cost of materials and equipment such as scaffolding and MEWPs.

- Bushing replacements are costed at approximately [redacted] (21/22 prices) per three phase set. This cost includes the cost of internal NGET resource including Commissioning Engineer resource, the cost to develop the intervention (including survey costs), the cost of project management, the cost of 3rd party / contractor resource and the cost of materials and equipment such as gas handling, scaffolding, MEWPs and cranes.

- Refurbishment of GIB involves strip-down and re-sealing of leaking and potentially leaking gas sealing points, particularly enclosure sealing flanges. The cost of this intervention type varies considerably depending upon the scale and complexity of the intervention.
  We have categorised refurbishment of GIB into 3 broad groups depending on intervention duration and complexity: small, medium and large. The approximate intervention costs for each of these is given below and includes the cost of internal NGET resource including Commissioning Engineer resource, the cost to develop the intervention (including survey costs), the cost of project management, the cost of 3rd party / contractor resource and the cost of materials and equipment such as gas handling, scaffolding, MEWPs and cranes.

- Small GIB Refurbishment – approximate intervention cost for 3 phases is £[redacted].
- Medium GIB Refurbishment – approximate intervention cost for 3 phases is £[redacted]
- Large GIB Refurbishment – approximate intervention cost for 3 phases is £[redacted]

  Above in 21/22 prices

- Whilst partial replacement of outdoor GIB separately from the main substation is not an established practice, costs have been derived based on NGET cost-book data per length of GIB. A cost of £[redacted] per metre of three phase GIB has been used.

- Retro-fill of SF_6 gas with an alternative gas in existing GIB will reduce the overall SF_6 inventory and will have a lower GWP. Where the opportunity exists to convert to an SF_6 free solution as part of refurbishment or replacement activities we expect there to be a small percentage premium over the equivalent like-for-like SF_6 activities. Whilst this solution is very new, we are in discussions with suppliers on the tendering and quoting for future retro-fill options and will form more detail on this in the proposed future submission as detailed in the project delivery section.

Below details the compiled costs for GIS interventions as per the above detailed summaries:
The details that form the costings below are recorded in the annex.

The below costs are based on 18/19 prices.

Asset Type	Estimating units	Capex/ Opex	Unit	Quantity	Unit Cost £k	Total £k
Other	3 phase GIS Encapsulation wrap	Capex	each	30	[redacted]	[redacted]
Other	Small 3 phase GIS refurbishment	Capex	each	5	[redacted]	[redacted]
Other	Medium 3 phase GIS refurbishment	Capex	each	6	[redacted]	[redacted]

Other	Large 3 phase GIS refurbishment	Capex	each	2	[redacted]	[redacted]
Other	3 phase GIS bushing replacement	Capex	each	6	[redacted]	[redacted]

Table 7.3 GIS interventions

The table below outlines our approach to the *small, medium* and *large* classification for GIS refurbishment that we have used in our cost build-up:

Categorisation	Considerations	Typical Example
Small GIS Refurbishment	Easily accessible spatially, short length GIS sections, small cranage requirements, <600kg SF_6 gas storage cylinder required	GIS Bus Coupler section
Medium GIS Refurbishment	Fairly accessible with some spatial challenge(s), larger cranage required often with scaffolding requiring bespoke load-bearing beams, 600kg SF_6 gas storage cylinder required	Line Circuits
Large GIS Refurbishment	Spatial constraints and more challenging access, GIS / GIB runs are long with changes in elevation and orientation due to more complex routing, large cranage required, 600kg SF_6 gas storage cylinder required	SGT Circuits (often GIS run is via noise enclosure)

Table 7.4 GIS refurbishment categorisation

The costs for cable installation are bespoke subject to the route & length of the cable required. The costs also need to account for: cable joints, containment, access, existing buried services and/or cable sealing end installations. Each cable installation will be estimated individually and detailed in the engineering justification report.

Below details the NGET cost book costs for Current Transformer replacements. The unit cost is shown for each phase for the CT replacement and the total for all 3 phases if they are to be replaced: There is an increase in the unit cost for SF_6-filled current transformer replacements compared to the T2 submission instrument transformer asset group strategy A9.09. The details of the cost increase are included within the CT engineering justification report.

The below costs are based on 18/19 prices

Asset Type	Estimating units	Capex/Opex	Unit	Qty	Unit Cost £k	Total £k

132kV Subs	CT (1-phase) - 132kV	Capex	each	3	[redacted]	[redacted]
275kV Subs	CT (1-phase) - 275kV	Capex	each	3	[redacted]	[redacted]
400kV Subs	CT (1-phase) - 400kV	Capex	each	3	[redacted]	[redacted]

Table 7.5 CT interventions

Below details the NGET cost book costs for Circuit Breaker Interventions. This assumes work on all 3 phases.

The below AIS gas circuit breaker interventions consider the cost of the refurbishment activities and the on-site delivery of the works. The variations in cost are due to the design differences and additional effort required on particular designs. (e.g. the SPL4 GCB has is a 4 break equivalent of the SPL2 GCB and requires an increase in refurbishment and delivery costs due to the additional components)

The below costs are based on 18/19 prices

Asset Type	Estimating units	Capex/Opex	Unit	Qty	Unit Cost £k	Total £k
400kV Subs	[redacted]	Capex	each	1	[redacted]	[redacted]
400kV Subs	[redacted]	Capex	each	1	[redacted]	[redacted]
400kV Subs	[redacted]	Capex	each	1	[redacted]	[redacted]
275kV Subs	[redacted]	Capex	each	1	[redacted]	[redacted]
275kV Subs	[redacted]	Capex	each	1	[redacted]	[redacted]
Other	[redacted]	Capex	each	1	[redacted]	[redacted]

Table 7.6 AIS GCB interventions

Portfolio Funding Options

Based upon our understanding of the assets present and future performance and the intervention options described previously, we have developed a portfolio of interventions that delivers our 2026 SBT and establishes the trajectory for future performance improvements. We have developed this overall portfolio by considering several specific intervention scenarios (numbered 3 to 11 below) and testing the effectiveness of each scenario to meet our targets. No single scenario from the list delivers our targets therefore we have identified the combination of these scenarios which delivers our 2026 SBT in the most efficient manner. This is our proposed portfolio of work.

The list of options considered and the options to determine which assets would require intervention to reduce or prevent leakage are:

1. Do Nothing
2. RIIO-2 Outputs (including NARM, IT PCD, SF_6 Asset Intervention & LOTI Re-opener)

All below options use the RIIO-2 outputs as a baseline position:

3. Remaining RIIO-1 high leaking sites from RIIO-2 AGS submission
4. Remaining RIIO-1 high leaking sites from RIIO-2 AGS submission + continued next RIIO-1 top 5 high leaking sites
5. Remaining RIIO-1 high leaking sites from RIIO-2 AGS submission + next top 5 forecasted high leaking sites
6. Current Transformer replacements only
7. Circuit breaker repairs only
8. GIB replacements
9. SF_6 alternative options only
10. GIS Site replacements
11. GIB Retro-fill

SF_6-free current transformers are readily available and widely deployed.The proposal for these assets is consistent across each option which is to progress the reduction of the SF_6 inventory by replacing the current transformers which will also address any leakage on the asset. The details of the options considered for current transformers is detailed in its EJR.

For circuit breakers at 275kV and 400kV SF_6-free technology will not be available until the end of RIIO-2. For replacement options this will be further progressed with suppliers and the updated position to be detailed in any future re-opener for the SF_6 reduction development. The details of the options considered for circuit breakers is detailed in its EJR.

Each option will be assessed against the time, leak mass and leak rate measures to determine the count of assets that are forecasted in each category after the option is completed. The two variable leak measures will be:

- Variable leak rates across different time periods
- Leak masses across different time periods

The time periods used for the assessment are:

1. Forecast annual leakage within RIIO-2
2. Forecast annual leakage by 2030
3. Actual leakage from previous year (2020/21)
4. Previous 3-year actual leakage average (2018/19, 2019/20, 2020/21)

The diagram shows how the variable measures (leakage and leakage %) can be assessed against different time periods.

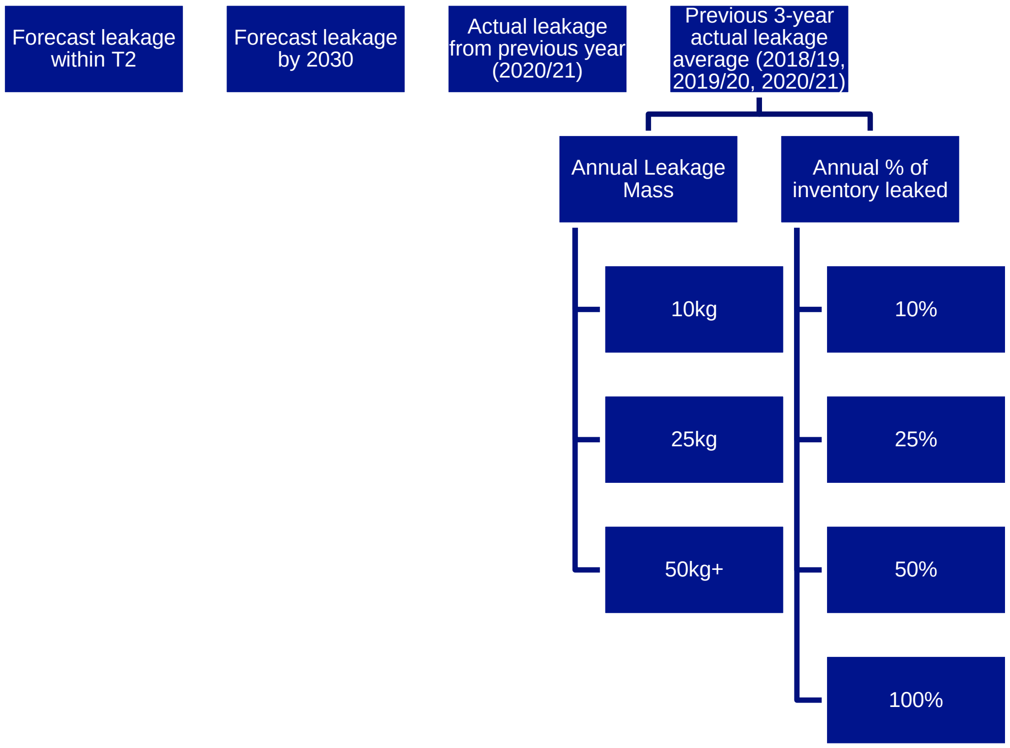


Figure 7.9 Emissions assessment criteria

Each option is assessed against the combinations highlighted in figure 7.9. The analysis for each option will count the assets that fall under each category in the following scenarios

- with no MSIP intervention.
- with MSIP intervention

If an asset meets one a criterion in any year, within the defined period (e.g. within RIIO-2), it is counted. An asset can be counted in more than one category e.g. if asset X leaks greater than 50kg in 2024 it will be counted in the “>50kg”, “25kg” & “10kg” column in the “within RIIO-2” and the “up to 2030” rows.

The outputs will be provided in the format of table 7.7:

Scenario Analysis – count of assets							
	Leak rate				Leak mass		
	10%	25%	50%	100%	10kg	25kg	>50kg
Previous 3-year average							
2020/21							
within RIIO-2							
Up to 2030							

Table 7.7 Count of assets meeting leak rate and leak mass thresholds for each emissions assessment criteria

The table 7.8 provides a description of the options not progressing.

	List	Options	Descriptions	Status
	1	Do nothing	As shown in the forecast section of this document the do-nothing position will not achieve the required emission reduction to meet targets for Net zero	Not progressing for this re-opener
	2	RIIO-2 existing outputs	As shown in the forecast section of this document the existing RIIO-2 outputs position will not achieve the required emission reduction to meet targets for Net zero	Not progressing for this re-opener
All options considered are from a T2 existing output baseline	3	Remaining sites from RIIO-2 AGS submission		Progressing
	4	Remaining sites from RIIO-2 AGS submission + next 5 top high leaking RIIO-1 sites		Progressing
	5	Remaining sites from RIIO-2 AGS submission + next top 5 forecasted high leaking sites	The forecast leakage helps support and understand future leakage mass but as this is a prediction it is unable to be used for further development to determine the right intervention to address the potential leakage location.	Not progressing for this re-opener
	6	CT replacements only		Progressing
	7	CB repairs only	Repair of these assets has the biggest impact on SF6 emissions, is cost favourable, less onerous on system access (more deliverable) and is an opportunity for more clean air/vacuum products, with lower, long-term global warming potential to be adopted.	Progressing
	8	GIB replacements		Progressing
	9	SF_6 alternative replacements only	SF_6 alternative technology is still under development (as detailed in the technology table in intervention strategies) the proposals for the SF_6 reduction are proposed for a future re-opener as detailed in the project delivery section.	Not progressing for this re-opener
	10	GIS site replacements	SF_6 alternative technology is still under development (as detailed in the technology table in intervention strategies) the proposals for the SF_6 reduction are proposed for a future re-opener as detailed in the project delivery section.	Not progressing for this re-opener
	11	GIB retro-fill options	SF_6 Retro-fill is in its infancy stages and requires more detailed analysis and alignment to the wider SF_6 inventory reduction strategy – it is proposed to for a future re-opener as detailed in the project delivery section to provide more time for a detailed assessment.	Not progressing for this re-opener

Table 7.8 Shortlisted options summary

A su**mmary description of the shortlisted options is provided in table 7.9**

	List	Options	Descriptions	Status
All options considered are from a T2 existing output baseline	1	Remaining sites from RIIO-2 AGS submission		Progressing
	2	Remaining sites from RIIO-2 AGS submission + next 5 top high leaking RIIO-1 sites		Progressing
	3	CT replacements only	Replacement of CT's with HV cable reduces the SF_6 inventory for a long term, stable alternative to any insulation gas with 0 future GHG emissions.	Progressing
	4	CB repairs only	Repair of these assets has the biggest impact on SF_6 emissions, is cost favourable, less onerous on system access (more deliverable) and is an opportunity for more clean air/vacuum products, with lower, long-term global warming potential to be adopted.	Progressing
	5	GIB replacements	Replacement of GIB with HV cable reduces the SF_6 inventory for a long term, stable alternative to any insulation gas with 0 future GHG emissions.	Progressing

Table 7.9 Options progressing summary

Each option will be assessed against the do nothing and RIIO-2 existing outputs options and measured in its ability to meet the SBT linear emission reduction target. The preferred option must be able to meet the SBT and responsible business charter commitments by the end of RIIO-2.

The baseline option (RIIO-2 existing outputs) assumes:

- No new addition of SF_6 to the existing asset base
- SF_6 leakage will continue if unabated
- SF_6 leakage will continue for an asset post-intervention based on the intervention modelling in the forecast unless the intervention removes the SF_6 inventory
- Asset intervention and dates are to be completed on the determined dates as per the T2 Outputs annex.

Options of Do nothing & T2 outputs have been assessed against the different measurable attributes to provide a baseline of assets that fall under each of the categories. These are shown in table 7.10 & 7.11

Do nothing:

Scenario analysis - count of assets							
	Leak rate				Leak mass		
	10%	25%	50%	100%	10kg	25kg	>50kg
Previous 3-year average	287	99	45	25	352	164	87
2020/21	191	73	33	15	220	108	50
within RIIO-2	224	73	20	10	292	150	67
Up to 2030	306	76	20	9	447	199	93

Table 7.10: 'Do Nothing' leak rate and mass distributions

T2 Outputs

The T2 outputs provide a significant reduction from the do nothing position but as the forecast model shows it is not sufficient to achieve the 2026 SBT milestone and still leaves several assets within the higher leak & leak rate ranges.

Scenario Analysis - count of assets							
	Leak rate				Leak mass		
	10%	25%	50%	100%	10kg	25kg	>50kg
Previous 3-year average	113	30	9	6	135	51	21
2020/21	72	21	10	5	79	32	12
within RIIO-2	82	24	8	6	115	56	23
Up to 2030	133	24	8	5	213	76	31

Table 7.11: 'T2 Outputs' leak rate and mass distributions

Option Details – *Short list of options. Table 7.9*

1. Remaining sites from T2 AGS submission:

Option 1 considers the 4 sites that have not been set an allowance within RIIO-2 which were in the original AGS RIIO-2 submission and were the next highest leaking sites in RIIO-1 as detailed in the inventory and emission section.

[redacted]

Since the original AGS RIIO-2 submission the development work at these sites have further refined the scope requirements for the asset interventions. The detail of the changes from the original AGS RIIO-2 submission is detailed in each engineering justification report.

The latest development outputs are used for the forecast modelling purposes targeting interventions at asset/bay level on the gas zones.

Option summary table:

Site	Scope	Costs (£k)	Forecast SF_6 abatement 2030
[redacted]	- 1x Repairs - 1x Bay refurbishments - 3x Bay refurbishments & Bushing replacements	[redacted]	[redacted]
[redacted]	- 1x Bay refurbishments & repair - 1x Bay refurbishment - 3x Bay refurbishments & bushing replacements	[redacted]	[redacted]
[redacted]	- 24x Repairs	[redacted]	[redacted]
[redacted]	- 4x Bay refurbishment - 5x Repairs	[redacted]	[redacted]
Total:		[redacted]	**12,360kg**

Table 7.12 – Option 1 Summary Table

Option spend profile table:

	2022 (£k)	2023 (£k)	2024 (£k)	2025 (£k)
[redacted] SF_6 Interventions	[redacted]			[redacted]
[redacted] SF_6 interventions		[redacted]		[redacted]
[redacted] SF_6 interventions	[redacted]	[redacted]	[redacted]	[redacted]
[redacted] SF_6 interventions	[redacted]	[redacted]	[redacted]	[redacted]
Total	[redacted]	[redacted]	[redacted]	[redacted]

Table 7.13 - Option 1 Spend Profile Table

Option leakage profile:

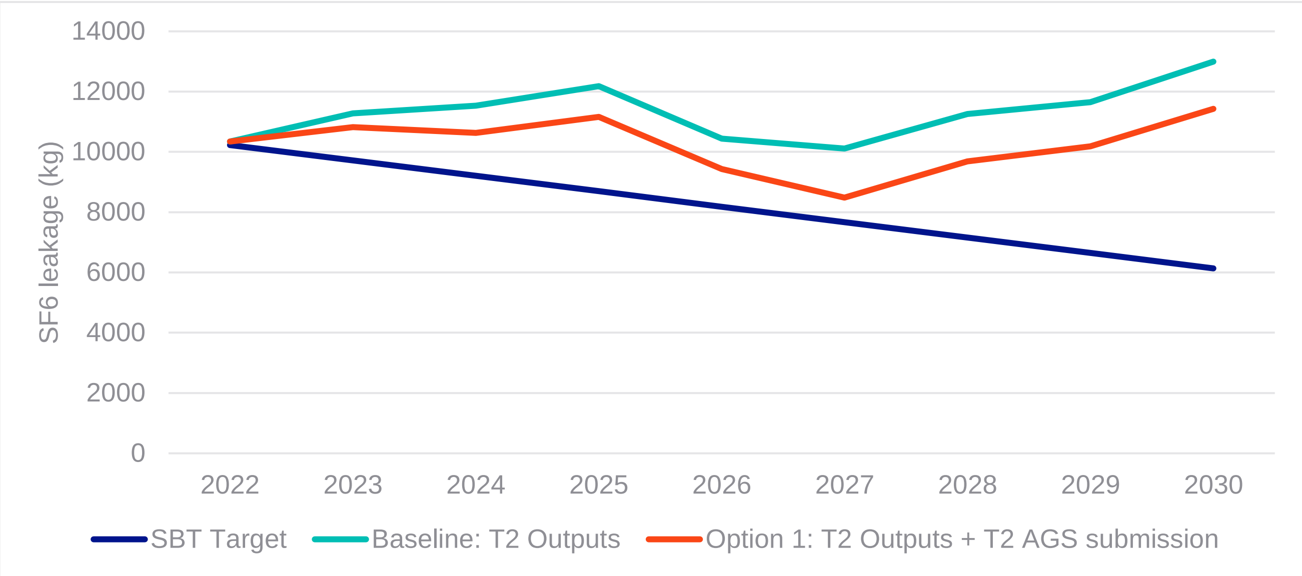


Figure 7.10 – Option 1 Leakage Profile

This option is not forecasted to meet the 2026 target in emissions reduction.

Option leak forecast analysis:

Scenario Analysis - count of assets							
	Leak rate				Leak mass		
	10%	25%	50%	100%	10kg	25kg	>50kg
Previous 3-year average	95	23	5	3	107	32	9
2020/21	57	14	5	1	57	16	2
within RIIO-2	65	15	4	2	91	35	10
Up to 2030	115	15	4	2	187	55	15

Table 7.14 - Option 1 Leak Forecast Analysis:

Summary position:

	Forecast SF_6 abatement 2030	Costs (£k)	Summary
RIIO-2 AGS submission	12,360kg	£[redacted]	This option presents significant SF_6 emission reduction and addresses

	high leak rate and mass assets, from the scenario analysis, it does not meet the required portfolio level emission reduction target.it does not meet the required portfolio level emission reduction target

Table 7.15 – Option 1 Summary Position

2. Remaining sites from T2 AGS submission + next 5 top high leaking T1 sites:

This option considers the sites detailed in option and details and includes the below sites based on the leakage from RIIO-1. the below sites have not been fully developed and the option assessment considers the leaking assets and anticipated leakage from a refurbishment intervention.

- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]

* [redacted] *400kV substation had 1 high leaking asset that contributed to the high leakage within RIIO-1 – this asset has been repaired which would not make it viable for being one of the next top leaking sites.*

The next top 5 high leaking RIIO-1 sites have not had detailed option assessment or development like the 4 sites from the AGS submission.

The below assumptions apply to the next top 5 high leaking RIIO-1 sites:

- Interventions will only happen on known leaking assets from RIIO-1 leakage data
- Medium sized refurbishments are assessed as the intervention choice for each site based on the age and health of the assets and no leak survey information available to determine optimum intervention option.
- Cable replacements costs copied from the [redacted] development cable cost. – further development would provide more accurate costs.
- Gas zone interventions are applied at a bay level

	Scope	Costs (£k)	Forecast SF_6 abatement 2030
[redacted]	- 1x Repairs - 1x Bay refurbishments - 3x Bay refurbishments & bushing replacements	[redacted]	2,393kg
[redacted]	- 1x Bay refurbishments & repair - 1x Bay refurbishment - 3x Refurbishments & bushing replacements	[redacted]	3,125kg
[redacted]	- 24x Repairs	[redacted]	5,420kg
[redacted]	- 4x Bay refurbishment - 5x Repairs	[redacted]	1,422kg
[redacted]	- 6x Bay Refurbishments	[redacted]	1,493kg
[redacted]	- 5x Bay refurbishments	[redacted]	809kg
[redacted]	- 9x Bay refurbishments	[redacted]	2,193kg
[redacted]	- 1x Bay refurbishments	[redacted]	30kg

[redacted]	-	GIB replacement with HV cable	[redacted]	608kg
Total			[redacted]	**17,493kg**

Table 7.16 – Option 2 Summary Table

	2022 (£k)	2023 (£k)	2024 (£k)	2025 (£k)
[redacted] SF_6 Interventions	[redacted]			[redacted]
[redacted] SF_6 Interventions		[redacted]		[redacted]
[redacted] SF_6 Interventions	[redacted]	[redacted]	[redacted]	[redacted]
[redacted] SF_6 Interventions	[redacted]	[redacted]	[redacted]	[redacted]
[redacted] SF_6 Interventions	[redacted]	[redacted]	[redacted]	[redacted]
[redacted] SF_6 Interventions		[redacted]	[redacted]	[redacted]
[redacted] SF_6 Interventions	[redacted]	[redacted]		[redacted]
[redacted] SF_6 Interventions	[redacted]			
[redacted] SF_6 Interventions	[redacted]	[redacted]	[redacted]	[redacted]
Total	[redacted]	[redacted]	[redacted]	[redacted]

Table 7.17 – Option 2 Spend Profile Table

Option leakage profile:

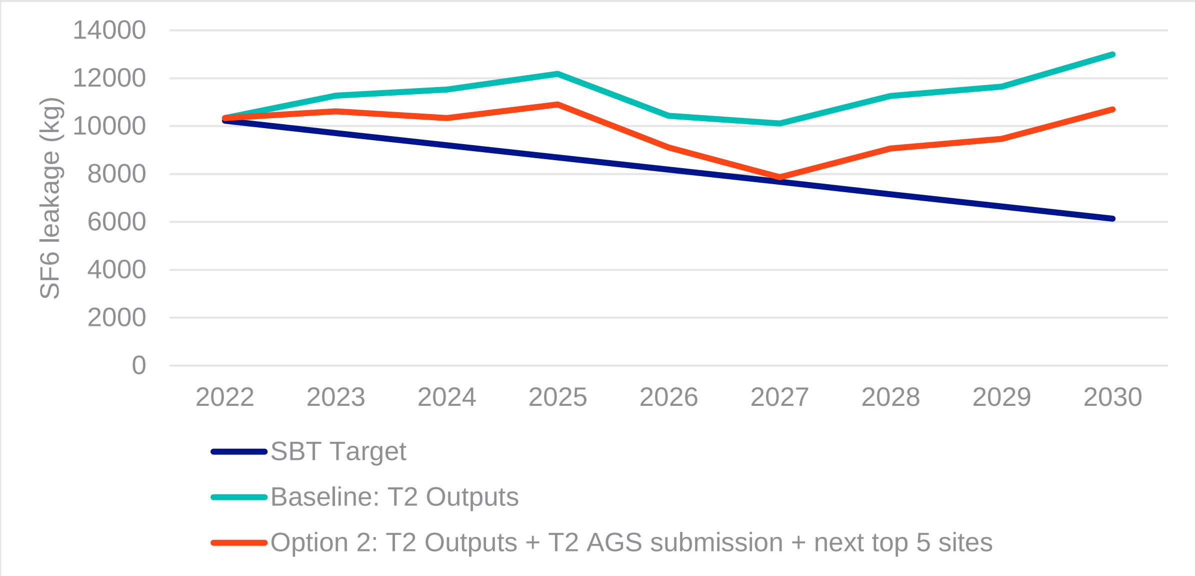


Figure 7.11 – Option 2 Leakage Profile

This option is not forecasted to meet the 2026 target in emissions reduction.

Option leak forecast analysis

Scenario Analysis - count of assets							
	Leak rate				Leak mass		
	10%	25%	50%	100%	10kg	25kg	>50kg
Previous 3-year average	88	23	5	3	96	28	8
2020/21	55	14	5	1	48	13	2
within RIIO-2	62	15	4	2	70	25	10
Up to 2030	100	15	4	2	160	40	14

Table 7.18 – Option 2 Leakage Forecast Analysis

Summary position:

	Forecast SF_6 abatement 2030	Costs (£k)	Summary
RIIO-2 Original submission + next top 5 sites	17,493kg	£[redacted]	This option presents significant SF_6 emission reduction and addresses high leak rate and mass assets, from the scenario analysis, it does not meet the required portfolio level emission reduction target.

	Further development work would be required at the next top 5 sites to assess the leakage on each bay for detailed optioneering to choose the optimum intervention.

Table 7.19 – Option 2 Summary Position

3. Current Transformer Replacements:

This option considers current transformer assets only that are at the end of their life by the end of RIIO-2.

This option supports not only the SF_6 leak abatement of the assets but also the SF_6 inventory reduction strategy.

The effectiveness of these assets on the forecasted leakage is considered by using the “replacement” intervention, whereby the SF_6 inventory is removed preventing any future leakage.

The development and assessment for interventions and assets in this option are detailed in the current transformer engineering justification report.

Option summary table:

	Scope	Costs (£k)	Forecast SF_6 abatement 2030	SF_6 Inventory reduction
427x SF_6 filled CT replacements	- 260x 400kV CT’s - 136x 275kV CT’s - 31x 132kV CT’s	£[redacted]	4,808kg	27,276kg

Table 7.20 - Option 3 Summary Table

Option spend profile table:

	2022 (£k)	2023 (£k)	2024 (£k)	2025 (£k)
400kV CT replacements	[redacted]	[redacted]	[redacted]	[redacted]
275kV CT replacements	[redacted]	[redacted]	[redacted]	[redacted]
132kV CT replacements	[redacted]	[redacted]	[redacted]	[redacted]
Total	[redacted]	[redacted]	[redacted]	[redacted]

Table 7.21 - Option 3 Spend Profile Table:

Option leakage profile:

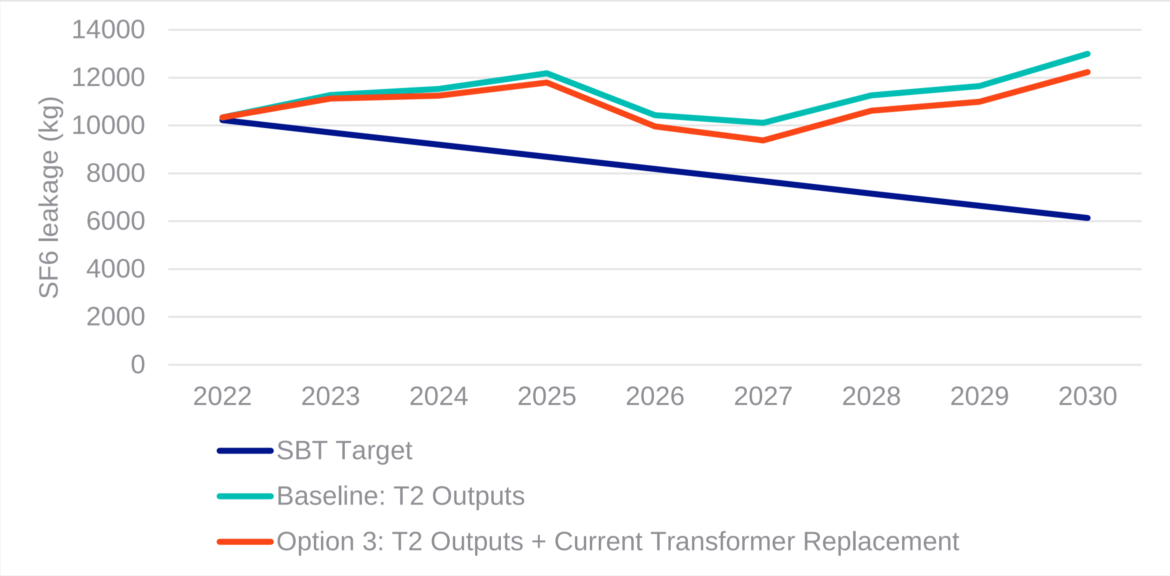
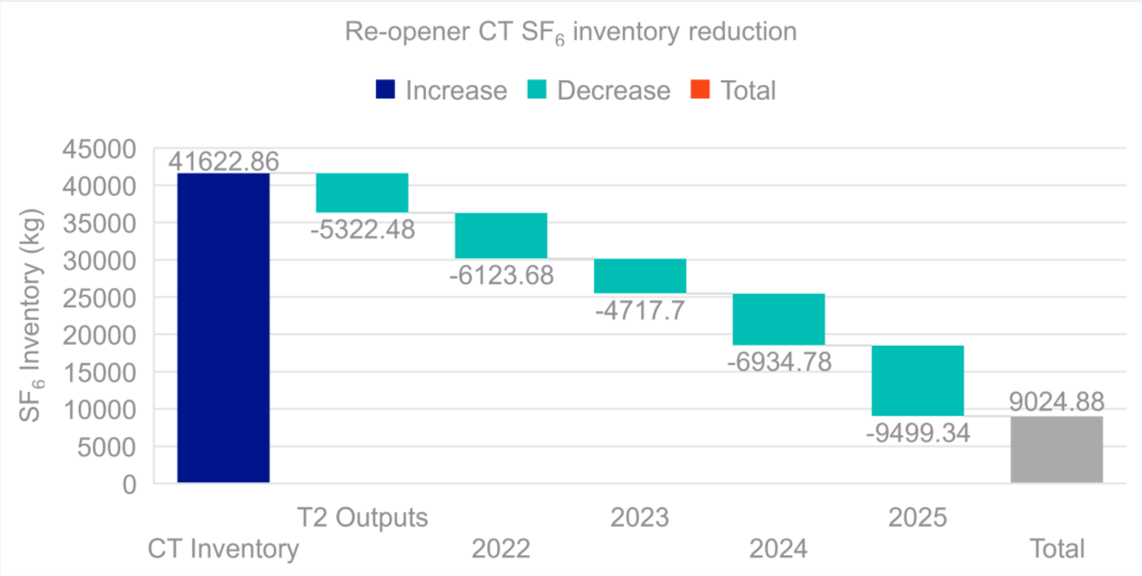


Figure 7.12 - Option Leakage Profile

This option is not forecasted to meet the 2026 target in emissions reduction.

In addition to the emission reduction the CT replacements also remove the inventory – the profile for the SF_6 inventory reduction is:



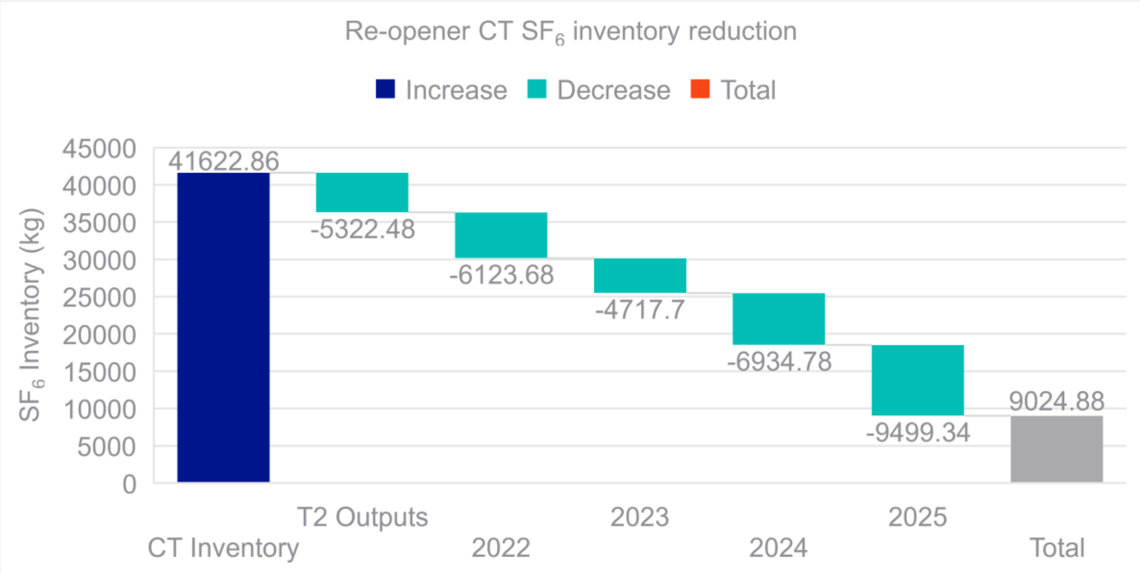


Figure 7.13 – Option 3 SF6 Inventory Reduction

Option leak forecast analysis

Scenario Analysis - count of assets							
	Leak rate				Leak mass		
	10%	25%	50%	100%	10kg	25kg	>50kg
Previous 3-year average	105	28	9	6	112	44	21
2020/21	65	20	9	5	69	29	12
within RIIO-2	77	22	7	6	104	53	23
Up to 2030	126	22	7	5	190	72	31

Table 7.22 – Option 3 Leak Forecast Analysis

Summary position:

	Forecast abatement 2030	Costs	Summary
CT replacements	3,547kg	[redacted]	This option presents the lower SF_6 emission to investment spend it also significantly reduces the SF_6 inventory. It does not meet the required portfolio level emission reduction target. The additional benefits of inventory reduction in this option provides a significant step in the removal of SF_6 from the existing asset base.

Table 7.23 – Option 3 Summary Position

4. AIS Gas Circuit Breaker Repairs:

This option considers AIS GCB assets only that have leaked within RIIO-1 and are at 275kV or 400kV. The development and details for this option are recorded in the AIS GCB EJR.

The intervention chosen for the assets is SF_6 repair to target the reduction in emissions from known leaking assets, whilst no SF_6 alternative gas circuit breaker exists within RIIO-2.

Option summary table:

	Scope	Costs (£k)	Forecast SF_6 abatement 2030
167x 275kV & 400kV AIS GCB SF_6 leak repairs	- [redacted] Repair - 91 SPL GCB repair - 20 Other GCB repair	£[redacted]	4,249kg

Table 7.24 - Option 4 Summary Table

Option spend profile table:

	2022 (£k)	2023 (£k)	2024 (£k)	2025 (£k)
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Other AIS GCB's	[redacted]	[redacted]	[redacted]	[redacted]
Total	[redacted]	[redacted]	[redacted]	[redacted]

Table 7.25 – Option 4 Spend Profile Table

Option leakage profile:

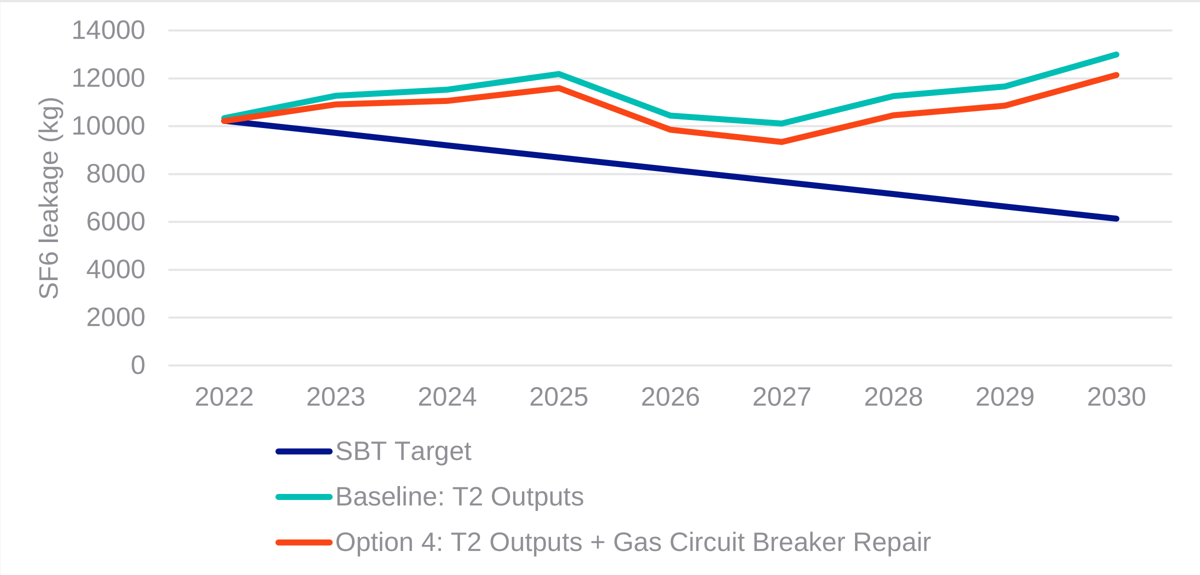


Figure 7.14 - Option 4 Leakage Profile:

Option leak forecast analysis

Scenario Analysis - count of assets							
	Leak rate				Leak mass		
	10%	25%	50%	100%	10kg	25kg	>50kg
Previous 3-year average	94	26	8	5	123	48	20
2020/21	60	17	10	5	71	30	12
within RIIO-2	63	22	8	6	106	55	23
Up to 2030	95	22	8	5	197	75	31

Table 7.26 – Option 4 Leak Forecast Analysis

Summary position:

	Forecast abatement 2030	Costs	Summary
AIS GCB repairs	4,249kg	[redacted]	This option presents the most favourable investment spend to SF_6 abatement and address known leaking GCB's. however, it does not meet the required portfolio level emission reduction target

Table 7.27 – Option 4 Summary Position

5. GIB Replacements:

This option considers stand-alone outdoor GIB assets that have no active components, these assets have multiple interventions and development options available (e,g, replacement for cable, OHL connection or SF_6 GIB alternative solution).

This intervention chosen for each GIB is for replacement with HV cable based on the emission abatement and inventory reduction benefits it provides. The comparison of intervention options are recorded in the [redacted] EJR.

The effectiveness of these assets on the forecasted leakage is considered by using the "removal" intervention, whereby the SF_6 inventory is removed preventing any future leakage.

[redacted]

The below assumptions apply to the next top 5 high leaking RIIO-1 sites:

- Cable replacements costs copied from the [redacted] development cable cost. – further development would provide more accurate costs based on each GIB's unique requirements
- Cable replacements would be bundled with other works requiring the same system access to utilise the same outage and resources, where possible.

Option summary table:

	Scope	Costs (£k)	Forecast SF_6 abatement 2030	SF_6 Inventory reduction
[redacted]	GIB to cable replacement	[redacted]	431kg	2,180kg
[redacted]	GIB to cable replacement	[redacted]	608kg	4,140kg
[redacted]	GIB to cable replacement	[redacted]	66kg	1,812kg
[redacted]	GIB to cable replacement	[redacted]	146kg	1,309kg

Table 7.28 - Option 5 Summary Table

Option spend profile table:

	2022 (£k)	2023 (£k)	2024 (£k)	2025 (£k)	2026 (£k)
[redacted]		[redacted]	[redacted]	[redacted]	
[redacted]	[redacted]	[redacted]	[redacted]		
[redacted]			[redacted]	[redacted]	[redacted]
[redacted]		[redacted]	[redacted]	[redacted]	

Table 7.29 - Option 5 spend Profile Table

Option leakage profile:

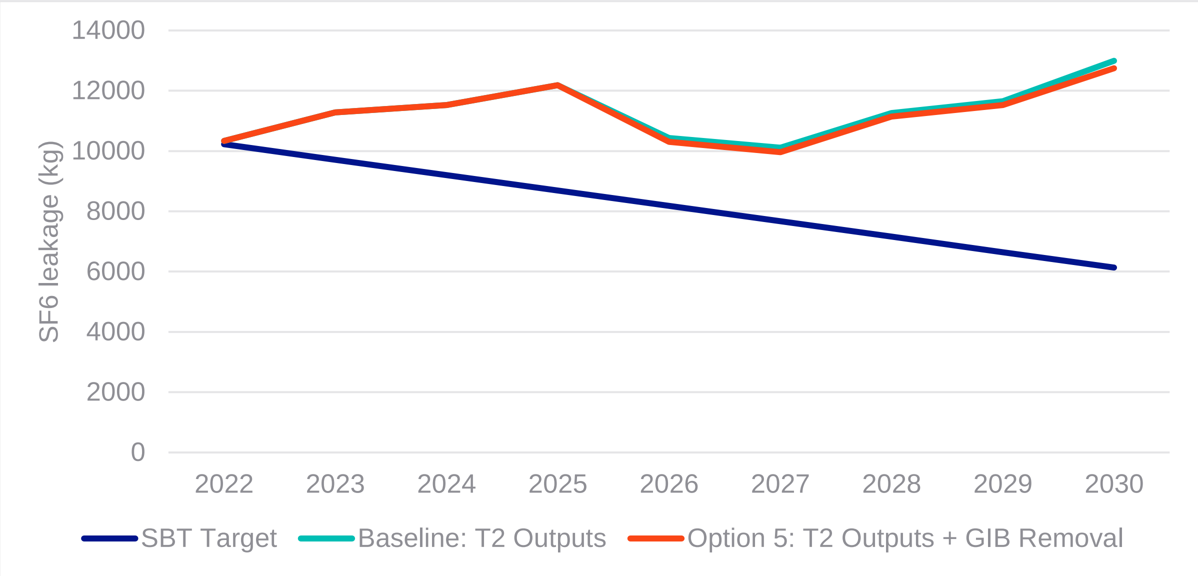


Figure 7.15 - Option Leakage Profile

This option is not forecasted to meet the 2026 target in emissions reduction.

In addition to the emission reduction the GIB replacements also remove the inventory – the profile for the SF_6 inventory reduction is:

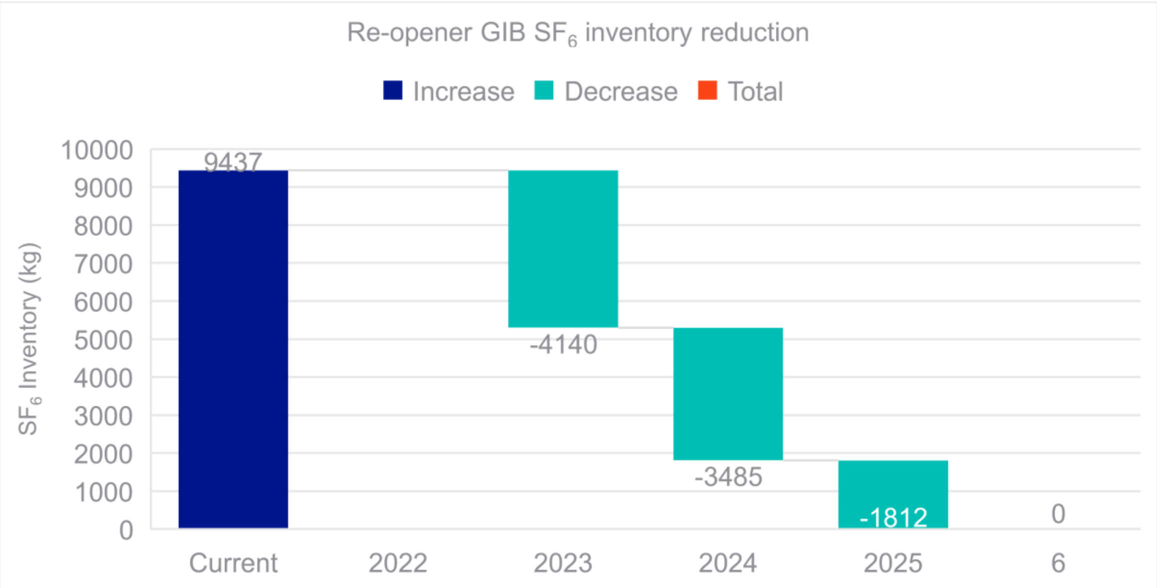


Figure 7.16 – Option 5 Inventory Reduction Profile

The current GIB/GIL only installations are a small component of the overall inventory and emissions but the alternative options to SF_6 are available now and should be considered.

Option leak forecast analysis

Scenario Analysis - count of assets							
	Leak rate				Leak mass		
	10%	25%	50%	100%	10kg	25kg	>50kg
Previous 3-year average	113	30	9	6	130	49	21
2020/21	71	21	10	5	78	32	12
within RIIO-2	80	24	8	6	112	54	23
Up to 2030	131	24	8	5	209	74	31

Table 7.30 – Option 5 Leak Forecast Analysis

Summary position:

	Forecast abatement 2030	Costs (£k)	Summary
GIB replacement with HV cable	1,252kg	£[redacted]	This option presents the least SF_6 emission to investment spend it also significantly reduces the SF_6 inventory. It does not meet the required portfolio level emission reduction target. The additional benefits of inventory reduction in this option provides a significant step in the removal of SF_6 from the existing asset base but the work involved requires further development to determine accurate delivery costs.

Table 7.31 - Summary Position:

Options Summary

The below table provides a summary of each of the options:

Options	Scope	Costs (£k)	Forecast SF_6 abatement 2030	Summary
Remaining sites from T2 AGS submission	4x sites with defined SF_6 interventions:	£[redacted]	12,360kg	*SF_6 (kg) abatement per £: 0.6kg/£* This option presents significant SF_6 emission reduction and addresses high leak rate and

	[redacted]			mass assets. From the scenario analysis, it does not meet the required portfolio level emission reduction target.it does not meet the required portfolio level emission reduction target
Remaining sites from T2 AGS submission + next 5 top leaking T1 sites	8x sites with defined SF_6 interventions. 1x GIB replacement with HV cable	£[redacted]	17,493kg	*SF_6 (kg) abatement per £*[redacted] This option presents significant SF_6 emission reduction and addresses high leak rate and mass assets. From the scenario analysis, it does not meet the required portfolio level emission reduction target. Further development work would be required at the next top 5 sites to assess the leakage on each bay for detailed optioneering to choose the optimum intervention.
Current transformer replacements only	427x CT replacements	£[redacted]	4,808kg	*SF_6 (kg) abatement per £:* [redacted] This option presents the lower SF_6 emission to investment spend it also significantly reduces the SF_6 inventory. It does not meet the required portfolio level emission reduction target. The additional benefits of inventory reduction in this option provides a significant step in the removal of SF_6 from the existing asset base.
Circuit breaker repairs only	167x CB repairs	£[redacted]	4,249kg	*SF_6 (kg) abatement per £:* [redacted] This option presents the most favourable investment spend to SF_6 abatement and address known leaking GCB's. however, it does not meet the required portfolio level emission reduction target
GIB to Cable replacements	4x GIB replacement with HV cable	£[redacted]	1,252kg	*SF_6 (kg) abatement per £:* [redacted] This option presents the least SF_6 emission to investment spend it also significantly reduces the SF_6 inventory. It does not meet the required portfolio level emission reduction target. The additional benefits of inventory reduction in this option provides a significant step in the removal of SF_6 from the existing asset base but the work involved requires further development to determine accurate delivery costs.

Table 7.32 – Options Summary Table

Each option contributes to the reduction in forecast emissions, but none are sufficient to achieve the required abatement on its own. This proposal is to combine options together to collectively meet the 2026 SBT requirements.

Where further development and survey works are required, these have not been included in the selected options as they require more detailed assessment on the interventions required and the associated costs to deliver the works.

The combination of proposed options is listed in table 7.33

	Forecast SF_6 abatement 2030	Costs (£k)	Details	Summary
List of options				
Remaining sites from original AGS submission	12,360kg	[redacted]	Asset interventions at: [redacted]	*SF_6 abatement (kg) to* [redacted]
Current transformer replacements only	4,808kg	[redacted]	427 Current Transformers	*SF_6 abatement (kg) to* [redacted] This intervention also reduces the inventory by 27,275kg
Circuit breaker repairs only	4,249kg	[redacted]	167 Circuit Breakers	*SF_6 abatement (kg) to* [redacted]
GIB to Cable replacements	431kg	[redacted]	Only the [redacted] cable replacement is proposed to trial the replacement of the GIB with a cable. The future GIB assets will be considered in future submissions	*SF_6 abatement (kg) to* [redacted] This intervention also reduces the inventory by 2,180kg
Total	**21,848kg**	**£54,294**		The combined delivery of the selected works provides significant leak abatement and inventory reduction across the network to achieve the 2026 SBT requirement.

Table 7.33 – Summary of Intervention Works

Option leakage profile:

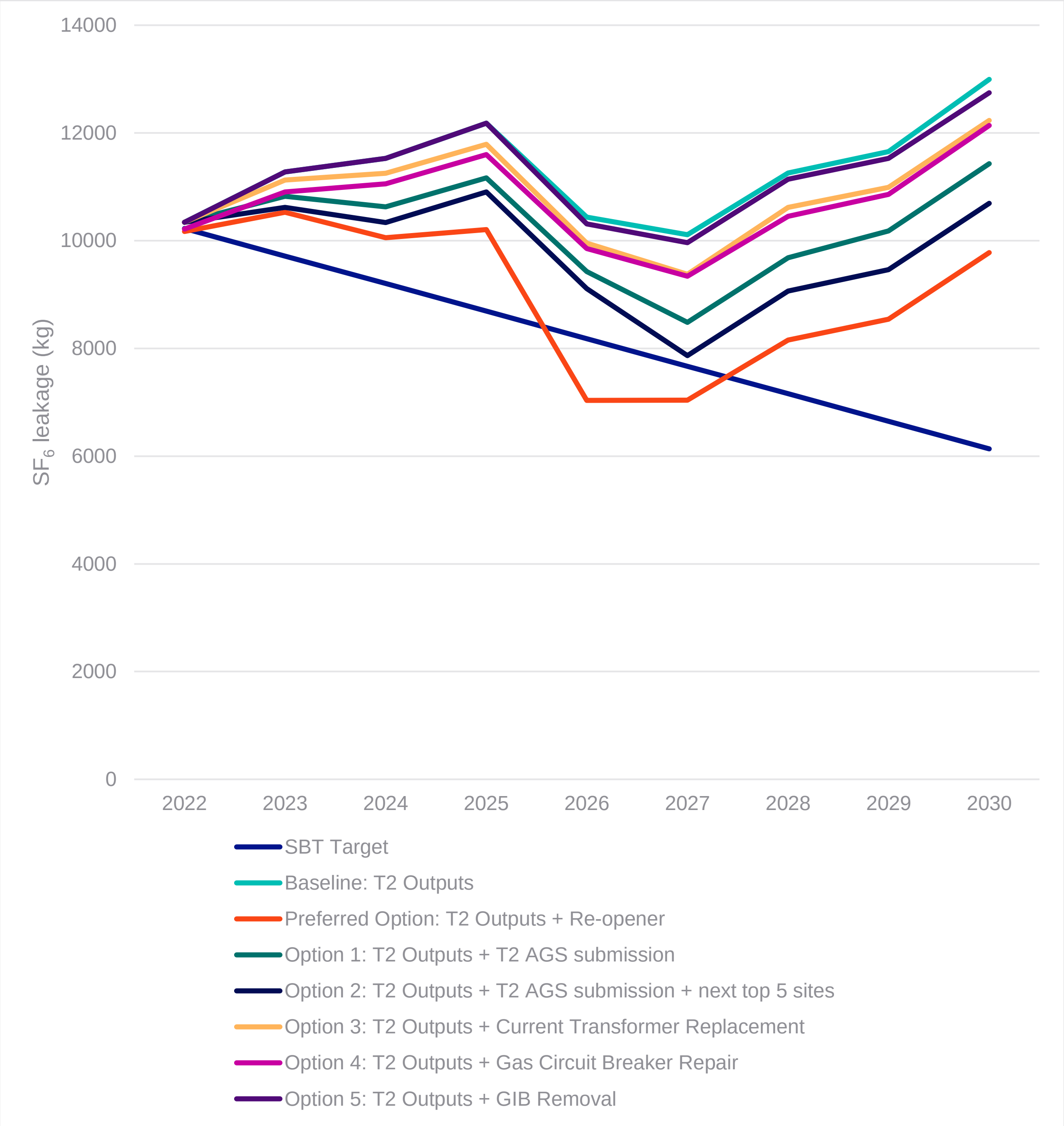


Figure 7.17 – Overall Options Leakage Profile

Each option has different contributions to the emission reduction target.

It is proposed to combine all the options from Table 7.33 together to form the preferred option.

Scenario analysis - count of assets							
	Leak rate				Leak mass		
	10%	25%	50%	100%	10kg	25kg	>50kg

Previous 3-year average	68	17	4	2	70	21	8
2020/21	37	9	4	1	39	11	2
within RIIO-2	39	11	3	2	70	30	10
Up to 2030	68	11	3	2	146	49	15

Table 7.34: Preferred option leak rate and mass distributions

From the scenario analysis on the re-opener proposal it provides the greatest reduction overall for assets forecasted to be in each category.

Within the leak rate at 100%, there is 2 assets, highlighted orange, that are within the RIIO-2 & 2030 forecast. Both these assets are 132kV AIS GCB's and are to be assessed as replacement candidates for non--SF_6 AIS GCB's as part of a future submission focused on inventory reduction.

The 2 assets within the >50kg category in 2020/21 have now been repaired within the 2021/22. The remaining assets are to be monitored closely on the actual leakage.

8. Methodology for selection of the preferred option

This section covers the criteria used in determining the preferred option. It uses the information covered under the earlier sections focusing on the requirements to reduce carbon emissions from SF_6 leakage in line with the governments and our targets in the interest of consumers.

The cost and cost benefit analysis methodology used for selecting the preferred option is also detailed within this section.

Summary of Key Messages:
Prioritisation:
Identification and prioritisation of intervention is primarily based on actual and forecast emissions of SF_6 to atmosphere; the key performance measure for this investment. The emissions forecast takes into account factors such as the age, health and historic performance of the asset family, and the SF_6 inventory of the relevant assets.

Consideration is also given to wider site strategy options and technology availability.

Cost Benefit Analysis:
The CBA accounts for the intervention expenditure and the SF_6 emission reduction as a societal benefit based on the carbon price. The CBAs have been conducted using Ofgem's template to determine the NPV. The NPV considers a 10 year period based on immediate needs to reduce emissions in line with SBT requirements and expected technology availability which makes replacements a stable, viable option from 10 years+.

Intervention Prioritisation

Based on the asset health and needs case described, this proposal is focused on optimal interventions based on asset types.

- For GIS it is interventions at defined sites to a bay level
- For Circuit Breakers it is interventions at an asset level
- For Current Transformers it is the replacement of the SF_6 filled portfolio for a non-SF_6 filled alternative CT

The selection of the interventions for each asset is detailed in its respective EJR document. Site visits for GIS assets have allowed for a thorough assessment on the intervention required to address where the leakage location has been found through leak detection surveys.

The preferred portfolio option considers the following factors to achieve the SBT for 2026:

- Inventory size
- Previous & actual leakage
- Forecasted leakage
- Asset Health & age
- Alignment to long term strategy of site

The below table details other considerations for determining the preferred intervention option:

Criteria	Detail
Financial	Each option will be compared on its financial impact. Short, medium- and long-term spend, including any ongoing maintenance costs, will be considered, and presented in a cost benefit analysis. The total Net Present Value will determine the best long-term financial option.

Environmental inc. SF_6 Emission Abatement	The environmental impact of each option will be considered which will include the carbon impact, the resources and materials required and impact to the natural environment. SF_6 Emission Abatement will be considered independently as it is the main driver for the investment. Any emission abatement through refurbishment, repair, etc will be deemed to include the residual risk of future emissions therefore the most effective emission abatement solution is to remove the SF_6 thus removing all residual risk.
Programme and System Access	The programme element will be broken down into two considerations; the lead time required to start the option, and the duration of the works for each option. The lead time is important when considering SF_6 emission abatement as any leak will continue, and potentially increase, during this period. System access will also be considered to judge the deliverability of each option and also the impact to other works on the network as any outage for this investment will likely impact outages elsewhere on the network required for other required interventions.
Risks and Opportunities	Key risks have been considered to ensure nothing is overlooked at this stage. Any opportunities identified may provide benefit to other investments or stakeholders.

Table 8.1: Decision making criteria

GIS Interventions

Intervention selection methodology:

The methodology for selection of intervention is unique for GIS equipment and is determined on a case-by-case basis through development.

Further details of individual investment proposals, optioneering and funding arrangements can be found in the EJR's attached in the Annexes.

Circuit Breakers

Intervention selection methodology:

The intervention options for circuit breakers covers:

- Repair
- Replacement (SF_6 Circuit breaker).

Current Transformers

Intervention selection methodology:

The intervention for current transformers is the replacement of the assets which abates any leakage and reduces the SF_6 inventory mass across the Current Transformer asset type.

Cost Benefit Analysis

The cost benefit analysis (CBA) uses the SF_6 emissions and incorporates the societal benefits to the consumer in terms of the carbon price from the carbon equivalent emissions abated from SF_6 leakage from assets.

The Ofgem CBA template has been used for each engineering justification report. This is using the 2020 HMRC Greenbook price of the carbon price.

In the CBA section in the annex the table provides a CBA view on societal benefits of the carbon price of SF_6 leakage for each kg per year. This helps provide a relative view of kg to £ for societal benefit based on the forecasted kg that would be abated.

The below graph shows the societal benefit cost impact of cumulative leakage over each year based on average annual SF_6 leakages.

A 10kg leakage in 2022 has a societal impact cost of £58,360, however if that 10kg annual leakage continued at the same rate over the T2 period and out to 2030 the cumulative societal impact would be:

- 2022 - £58,360
- 2026 - £297,200
- 2030 - £550,930

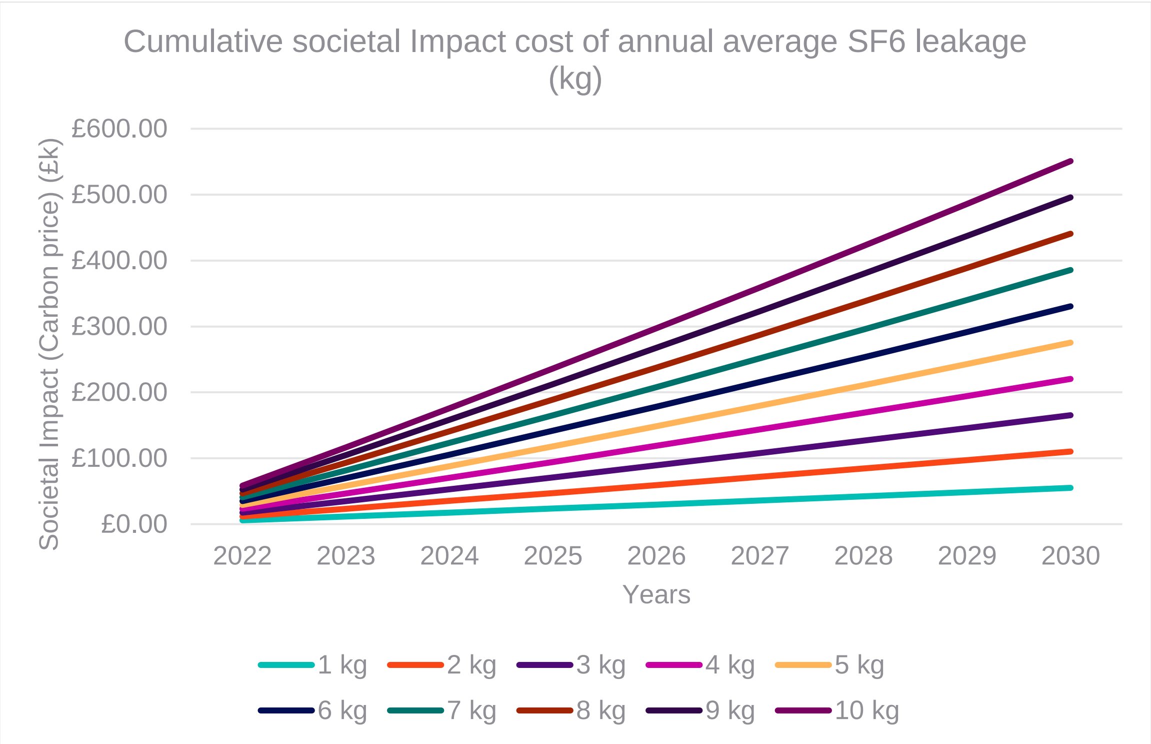


Figure 8.1: Cumulative societal impact cost of annual average SF_6 leakage (kg)

The CBA has assessed the cost of intervention against the cost of the societal benefit based upon the above methodology.

The threshold of SF_6 leakage that would deliver a societal benefit equal to the cost of intervention is detailed below.

Asset Type	Estimating units	Capex / Opex	Unit	Qty	Unit Cost £k	Total £k	SF_6 (kg) leakage to be abated for intervention spend Carbon price (2022)
132kV Subs	CT (1-phase) - 132kV	Capex	each	3	[redacted]	[redacted]	12.72*
275kV Subs	CT (1-phase) - 275kV	Capex	each	3	[redacted]	[redacted]	22.42*
400kV Subs	CT (1-phase) - 400kV	Capex	each	3	[redacted]	[redacted]	33.90*
400kV Subs	[redacted]	Capex	each	1	[redacted]	[redacted]	7.97
400kV Subs	[redacted]	Capex	each	1	[redacted]	[redacted]	4.98
400kV Subs	[redacted]	Capex	each	1	[redacted]	[redacted]	5.49
275kV Subs	[redacted]	Capex	each	1	[redacted]	[redacted]	6.38
275kV Subs	[redacted]	Capex	each	1	[redacted]	[redacted]	4.98
132kV Subs	GCB repair	Capex	each	1	[redacted]	[redacted]	2.15
Other	GCB repair	Capex	each	1	[redacted]	[redacted]	4.98
Other	3 phase GIS Encapsulation wrap	Capex	each	1	[redacted]	[redacted]	19.16
Other	Small 3 phase GIS refurbishment	Capex	each	1	[redacted]	[redacted]	97.85
Other	Medium 3 phase GIS refurbishment	Capex	each	1	[redacted]	[redacted]	189.75
Other	Large 3 phase GIS refurbishment	Capex	each	1	[redacted]	[redacted]	373.53
Other	3 phase GIS bushing replacement	Capex	each	1	[redacted]	[redacted]	91.22

Table 8.2: Unit costs

**Based on 3 phase replacement costs*

Using the above details, the profiling of spend and benefit are combined to generate a profiled view of when the societal benefit is recognised against the intervention spend.

The interventions proposed include replacements for current transformers and removal of GIB/GIL sections for cable. All other asset types and interventions focus on the repair of the existing asset. For the replacement interventions the WLC of the new equipment is included in the CBA profiling.

Asset Plant Number (FP)	Intervention	Delivery Date	Costs (£k)	2022 (£k)	2023 (£k)	2024 (£k)	2025 (£k)	2026 (£k)	2027 (£k)	2028 (£k)	2029 (£k)	2030 (£k)
ALDW2 L4CT	Replacement – SF_6 alternative (OIP CT)	2022	£130.83	-£130.83	£6.57	£8.88	£12.74	£14.41	£20.10	£22.59	£25.99	£26.72
			Cumulative Costs (£k)	-£130.83	-£124.26	-£115.38	-£102.64	-£88.23	-£68.13	-£45.55	-£19.55	£7.16
			SF_6 forecast leakage (kg)	1.04	1.13	1.50	2.12	2.36	3.24	3.59	4.07	4.12
			SF_6 forecast leakage (cumulative) (kg)	1.04	2.16	3.66	5.78	8.14	11.38	14.97	19.03	23.15

Table 8.3: Payback example ALDW2L4CT

The above example shows payback in 2030 from the societal benefits against the intervention spend based on the abated SF6 forecasted leakage.

This is conducted for every asset having an intervention and the portfolio output is shown below:

This is only on the assets detailed in the re-opener not all the assets. And only considers costs based on abated carbon emission post intervention.

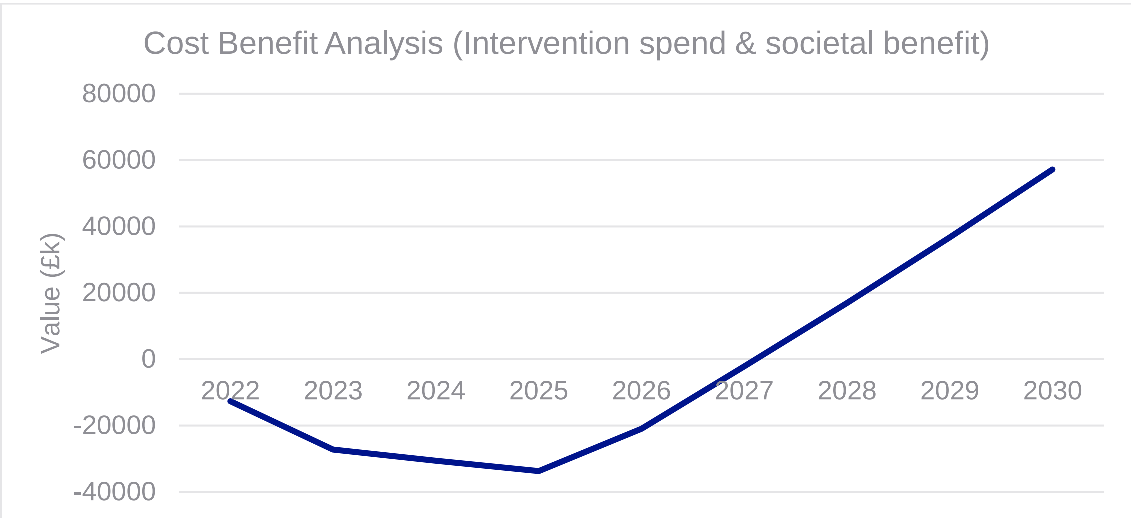


Figure 8.2 – Societal Cost Benefit Analysis

The focus of the CBA up to 10 years is prioritised based on the immediate emission abatement ahead of future SF_6 inventory reduction interventions in the next 10 years.

Option no.	Desc of Option	Preferred Option	Total Forecast Expenditure (£m)	Total NPV	10 Years	20 Years	30 Years	45 Years
Baseline	Do Nothing	N						

1	Remaining sites from T2 AGS submission	N	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
2	Remaining sites from T2 AGS submission + next 5 top high leaking T1 sites	N	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
3	CT Replacements	N	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
4	AIS GCB Repairs	N	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
5	GIB replacements	N	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
6	**Selected Scenarios**	**Y**	**-£54.29**	**£335.25**	**£118.25**	**£250.63**	**£341.28**	**£335.67**

Table 8.4: Cost benefit analysis – NPV option comparison

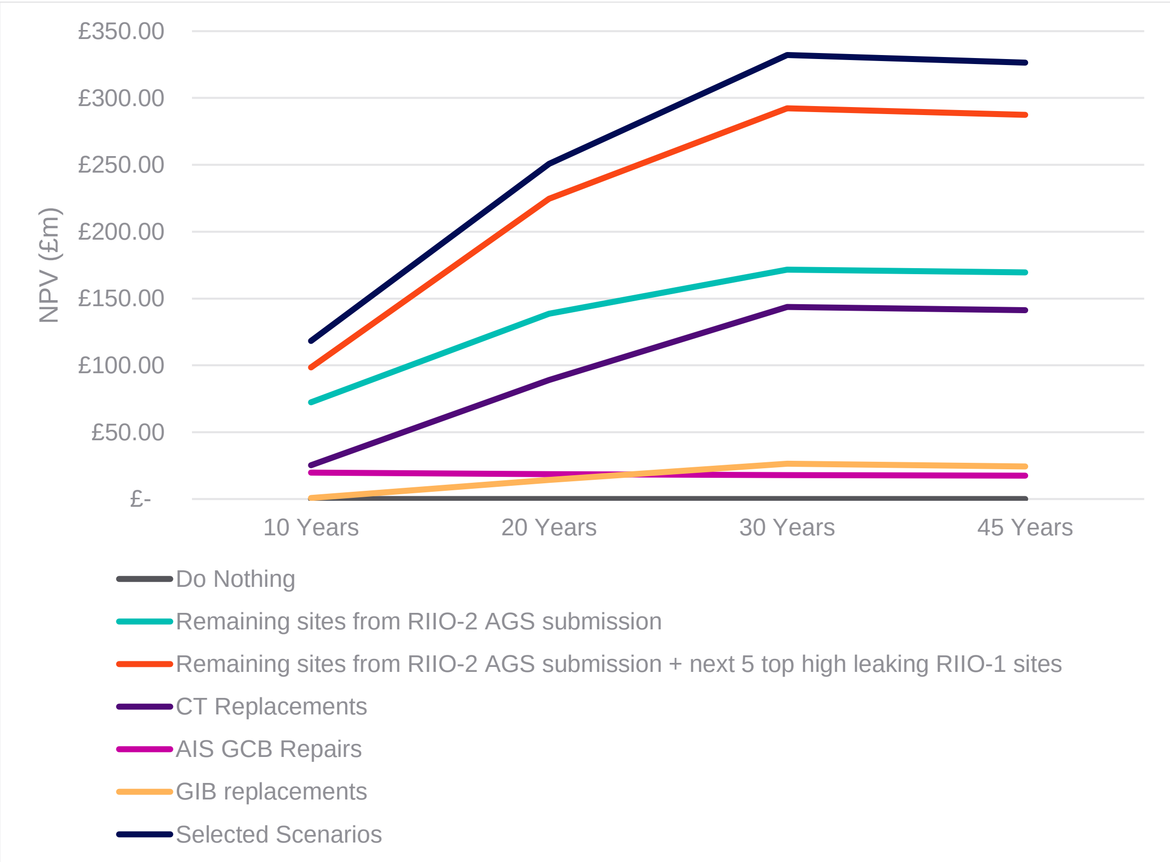


Figure 8.3: Cost benefit analysis – NPV option comparison

9. The preferred option and detailed costs

Summary of Key Messages:

Intervention:

GIB replacement with HV cable at [redacted]. Multiple GIS interventions at [redacted]. 427 current transformer replacements. 167 SF6 leak repairs.

Cost:

Total cost of interventions is £54,294k

Benefit:

Cumulative reduction in emissions by 21,848kg (513,429 tCO2e) out to 2030 with consumer payback in this period. Forecast to achieve NGET target to reduce emissions by 33% in 2026.

Preferred option

The preferred option chosen for this document is comprised of the below interventions:

- GIB removal, Cable installation at [redacted] S/S
- Targeted Interventions at [redacted] S/S
- Targeted Interventions at [redacted] S/S
- Targeted Interventions at [redacted] S/S
- Targeted Interventions at [redacted] S/S
- Current Transformer replacements
- Circuit Breaker interventions

The graph provides an overview of the forecasted leakage from the interventions in relation to the do nothing scenario, T2 outputs (baseline) and against the SBT.

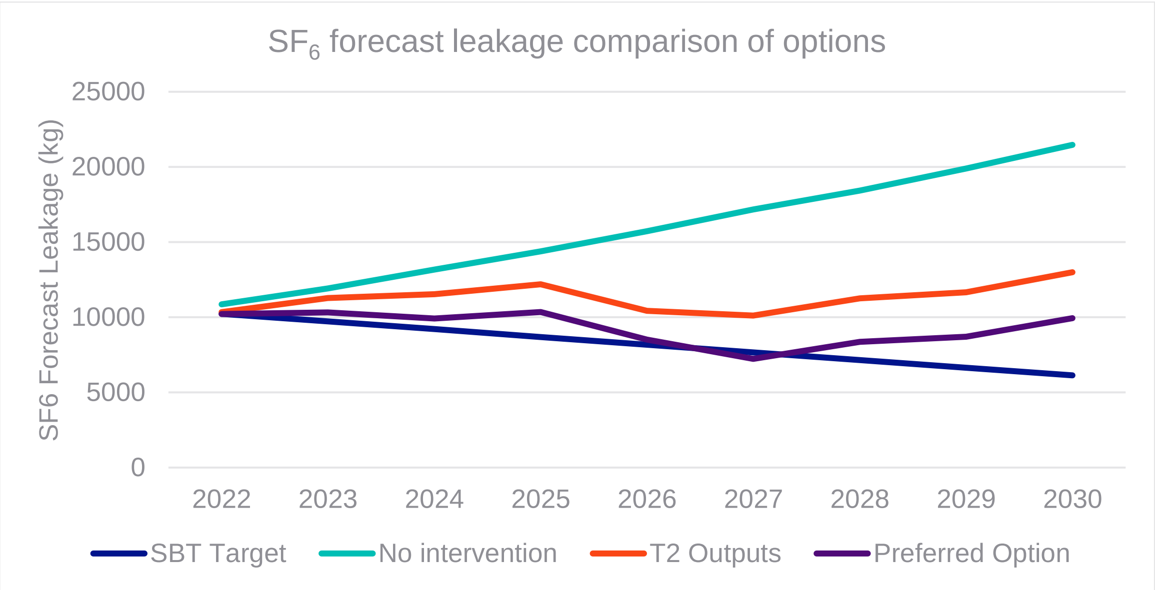


Figure 9.1 – Forecast Leakage Options Comparison

This option is chosen for its ability to meet the SBT requirements for the 2026 SF_6 leak reduction goal and to be on track for Net Zero.

Without the option the SBT will not be met to achieve Net zero and the associated carbon emissions not abated to 2030 is equivalent to 21,848kg SF_6 which is 513,429 tonnes carbon emission.

In addition to the emission reduction, the interventions will reduce the SF_6 inventory by 29,455kg

The summarised details of each portfolio option is captured below:

GIB removal, Cable installation at [redacted] S/S

Bay	Gas Zone	Intervention	Costs (£k)	System Access (weeks)	SF_6 Emission Abatement from 2022 to 2030 (kg)	SF_6 Emission Abatement from 2022 to 2049 (kg)
[redacted]	[redacted]	GIB Replacement with HV Cable	[redacted]	10	431	2,833
	[redacted]	GIB Replacement with HV Cable				
	[redacted]	GIB Replacement with HV Cable				
	[redacted]	GIB Replacement with HV Cable				
	[redacted]	GIB Replacement with HV Cable				
	[redacted]	GIB Replacement with HV Cable				
Total			[redacted]		**431kg**	**2,833kg**

Table 9.1 - GIB removal, Cable installation at Xxxxxxxxxxxxxxxxxx S/S

Targeted Interventions at Xxxxxxxxxxxxxxx S/S

Bay	Gas Zone	Intervention	Cost (£k)	System Access	SF_6 Emission Abatement	SF_6 Emission Abatement

					(2022 to 2030)	(2022 to 2049)
SGT5A & 5B	X513AG5	Refurbishment	[redacted]	12 Weeks	175kg	1,924kg
	X513BG6	Refurbishment				
	X513CG3	Refurbishment				
	SGT5AG4	Refurbishment				
	SGT5BG7	Refurbishment				
	SGT5BG8	Refurbishment				
[redacted]	X303G3	Refurbishment & bushing replacement	[redacted]	8 Weeks	32kg	469kg
[redacted]	X203G3	Refurbishment & bushing replacement	[redacted]	8 Weeks	1012kg	2,905kg
[redacted]	X403G3	Refurbishment & bushing replacement	[redacted]	8 Weeks	310kg	2,098kg
SGT6	X613G3	Repair	[redacted]	N/A	864kg	2,173kg
Total			[redacted]		**2,393kg**	**9,571kg**

Table 9.2 - Targeted Interventions at [redacted] S/S

Targeted Interventions at [redacted] S/S

Bay	Gas Zone	Intervention	Cost (£k)	System Access	SF_6 Emission Abatement (2022 to 2030)	SF_6 Emission Abatement (2022 to 2049)
SGT1	X113G3	Refurbishment & Repair	[redacted]	12	772	2,411
SGT2	X213G3	Refurbishment	[redacted]	12	1,438	3,244
SGT4	X413G3	Refurbishment & bushing replacement	[redacted]	12	1	55
[redacted]	X203G3	Refurbishment & bushing replacement	[redacted]	8	567	1,619
[redacted]	X103G3	Refurbishment & bushing replacement	[redacted]	8	347	1,531

Total	[redacted]	**3,125kg**	**8,860kg**

Table 9.3 - Targeted Interventions at [redacted] S/S

Targeted Interventions at [redacted] S/S

Bay	Gas Zone	Intervention	Cost (£k)	System Access	SF_6 Emission Abatement (2022 to 2030)	SF_6 Emission Abatement (2022 to 2049)
Bus Section 1	xxxxxxxxxxxxx	Repair	£xxx	N/A	62	345
	xxxxxxxxxxxxx	Repair				
	xxxxxxxxxxxxx	Repair				
	xxxxxxxxxxxxx	Repair				
xxxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxx	Repair	£xxx	N/A	400	1,733
xxxxxxxxxxx	xxxxxxxxxxxxx	Repair	£xxx	N/A	371	1,642
	xxxxxxxxxxxxx	Repair				
Series Reactor	xxxxxxxxxxxxx	Repair	£xxx	N/A	917	3,328
	xxxxxxxxxxxxx	Repair				
	xxxxxxxxxxxxx	Repair				
Dungeness 1	xxxxxxxxxxxxx	Repair	£xxx	N/A	31	145
SGT 3	xxxxxxxxxxxxx	Repair	£xxx	N/A	137	451
	xxxxxxxxxxxxx	Repair				
xxxxxxxxxx	xxxxxxxxxxxxx	Repair	£xxx	N/A	859	2,093
	xxxxxxxxxxxxx	Repair				
SGT5A&B	xxxxxxxxxxxxx	Repair	£xxx	N/A	1,530	5,198
	xxxxxxxxxxxxx	Repair				
	xxxxxxxxxxxxx	Repair				
	xxxxxxxxxxxxx	Repair				
	xxxxxxxxxxxxx	Repair				
SGT6	xxxxxxxxxxxxx	Repair	£xxx	N/A	866	2,290
	xxxxxxxxxxxxx	Repair				
	xxxxxxxxxxxxx	Repair				
Shunt Reactor 2	xxxxxxxxxxxxx	Repair	£xxx	N/A	248	802

Total:	[redacted]	**5,420kg**	**18,027kg**

Table 9.4 - Targeted Interventions at [redacted] S/S

Targeted Interventions at [redacted] S/S

Bay	Gas Zone	Intervention	Cost (£k)	System Access (weeks)	SF$_6$ Emission Abatement 2022 - 2030	SF$_6$ Emission Abatement 2022- 2049
Main / Reserve bus sections. Bus Couplers 1 and 2	X124G1	Repair	[redacted]	6	77kg	365kg
	X234G1	Repair				
[redacted]	X106G1	Repair	[redacted]	6	65kg	310kg
SGT3	X313G2 X313G3 X313G4	Refurbishment	[redacted]	20	387kg	1,770kg
SGT4	X413G2 X413G3 X413G4	Refurbishment	[redacted]	20 Proximity outage on Barking 1 cct 4 weeks	326kg	1,530kg
QB2	X342G3 X342G4 X342G5 X342G6 X343G1 X347G2	Refurbishment	[redacted]	20	450kg	1,916kg
QB1	X442G3 X442G4 X442G5 X442G6 X443G1 X447G2	Refurbishment	[redacted]	20	49kg	1,159kg
[redacted]	X706G1		[redacted]	6	36kg	150kg
[redacted]	X806G1		[redacted]	6	32kg	142kg
Total	£xxx				**1,422kg**	**7,340kg**

Table 9.5 - Targeted Interventions at [redacted] S/S

Current Transformer Replacements

	Asset Count	Unit Cost £k	Total MSIP Proposal (£k)	Total Abated SF$_6$ Emissions	SF$_6$ inventory

				to 2030 (kgs)	reduction (kg)
400kV CT replacements	31	[redacted]	[redacted]	3,999kg	23,112kg
275kV CT replacements	136	[redacted]	[redacted]	671kg	3,874kg
132kV CT replacements	260	[redacted]	[redacted]	193kg	290kg
Total	**426**		[redacted]	**4,808kg**	**27,276kg**

Table 9.6 - Current Transformer Replacements

275kV & 400kV AIS gas circuit breaker SF_6 leak repairs

	Asset Count	Unit Cost £k	Total MSIP Proposal (£k)	Total Abated SF_6 Emissions to 2030 (kgs)
[redacted]	16	[redacted]	[redacted]	451
[redacted]	19	[redacted]	[redacted]	206
[redacted]	4	[redacted]	[redacted]	166
[redacted]	36	[redacted]	[redacted]	812
[redacted]	12	[redacted]	[redacted]	325
[redacted]	60	[redacted]	[redacted]	1696
275kV Other GCB	1	[redacted]	[redacted]	4
400kV Other GCB	19	[redacted]	[redacted]	589
Total	**167**	[redacted]	[redacted]	**4249**

Table 9.7 - 275kV & 400kV AIS gas circuit breaker SF_6 leak repairs

Each of the above deliverables abate SF_6 leakage in order to meet the 2026 target to stay on track for the 2030 commitment and 2050 net zero target.

	Forecast SF_6 abatement 2030	Costs (£k)	Details	Summary
List of options				
Remaining sites from original AGS submission	12,360kg	[redacted]	Asset interventions at: [redacted]	*SF_6 abatement (kg) to* [redacted]

		[redacted]	[redacted]	
Current transformer replacements only	4,808kg	[redacted]	427 Current Transformers	*SF_6 abatement (kg) to* [redacted] This intervention also reduces the inventory by 27,275kg
Circuit breaker repairs only	4,249kg	[redacted]	167 Circuit Breakers	*SF_6 abatement (kg) to* [redacted]
GIB to Cable replacements	431kg	[redacted]	Only the [redacted] cable replacement is proposed to trial the replacement of the GIB with a cable. The future GIB assets will be considered in future submissions	*SF_6 abatement (kg) to* [redacted] This intervention also reduces the inventory by 2,180kg
Total	**21,848kg**	**£54,294**		The combined delivery of the selected works provides significant leak abatement and inventory reduction across the network to achieve the 2026 SBT requirement.

Table 9.8 – Summary of Intervention Works

Detailed costs

The cost profile of the preferred re-opener option is shown in the table:

	2022 (£k)	2023 (£k)	2024 (£k)	2025 (£k)
[redacted] GIB to cable replacement	[redacted]	[redacted]	[redacted]	
[redacted] SF_6 Interventions	[redacted]			[redacted]
[redacted] SF_6 Interventions		[redacted]		[redacted]
[redacted] SF_6 Interventions	[redacted]	[redacted]	[redacted]	[redacted]
[redacted] SF_6 Interventions	[redacted]	[redacted]	[redacted]	[redacted]
Current Transformer replacements	[redacted]	[redacted]	[redacted]	[redacted]
AIS Gas Circuit Breaker Interventions	[redacted]	[redacted]	[redacted]	[redacted]
Total	**£9,831**	**£14,999**	**£10,954**	**£18,510**

Table 9.9 – Intervention Option Cost Profiling

Cost benefit analysis

The value of the re-opener interventions based on the societal benefit from abated SF_6 and intervention spend is shown in the payback graph.

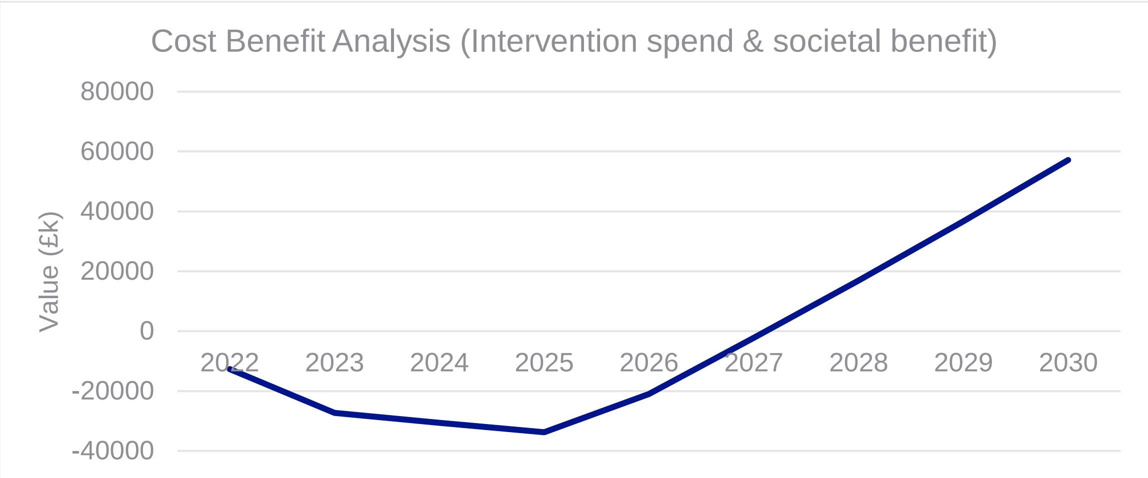


Figure 9.2 – Societal Cost Benefit Analysis

This details that the payback of the interventions will be completed by the year 2028 based on the societal benefits from the abated SF_6 emissions.

The economic assessment outlined by the CBA shows that the preferred solution of SF_6 interventions presents the best value to consumers, considering all investment costs, societal benefit costs and discounted using the Spackman method.

Option no.	Desc of Option	Preferred Option	Total Forecast Expenditure (£m)	Total NPV	10 Years	20 Years	30 Years	45 Years
Baseline	Do Nothing	N						
1	Remaining sites from T2 AGS submission	N	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
2	Remaining sites from T2 AGS submission + next 5 top high leaking T1 sites	N	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
3	CT Replacements	N	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
4	AIS GCB Repairs	N	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
5	GIB replacements	N	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
6	**Selected Scenarios**	**Y**	**-£54.29**	**£335.25**	**£118.25**	**£250.63**	**£341.28**	**£335.67**

Table 9.10 – Summary of Works NPV Analysis

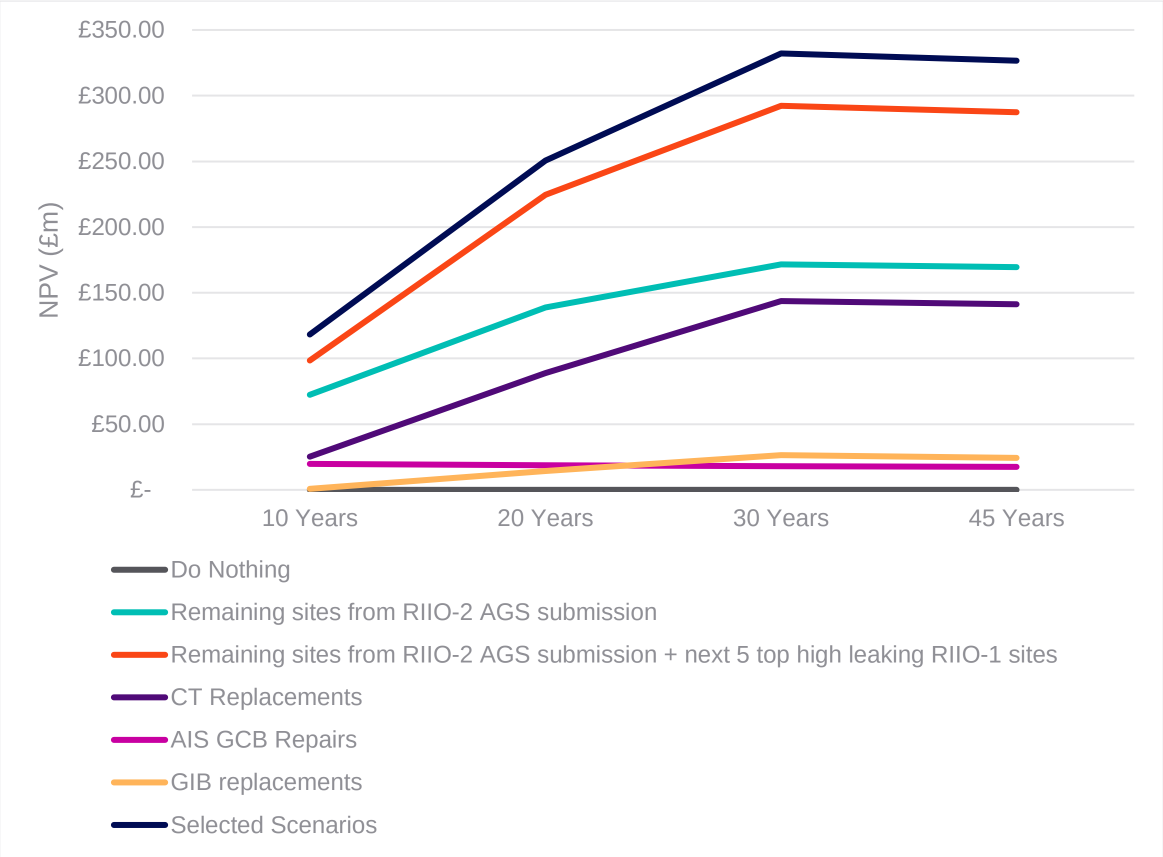


Figure 9.3 – Graphical Summary of Works NPV Analysis

Risk & Contingency

The below risks have been considered as part of the preferred option and the likelihood and mitigations applied to reduce the impact it could have on the delivery of the option.

	Impact	Likelihood	Mitigation
New SF_6 deterioration modes	• No intervention options available to address SF_6 leakage.	• Low	• Attendance to several technical working groups on sharing best practices and knowledge on SF_6 asset health and intervention methods
Legislative changes	• Requirement to remove SF_6 inventory	• High	• Attendance to DEFRA on updates to legislative or regulation changes. • Attendance to several technical working groups on sharing best practices and knowledge

Technology development	• Changes to technology availability and option selection for interventions	• Medium	• Close working with OEM's on development progress and availability to deliver SF_6-free technology • Proposed 2nd MSIP re-opener to focus on SF_6 reduction and development progress of alternative technology
Carbon cost changes	• Changes to CBA on the value of removing SF_6	• Medium	• Using latest HMRC Greenbrook values and monitoring potential changes
Outage availability	• Increased period of SF_6 leakage	• High	• Alignment with long term outage plans submitted (existing in eNAMS outage planning system & outages submitted as part of the long-term outage plan grid code requirement OC2) • Close working with power system engineers and ESO on in year opportunities where reactive interventions are required
Resource Availability	• Unavailability of NG resource could lead to delays in commissioning	• Medium	• Alignment with long term outage plans and associated resource scheduling • Internal and contracted resource delivery options to be considered
Leak location surveys	• Unable to accurately determine leakage location	• Medium	• Several leak survey types are available for locating leakage points • Further innovation work is underway to determine more methods of identifying leakage areas
Unidentified Buried Services	• Delays to cable installation where proposed as replacement for existing GIB	• Low	• Site surveys • Site drawings check in early phases of development and design
Age of SF_6 assets and obsolescence	• Delays in back-engineering some parts that may not be readily available from OEMs for refurbishment interventions	• Medium	• Close collaboration with OEMs during development, design and work planning stages
Inclement Weather	• Delays to programme and potential damage to ongoing works	• Low	• Use of weather-proof temporary structure for refurbishments • Prudent programme management ensuring sensible float and contingency in place
Stock availability	• Unable to deliver the intervention on time or at all	• Low	• Engagement with suppliers to inform them of window outage dates for

			delivery and working with them on product lead times.
Increased leakage	• Higher impact on SF_6 leakage if left and require more urgent intervention.	• High	• Close monitoring of leakage performance on assets against forecast prediction.

Table 9.11 List of risks and mitigations

10. Project delivery and monitoring

This section sets out the approach to assessing the deliverability of the works and the timing of delivery in line with intervention strategy assessments (technology availability, site strategies) along with alignment to future submissions.

Plan alignment

The deliverables in this proposal have been assessed and aligned where possible with other T2 outputs on the same bay or circuit to utilise the same resource or outages to not further constrain availability of system access. This is primarily bundling the works to be delivered at the same time as other PCD or NARM outputs such as SGT or circuit breaker replacements.

The information used for plan optimisation has assessed in the below alignment order:

1. Optimised plan output alignment
2. NARM, PCD, NLR T2 outputs alignment
3. Existing planned outage alignment
4. Grid code (OC2) Week 44 long term outage plan submission alignment.

Project monitoring

We will monitor project and programme progress and measure earned-value metrics in the same way that we do for other capital investments in our capital plan. Milestones, deliverables and spend (actuals and forecasts) will be monitored by our project control's function.

Monitoring activities will typically consist of:

- Measuring planned performance vs actual performance
- Ongoing assessment of the project / programme performance to identify any preventative or corrective actions needed
- Keeping and maintaining accurate, timely project / programme information and documentation
- Providing information that supports status updates, forecasting and measuring progress
- Delivering forecasts that update current costs and project / programme schedules
- Monitoring the implementation of any approved changes or schedule amendments.

The programme for gas zone sites illustrated below is due to the bespoke requirements that need careful development ahead of delivery. Circuit breaker and current transformer interventions have been standardised and can be delivered with a reduced development & design timescale.

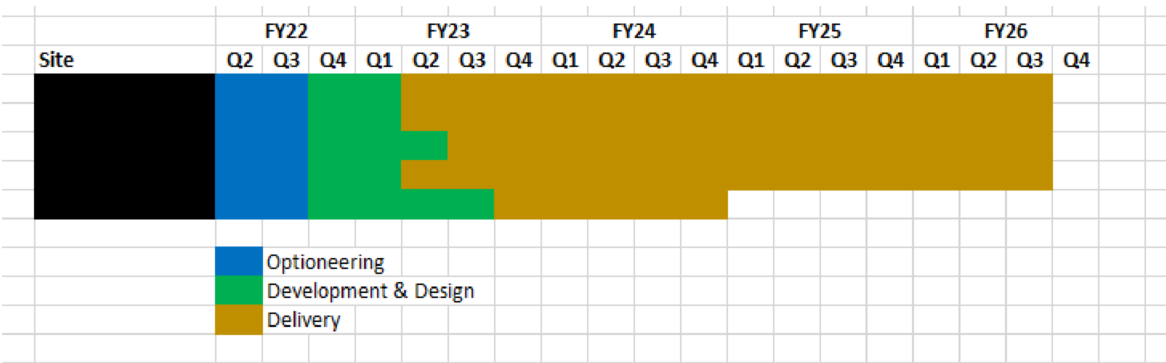


Figure 10.1 Delivery programme for works

High-level project milestones for each site are provided in the Project Delivery Key Milestones annex. SF_6 leakage detectability

As previously mentioned, the use of top-ups to detect leakage is limited in its capability to reliably detect low levels of annual emissions since the assessment of a rate requires at least two data points. The graph in figure 10.2 demonstrates this based upon some simplifying assumptions that:

- The design margin between rated pressure and alarm pressure is 10%
- Top-ups are triggered by the alarm condition
- Top-ups restore the asset to rated pressure

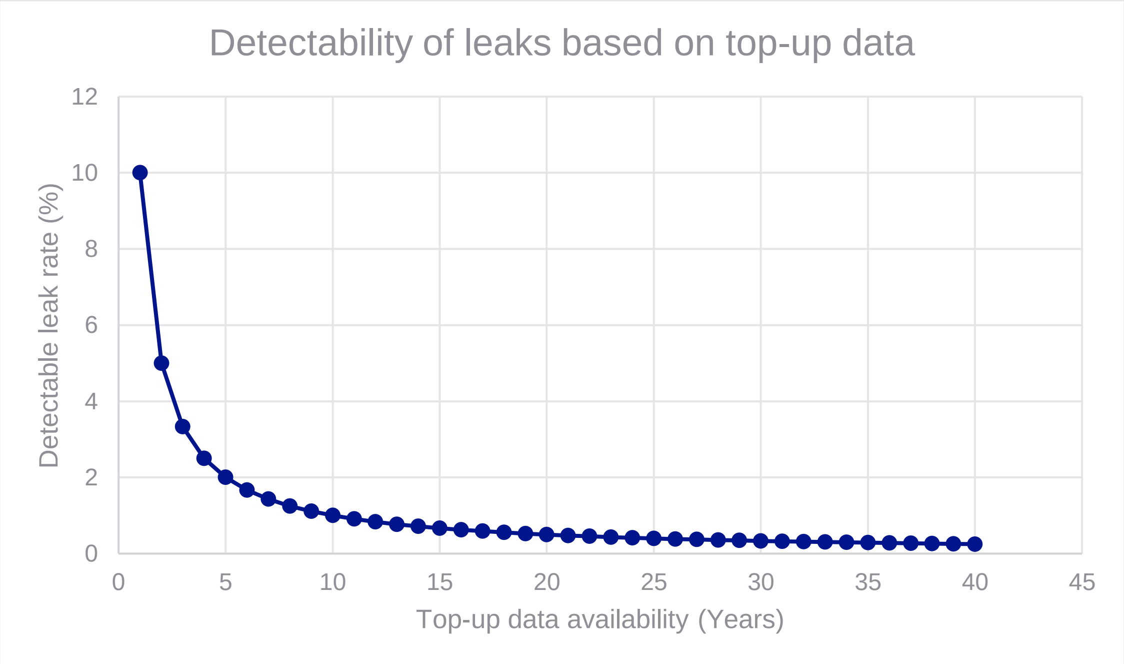


Figure 10.2 Detectability of leak rate based on top-up data

Furthermore, moderate leaks that become detectable often deteriorate rapidly such that they are emitting large quantities of SF_6 within a relatively short time from having been detected. Asset categories and families which exhibit this behaviour can be identified and this information forms part of our asset health assessment process. However, the rapid change in behaviour at an individual asset level is not predictable in terms of timing and/or severity and cannot be reliably forecast. Our forecast tends to smooth out the predicted emissions across asset groupings, giving a good estimate of aggregate behaviour whilst underestimating the development of new large leaks and overestimating the occurrence of smaller, distributed leakage.

To cater for the unpredictability of newly detected, large leaks it is vital that we retain the ability to plan the proposed works in a flexible manner such that we can react to the development of these leaks and minimise their impact upon delivery of our emission reduction targets. The proposed emission reduction works will be integrated into existing outage plans as far as practicable however we must retain the ability to re-plan in response to developments in asset behaviour.

Future re-opener & submissions

SF_6 leak abatement and emission reduction is the main driver for this submission but ensuring it aligns with the long term strategic objective of reducing the SF_6 inventory it is proposed that for future re-openers will focus on SF_6 inventory reduction and factor further maturity in the retro-fill technique as a viable option.

The extensive detail within this re-opener is expected to be used in supporting future submissions for additional allowances.

The figure 10.3 indicates the proposed focus areas of each submission.

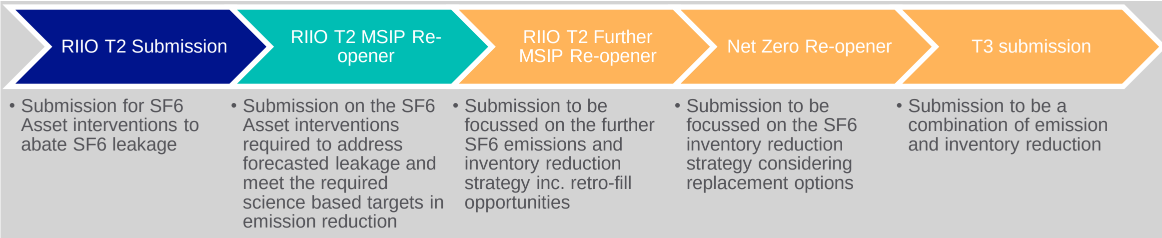


Figure 10.3 Future SF_6 submissions

Phased Net Zero SF_6 reduction approach

Reducing SF_6 inventory is a requirement for meeting Net Zero targets and the NGET responsible business charter ambition.

Whilst the primary focus of this specific proposal is leak abatement, to meet commitment targets, the long-term endeavours to abate SF_6 emissions to zero must also include specific actions addressing inventory reduction. The below graph indicates the SF_6 inventory challenge out to 2050. Assuming an ambition to eliminate SF_6 emissions from our network by this date and recognising that all transmission level SF_6 equipment has a measurable leak rate in the 0.1% to 1% range, the optimum environmental solution is to eliminate our SF_6 inventory by 2050. This however does not factor in the socio-economic and practical challenges of complete SF6 inventory elimination by 2050.

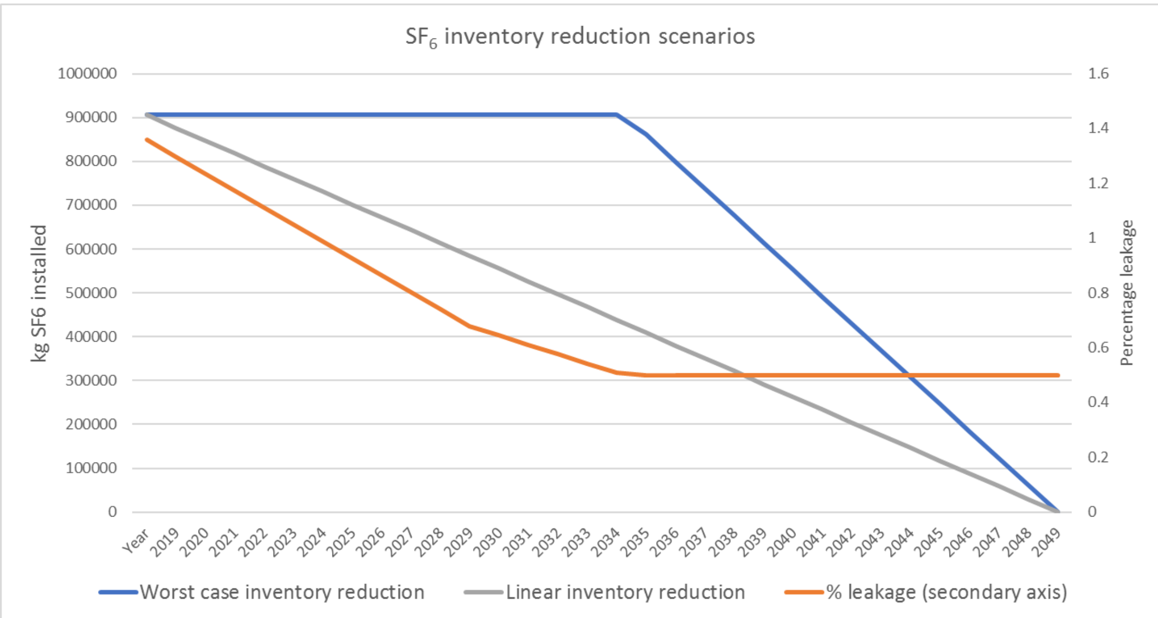


Figure 10.4: SF_6 inventory reduction scenarios towards net-zero (2050)

Based on a linear trajectory from today this equates to the net removal of ~30 tonnes of SF_6 inventory per year (grey line of Figure 10.4). With no specific actions to remove inventory and a focus solely upon emissions reduction in accordance with SBT through leak repair and prevention there is a “designed-in” limit to the emission reduction that can be achieved. With reference to Figure 10.4, assuming a minimum achievable fleet-wide leak rate of 0.5% (orange line of Figure 10.4) and no significant reduction in inventory until this level is reached, inventory reduction becomes the only major influence upon emissions from 2036 onwards (blue line of Figure 10.4). Under this scenario the annual inventory reduction target is approximately doubled to ~60 tonnes per annum. Neither of these scenarios represent an accurate forecast of future developments however it is clear that greater early focus upon inventory reduction is essential.

However, the volumes of sites and mass of SF_6 inventory required to achieve reduction at this scale for achieving the 2050 ambition needs to be correctly assessed, developed, and phased to ensure its reduction is optimised, balancing the economic and environmental factors.

The phasing of the inventory reduction plan will need to include, but is not limited to, consideration of the below factors.

- Future customer connections
- Network design changes of the transmission system
- Connected 3rd party asset strategies
- Land arrangements and options
- Wider asset portfolio health and plans
- Future legislative or regulatory requirements
- Modelling of alternative gases and impact on global warming

An initial mapping of the SF_6 inventory reduction required has been completed showing the differences in masses per 5 yearly periods. The use of the label ‘constrained’ or ‘unconstrained’ relates to meeting a 2050 deadline or not. Figure x below outlines some initial inventory reduction scenarios, however, further work is required to fully detail all the relevant scenarios and the trade-offs which need to be assessed to form the plan development

- An unconstrained view of natural attrition based on asset end of life
- A constrained to 2050 (Net Zero) view based on removal as late as possible

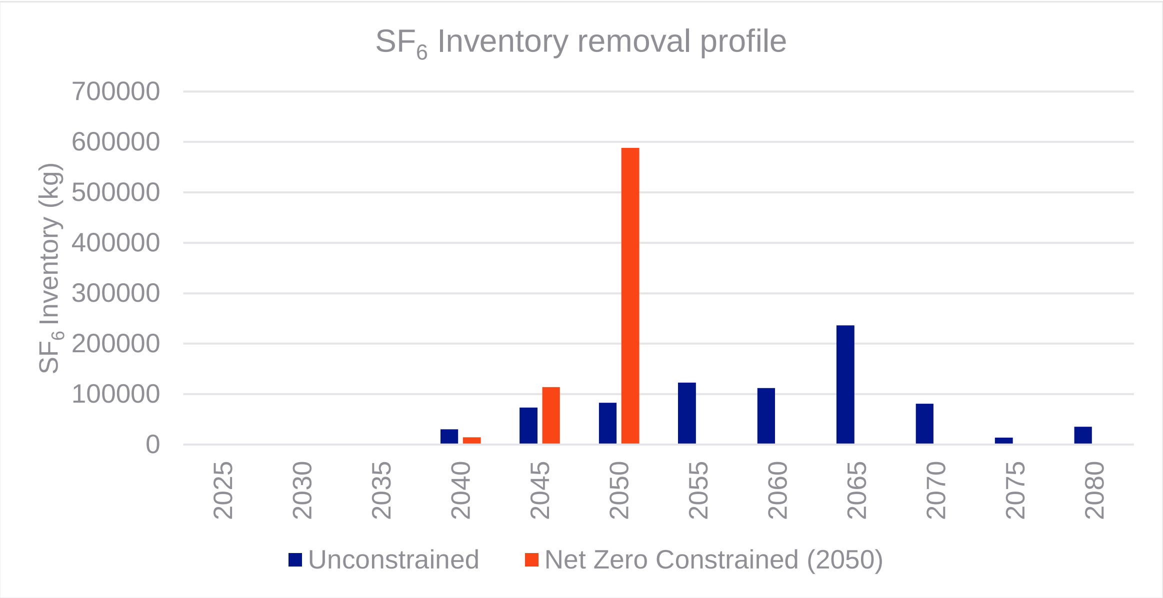


Figure 10.5 SF_6 inventory removal profile – comparison scenario

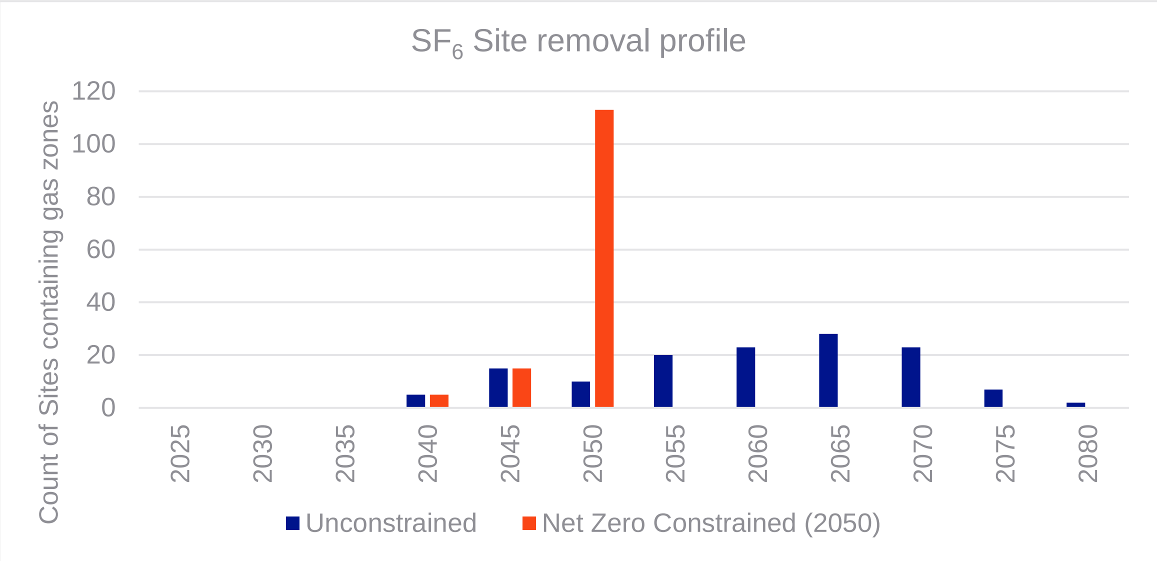


Figure 10.6 Count of SF_6 sites requiring inventory removal – comparison scenario

The volumes of site replacements and inventory reduction required, if retaining the replacement to as close to end of life for the assets as possible, would be un-deliverable due to the resource, outage and stock required across the transmission system.

Whole site replacements can take several years to complete due to the system access and system security requirements around phasing the transfers of circuit from the old site to the new site.

133 sites contain SF_6 filled gas zones, which would require a run rate of 5 sites per year to be replaced or intervened on to remove the inventory from 2026 to 2050.

The sequencing of circuit transfers, and the multiple complex replacements require careful consideration and phasing to maintain high levels of system security and minimising system access constraints.
The geographical map in the needs case section provides a visual of the regional sensitivities that need to be factored, an example of this is the London region which has a several sites with large SF_6 inventory installed

An update to the development and progress of the phasing and long term SF_6 reduction strategy will be included within future submissions. This will allow further analysis and optimisation of options and engagement across wider industries and stakeholders on different scenarios.

Initial mapping of the SF_6 reduction strategy and plan development framework:

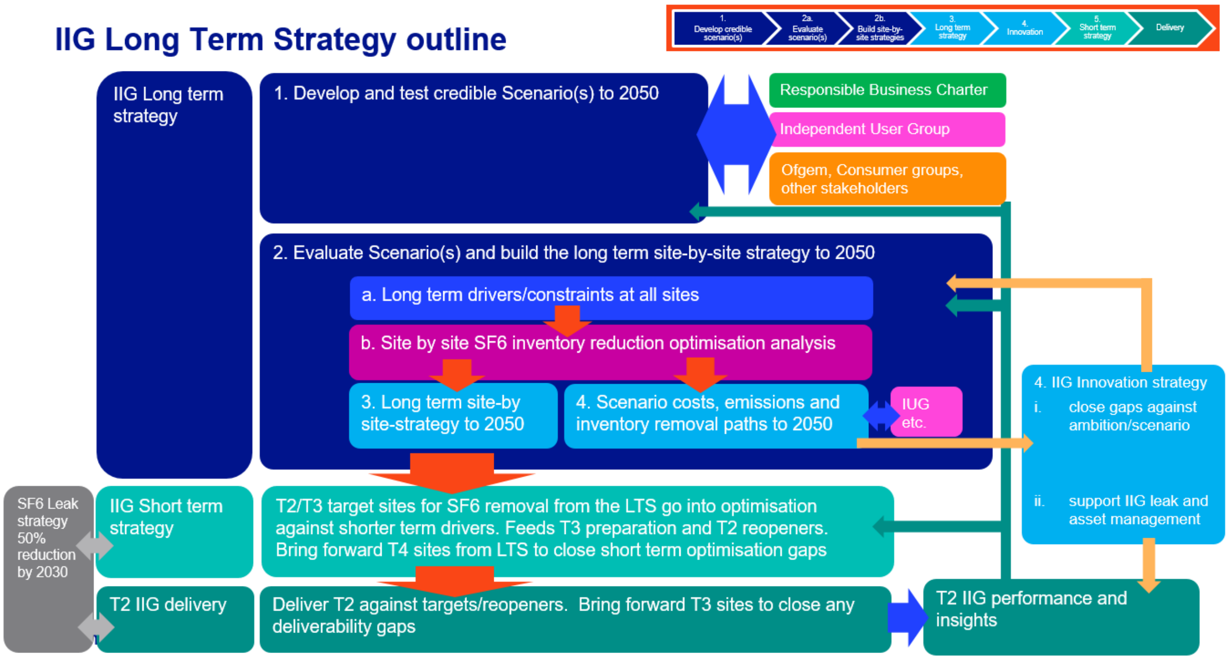


Figure 10.7 Draft long term strategy plan mapping for IIG

11. Price Control deliverables and ring fencing

T2 existing Outputs

This submission builds on the existing price control deliverable SF_6 Asset Intervention Plan. It also considers the other T2 Outputs where there is SF_6 interactions to ensure no overlap or conflicting driver with them. Based on this the proposal in this document only covers assets not funded through existing allowances.

The T2 outputs with SF_6 interactions include:

- **SF_6 Asset Intervention – Price Control Deliverable**

10 sites are currently listed and funded under the existing SF_6 asset intervention output.

Table 6: Site-Specific Asset Interventions

Site	Output	Delivery Year
Osbaldwick	Gas Insulated Busbar (GIB) Refurbishment	2022
Eaton Socon	Targeted Refurbishment	2024
Eggborough	Targeted Refurbishment	2023
Rassau	Gas Insulated Switchgear (GIS)/GIB Refurbishment/Resealing	2023
Dinorwig	Targeted Repair	2022
Northfleet East	GIS/GIB Refurbishment	2025
Lackenby	GIB Refurbishment	2024
Littlebrook	GIB Refurbishment	2024
Sizewell	Targeted repair in T2 (replace in T3)	2026
Norton	GIB Refurbishment	2025

Figure 11.1 List of SF_6 Asset intervention sites

- **NGET A9.03 – CB – Portfolio circuit breaker replace/refurb (AHR_CBR_NRM)**

40 SF_6 gas circuit breakers are currently funded under the NARM output. There is no change to the below funding, output, or assets. The list of assets is detailed in the annex section T2 Existing Outputs, NGET A9.03 – CB – Portfolio circuit breaker replace/refurb (AHR_CBR_NRM)

- **NGET A9.05 - Instrument Transformer (AHR_INT_PCD)**

123 AIS SF_6 Current Transformers are currently funded under the Instrument Transformer PCD output. (named assets & family condition funding). Part of this proposal is to increase the funding and delivery of 5 Functional Position CT's by replacing a further 10 physical item CT's. This adjustment would replace all the SF_6 CT's linked to the functional position where currently it is just funded for 1 or 2 physical items to the functional position.

These assets are listed below:

Funding Mechanism	Asset Plant Number (FP)	IDP Name	T2 RIIO Code	OFGEM Scheme Reference (OSR) Submitted in Sept 2020 Submission	Intervention Delivery Year
PCD's - Mechanistic	[redacted]	NGET_A9.05_Instrument Transformer	AHR_INT_PCD	NGNLT20234	2024-25
PCD's - Mechanistic	[redacted]	NGET_A9.05_Instrument Transformer	AHR_INT_PCD	NGNLT20234	2021-22
PCD's - Mechanistic	[redacted]	NGET_A9.05_Instrument Transformer	AHR_INT_PCD	NGNLT20234	2024-25
PCD's - Mechanistic	[redacted]	NGET_A9.05_Instrument Transformer	AHR_INT_PCD	NGNLT20234	2021-22

PCD's - Mechanistic	[redacted]	NGET_A9.05_Instrument Transformer	AHR_INT_PCD	NGNLT20234	2021-22

Table 11.1 List of SF_6 current transformers in the instrument transformer PCD

This will then fully remove the SF_6 inventory from that assets functional position. The assets affected are also coloured blue in the annex listing all the existing T2 PCD current transformers. Further detail is provided in the current transformer EJR. There is no change to the other output or assets.

- **NGET A9.03 – CB – SF_6 Repairs (AHR_SF6_BSL)**

80 SF_6 gas circuit breakers are currently funded under the SF_6 repair asset health baseline output. There is no change to the below funding, output or assets. The list of assets are detailed in the annex section T2 Existing Outputs, NGET A9.03 – CB - SF_6 Repairs (AHR_SF_6_BSL).

- **Palliative Works**

£3.3m funding has been allocated for palliative works under the repairs and maintenance sub-category in Network Operating Costs. This re-opener proposes no adjustment to the existing funding or assets listed in this funding.

The list for the total selected assets for palliative coatings is taken from the IDP A11.09-9. It shows the asset ID, SF_6 Inventory, Fitment Date & Indoor/Outdoor status in the annex section T2 Existing Outputs, Palliative works.

- **[redacted] – Large Onshore Transmission Investment**

The [redacted] project is the construction of an offline greenfield rebuild of the Harker 132kV (incl. 132kV overhead lines) and 400kV substations, and the rationalisation of the 275kV substation for completion in 2026 using SF_6 alternative technology.

This is in line with the strategy and proposal in this document for reducing the existing SF_6 emissions and inventory located in the 400kV substation.

This re-opener proposes no adjustment to the existing funding.

- **[redacted] – Large Onshore Transmission Investment**

This investment involves the delivery of the [redacted] and substation replacement project. The [redacted] 400kV cable circuits require replacement. There is a history of poor reliability on these cables and the asset health condition data supports replacement by 2026 to reduce risk on the network.

A robust options assessment and cost benefit analysis (CBA) demonstrates that the development of a three-circuit XLPE single core per phase cable system and acceleration of the 400kV substation replacement by 2026 is the most economic and efficient solution providing whole life cost benefits to consumers.

To maintain system resilience during construction, the third cable will be built offline and commissioned in May 2024. To accommodate this third cable, one third of the substation must be replaced by 2024 and there is currently no SF_6 alternative option commercially available. National Grid have considered several of options and are proposing to install an SF_6 hybrid solution. This will install clean air technology for non-active parts and SF_6 on the active parts. This reduces the SF_6 inventory at [redacted] by 68% from 16,020kg to 5,112kg and lowers the SF_6 leakage.

- **Projects adding SF_6 to the existing asset base:**

There are several projects adding additional SF_6 on to the asset base of the transmission system within T2 to facilitate customer connections whilst alternative technology isn't available. The timescale for alternative SF_6 technology is detailed within the options strategy section and will be a key focus within the long term strategy for phasing these new assets for replacements as part of the Net Zero target which will be detailed in future submissions.

There is no proposed funding or interventions on the new SF_6 assets from customer connections projects in this submission.

Ongoing Project deliverables:

There is ongoing work in the replacement/removal of SF_6 assets at the below sites. The replacement of SF_6 assets for newer SF_6 assets will be modelled within the forecast. As the assets at these sites will be new there is no proposed funding or interventions on these assets within T2.

- [redacted]

12. Stakeholder engagement and whole system opportunities

The below stakeholder engagement sections provide a summary on the engagements which relate to this reopener detailing how it supports the proposal across several different areas.
It highlights the stakeholders view on priority for the reduction of NGET emissions, it shows the engagement across the wider engineering and asset management communities for innovative ways in identifying, reducing, and preventing emissions and continual support in understanding the technology landscape for SF_6 alternatives and the ability to achieve net zero.

We will continue our stakeholder engagement through RIIO-2 and beyond to continual review and act on feedback provided. Some of the future stakeholder engagements scheduled includes:

- Engaging the IUG on our Net Zero strategy
- Engaging with stakeholders to understand consumers willingness to pay for net zero scenarios
- Engaging the wider SF_6 community on the forecasting methodology and sharing knowledge on the development of the model

Stakeholder Informed

During our RIIO-2 engagement, we spoke to our stakeholders to understand their views about our impact on the environment, including carbon emissions and local impacts, and the improvements we could make. Our stakeholders, especially consumers, told us they want us to take ambitious action on climate change, and potentially use carbon offsetting to make relevant activities carbon neutral as well as maximising responsible use of assets. We should reduce the overall mass of SF_6 leakage and continue efforts to find alternative insulating gases.

In 2019, our consumer survey also indicated that reducing emissions is almost as important as safety and reliability. With no associated costs indicated at the time of testing, 60% of consumers want us to be a “net zero business” by 2030 or 2040, with younger citizens and women being the most supportive. Some consumers said they would also prefer our efficiency savings to be channelled into environmental investments.

Our stakeholders also wanted us to make investment decisions based on the whole-life cost of each option, including the cost of carbon emissions, and use this approach to help minimise our overall carbon emissions. Our SF_6 investment plan has been designed to take these stakeholder requirements into account.

Engagement with TO’s

We engage with other UK TO’s, UK DNO’s and the wider TO community both directly and through structured forums.

We have established a small SF_6-related steering group between the three UK TO’s. This group has two key focus areas; to direct and manage the innovation activities we are progressing through EIC relating to SF_6-management and to ensure that our respective innovation projects in the field of SF_6-alternatives are complementary and deliver outputs that are broadly applicable.

We are actively engaged in the relevant activities of the Energy Networks Association (Switchgear Assessment Panel, SF_6 Strategy Group) and ENTSOE (SF_6 and Alternative Gases Working Group) to share knowledge, gain insights from the activities of other TO/DNO’s,and advocate the widespread early adoption of SF_6-free technologies in a risk-managed manner.

Legislation, Standards and International Knowledge Development (IEC/CIGRE/IEEE)

We participate directly in a variety of international activities specific to this field including the following:

CIGRE WG A3.41: Interrupting and switching performance with SF_6 free switching equipment

CIGRE WG B3.45: Application of non-SF_6 gases or gas-mixtures in MV & HV gas-insulated switchgear (Completed)

CIGRE WG B3/A3.60: User guide for non-SF_6 gases and gas mixtures in Substations

IEC TC10/WG41: Mixtures of gases alternative to SF_6 and their re-use

IEC TC17/WG10: High-voltage switchgear and controlgear - Part 320: Environmental aspects and life cycle assessment rules

IEEE C37.100.7: Guide for the qualification of SF_6-alternatives in switchgear

These, in conjunction with more general engagement with the preparation of international standards and guidance, make us well placed to make informed & timely decisions regarding the risk-managed early adoption of SF_6-free technologies.

We are also participating in the evidence gathering and pre-legislation activities of the DEFRA power sector group, F-gas team.

Energy Innovation Centre (EIC)

We have collaborated with the other UK TO's to run a call for innovation through EIC relating to "Tools to Manage Sulphur Hexafluoride". This includes aspects such as leak detection, leak location, leak prevention/mitigation/repair. Whilst the call for innovation did not bring forward anything of major interest that we were not already aware of and engaged with, we are now working across the TO's to establish the best way forward regarding those innovations that are of common interest.

Independent User Group (IUG)

We will be presenting our SF_6 emissions & inventory reduction plans to our Independent User Group as part of our wider environmental and Net Zero commitments. We are actively engaging the IUG for feedback on our plans and our strategy for reducing inventory to support achieving net zero.

Engagement with Original Engineering Manufacturers (OEM's)

We are in close contact with the leading suppliers of SF_6-free solutions regarding their product development timelines and are co-ordinating these with our asset replacement & construction plans to ensure the use of SF_6-free solutions wherever possible. Our latest view of these timelines is reflected in the Technology Availability section within the intervention strategies.

We are also working closely with them on retro-fill and conversion opportunities for existing SF_6-filled gas-insulated busbars which we will be able to deliver during T2 providing that they are cost-effective in the long term.

Engagement with Ofgem

We have been in regular discussions with Ofgem sharing the progress of our compiled re-opener proposal, development of the data forecast model, engagement updates across the TO's and the insights into the development for our SF_6 inventory reduction strategy.

- 20th December 2021 – Draft submission of re-opener & engineering justification reports
- 9th December 2021 – Continued discussion on SF_6 data modelling & governance
- 24th November 2021 – Discussion on SF_6 data modelling & governance
- 16th November 2021 – Review of progress and proposed SF_6 Re-opener content
- 12th November 2021 – Review of SF_6 master spreadsheet and portfolio scenarios

- 26th October 2021 – Discussion on long term strategy for SF_6 inventory reduction
- 1st October 2021 – Discussion on option assessments for assets
- 23rd September 2021 – Discussion on data modelling and leakage forecast output
- 21st September 2021 – Overview of SF_6 comparison and discussion with other TO’s
- *7th September 2021 – Knowledge share of data model forecast and interventions with other TO’s*
- 24th August 2021 - Overview of SF_6 inventory, commitments, and asset health
- 12th May 2021 - Ofgem Engineering Meeting – Leadership update on alternate technologies
- 4th April 2021 – [redacted] Solar Deep Dive on the use of SF_6
- Monthly meetings from 6th April 2021 to cover SF_6 updates including forecasting development

13. Overview of assurance and point of contact

The content and details within this submission have been assessed and checked for quality, alignment, and assurance across the below areas:

- Unit cost data & cost details
- CBA accuracy
- Forecast data used and alignment to model outputs
- Assessment on data analysis and data inputs
- Existing RIIO-2 outputs (cost and assets) assessment

The senior persons in National Grid have provided confirmation of the assurance checks performed:

14. Annexes

	Description
Glossary	
Engineering Justification Reports	List of the Engineering Justification reports supporting the MSIP re-opener
Asset level SF_6 forecast methodology	Technical report detailing the modelling methodology
T2 Existing Output tables	List of the outputs already detailed within the RIIO-2 deliverables
T1 Asset Condition and Performance	Summary of the T1 approach to SF_6 leak reduction and performance
Ofgem Guidance Checklist	A summary of the location of each item requested within the guidance
Cost Benefit Analysis	Table view of the cost benefit analysis of SF_6 leak abatement for societal benefit based on the latest HMRC green book for carbon price
Cost Model and Supplier Quotes	Cost model summary table and various quotes received from Suppliers
External Reports & References	Links to external reports on the details of SF_6 and contribution to global warming
Gas Zone diagram	A visual relationship of the gas zone diagram and design of a gas zone

Table 14.1

Engineering Justification Reports

Below is a list of the Engineering Justification Reports detailing the considerations, intervention options and costs for each one.

Each EJR will have a supporting Cost Benefit Analysis associated to it.

- [redacted] Substation SF_6 Interventions
- [redacted] Substation SF_6 Interventions
- [redacted] Substation SF_6 Interventions
- [redacted] Substation SF_6 Interventions

[redacted]

- Air Insulated Gas Circuit Breaker Intervention Portfolio
- Current Transformer Intervention Portfolio

Asset level SF_6 forecast methodology

T2 existing Outputs

The below file is a list of SF_6 assets with existing T2 outputs.

T1 Asset Condition and Performance

Our SBT is based on 2018/19 actual leakage giving a benchmark value of 12,268 kg. This value differs from the value reported for the same period in Business Plan Data Table A6.5 (11,588 kg), which requires reporting of leakage from only those assets commissioned on the NGET system at the time of the completion of that Table. Assets which may have leaked but have been removed from the system within the reporting period are excluded from the A6.5 values, as required by Ofgem. All future/forecast analysis in this proposal is based upon actual emission data to be consistent with our SBT. As requested by Ofgem, all historic emission reporting presented in this paper is based upon A6.5 data. At the network level the difference between real emission and A6.5 emissions is approximately 5.5%. However, for the specific sites mentioned in this proposal, where no significant inventory changes have taken place, real and A6.5 emissions do not differ. As such the use of real or A6.5 emission data has no material impact upon these proposals.

Graph below shows NGET SF_6 emissions over the T1 period in the context of inventory growth, non-load replacement of leaking assets, and a programme of repair interventions. Following a fall from 2013 to 2014 there has been a consistent upwards trend from 2014 to-date. From this data, we conclude that perpetuating the existing status-quo approach will not deliver the considerable year-on-year reductions that are required to achieve our SBT. We predict that if we maintain a T1 status-quo approach to SF_6 emission abatement (i.e. perpetuate the focus primarily on fixing leaking assets) emissions will increase significantly in future years (see forecasting section).

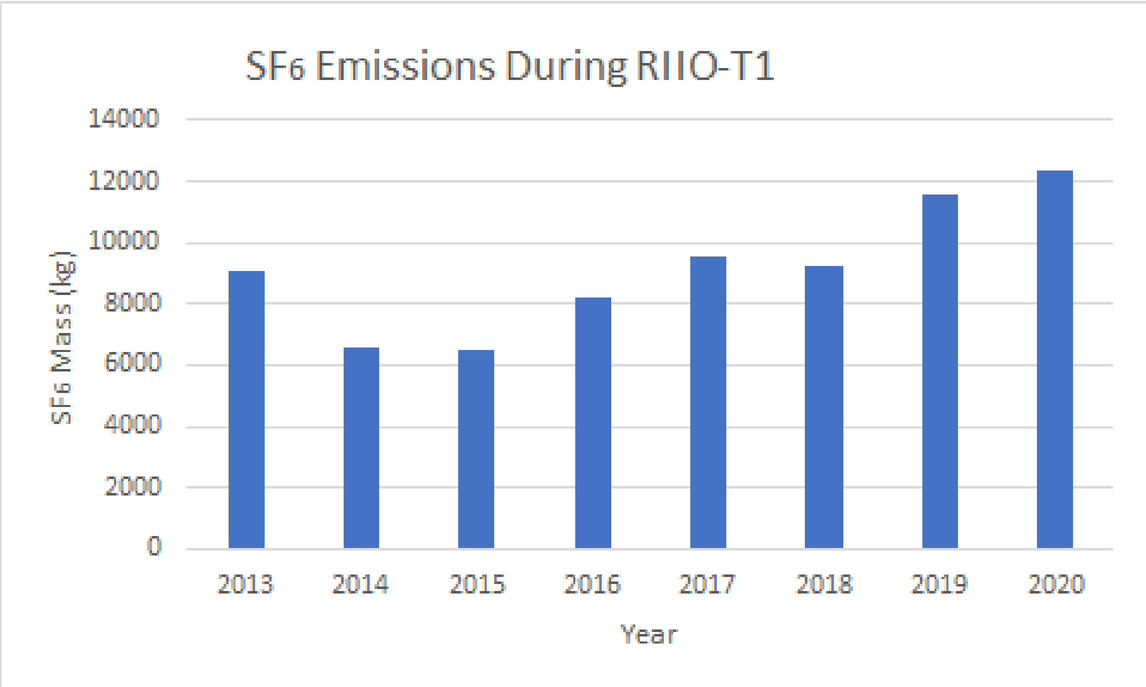


Figure 14.1: NGET annual SF_6 emissions during RIIO-1 period

During RIIO-1, we have improved collation and reporting of SF_6 emissions and have established a programme of SF_6 repairs to mitigate loss of SF_6 to the atmosphere. The approach in T1 was a reactive approach based on repairing leaks means an ongoing loss of SF_6 in the period between leak detection and leak repair. Such an approach is therefore fundamentally unsuitable to achieve long-term abatement of SF_6 emissions to levels consistent with equipment design values. To prevent the development of unacceptable leak rates, a proactive approach to SF_6 emission abatement is required that embodies the need to forecast asset leak performance and make timely, pre-emptive interventions.

SF_6 emission data gathered during the RIIO-1 period is now sufficiently complete and detailed to form the basis of an SF_6 forecasting capability.

Ofgem Guidance Checklist

Guidance Reference	Guidance Name	Reference Notes
2.2 – 2.3	Assurance Requirements	See assurance letter appended to this submission pack
2.4 – 2.6	Publication & redaction	Submission to be published here before the 5th February: https://www.nationalgrid.com/uk/electricity-transission/about-us/business-plan
3.1 – 3.3	Readability, structure & detail	Throughout this document, detail has been provided to offer Ofgem sufficient information to assess the application. The executive summary has been written to summarise the request in a short self-contained format.
3.4	Glossary of terms References and annexes linked	See page 110 of this document
3.5	Table that maps out the relevant reopener requirements	Ofgem Guidance Checklist within the annexes of the reopener document
3.6	Gas Distribution	N/A
3.7 – 3.11	Demonstration of needs case	See pages 12-15 of this reopener document
3.12	Optioneering	Generic optioneering information is included in this document on pages 59 - 75
3.13 - 3.16	Preferred option description including delivery plan	Preferred option details and delivery plans are included in each individual site EJR
3.17	Stakeholder Engagement	This is included in section 12 on page 102 of this reopener document
3.18 – 3.21	Detailed cost information	• Included in executive summary and cost assessment (page 52) sections of the main reopener document • Within 'The preferred option and detailed costs' section of the individual EJR documents • Within the separate CBAs and the UM cot template
3.22 – 3.33	Cost benefit analysis	• CBAs are included with the reopener pack as separate documents • The CBA narrative and details are also included in section x of the individual EJR

Table 14.2

Cost Benefit Analysis

The table provides a societal impact view in £ based on the SF_6 leakage (kg) per year.

This uses the latest 2020 HMRC green book values for carbon price aligned with the Ofgem CBA model.

		Societal Impact (Carbon price) (£k)								
	Carbon price (£)	248.35	252.14	255.97	259.87	263.83	267.85	271.93	276.07	280.27
SF_6 (kg)	**tCO2e (*23.5)**	2022	2023	2024	2025	2026	2027	2028	2029	2030
1	23.5	£5.84	£5.93	£6.02	£6.11	£6.20	£6.29	£6.39	£6.49	£6.59
2	47	£11.67	£11.85	£12.03	£12.21	£12.40	£12.59	£12.78	£12.98	£13.17
3	70.5	£17.51	£17.78	£18.05	£18.32	£18.60	£18.88	£19.17	£19.46	£19.76
4	94	£23.35	£23.70	£24.06	£24.43	£24.80	£25.18	£25.56	£25.95	£26.35
5	117.5	£29.18	£29.63	£30.08	£30.54	£31.00	£31.47	£31.95	£32.44	£32.93
6	141	£35.02	£35.55	£36.09	£36.64	£37.20	£37.77	£38.34	£38.93	£39.52
7	164.5	£40.85	£41.48	£42.11	£42.75	£43.40	£44.06	£44.73	£45.41	£46.10
8	188	£46.69	£47.40	£48.12	£48.86	£49.60	£50.36	£51.12	£51.90	£52.69
9	211.5	£52.53	£53.33	£54.14	£54.96	£55.80	£56.65	£57.51	£58.39	£59.28
10	235	£58.36	£59.25	£60.15	£61.07	£62.00	£62.94	£63.90	£64.88	£65.86
11	258.5	£64.20	£65.18	£66.17	£67.18	£68.20	£69.24	£70.29	£71.36	£72.45
12	282	£70.04	£71.10	£72.18	£73.28	£74.40	£75.53	£76.68	£77.85	£79.04
13	305.5	£75.87	£77.03	£78.20	£79.39	£80.60	£81.83	£83.07	£84.34	£85.62
14	329	£81.71	£82.95	£84.22	£85.50	£86.80	£88.12	£89.46	£90.83	£92.21
15	352.5	£87.54	£88.88	£90.23	£91.61	£93.00	£94.42	£95.85	£97.31	£98.80
16	376	£93.38	£94.80	£96.25	£97.71	£99.20	£100.71	£102.24	£103.80	£105.38
17	399.5	£99.22	£100.73	£102.26	£103.82	£105.40	£107.01	£108.63	£110.29	£111.97
18	423	£105.05	£106.65	£108.28	£109.93	£111.60	£113.30	£115.03	£116.78	£118.56
19	446.5	£110.89	£112.58	£114.29	£116.03	£117.80	£119.59	£121.42	£123.26	£125.14
20	470	£116.73	£118.50	£120.31	£122.14	£124.00	£125.89	£127.81	£129.75	£131.73
21	493.5	£122.56	£124.43	£126.32	£128.25	£130.20	£132.18	£134.20	£136.24	£138.31
22	517	£128.40	£130.35	£132.34	£134.35	£136.40	£138.48	£140.59	£142.73	£144.90
23	540.5	£134.23	£136.28	£138.35	£140.46	£142.60	£144.77	£146.98	£149.21	£151.49
24	564	£140.07	£142.20	£144.37	£146.57	£148.80	£151.07	£153.37	£155.70	£158.07
25	587.5	£145.91	£148.13	£150.39	£152.68	£155.00	£157.36	£159.76	£162.19	£164.66
26	611	£151.74	£154.05	£156.40	£158.78	£161.20	£163.66	£166.15	£168.68	£171.25
27	634.5	£157.58	£159.98	£162.42	£164.89	£167.40	£169.95	£172.54	£175.17	£177.83
28	658	£163.42	£165.90	£168.43	£171.00	£173.60	£176.24	£178.93	£181.65	£184.42
29	681.5	£169.25	£171.83	£174.45	£177.10	£179.80	£182.54	£185.32	£188.14	£191.01
30	705	£175.09	£177.76	£180.46	£183.21	£186.00	£188.83	£191.71	£194.63	£197.59
31	728.5	£180.93	£183.68	£186.48	£189.32	£192.20	£195.13	£198.10	£201.12	£204.18
32	752	£186.76	£189.61	£192.49	£195.42	£198.40	£201.42	£204.49	£207.60	£210.76
33	775.5	£192.60	£195.53	£198.51	£201.53	£204.60	£207.72	£210.88	£214.09	£217.35
34	799	£198.43	£201.46	£204.52	£207.64	£210.80	£214.01	£217.27	£220.58	£223.94
35	822.5	£204.27	£207.38	£210.54	£213.75	£217.00	£220.31	£223.66	£227.07	£230.52
36	846	£210.11	£213.31	£216.55	£219.85	£223.20	£226.60	£230.05	£233.55	£237.11
37	869.5	£215.94	£219.23	£222.57	£225.96	£229.40	£232.89	£236.44	£240.04	£243.70
38	893	£221.78	£225.16	£228.59	£232.07	£235.60	£239.19	£242.83	£246.53	£250.28
39	916.5	£227.62	£231.08	£234.60	£238.17	£241.80	£245.48	£249.22	£253.02	£256.87
40	940	£233.45	£237.01	£240.62	£244.28	£248.00	£251.78	£255.61	£259.50	£263.46
41	963.5	£239.29	£242.93	£246.63	£250.39	£254.20	£258.07	£262.00	£265.99	£270.04
42	987	£245.12	£248.86	£252.65	£256.49	£260.40	£264.37	£268.39	£272.48	£276.63
43	1010.5	£250.96	£254.78	£258.66	£262.60	£266.60	£270.66	£274.78	£278.97	£283.21
44	1034	£256.80	£260.71	£264.68	£268.71	£272.80	£276.95	£281.17	£285.45	£289.80
45	1057.5	£262.63	£266.63	£270.69	£274.82	£279.00	£283.25	£287.56	£291.94	£296.39
46	1081	£268.47	£272.56	£276.71	£280.92	£285.20	£289.54	£293.95	£298.43	£302.97
47	1104.5	£274.31	£278.48	£282.72	£287.03	£291.40	£295.84	£300.34	£304.92	£309.56
48	1128	£280.14	£284.41	£288.74	£293.14	£297.60	£302.13	£306.73	£311.40	£316.15
49	1151.5	£285.98	£290.33	£294.76	£299.24	£303.80	£308.43	£313.12	£317.89	£322.73
50	1175	£291.82	£296.26	£300.77	£305.35	£310.00	£314.72	£319.51	£324.38	£329.32

Table 14.3

Cost model and supplier quotes

Below is the cost model breakdown used for the proposed GIS interventions.

Gas Zone Unit Cost																
2021/22 Price	Base		364.5	433.5	415.8	415.8					500	1000			21/22 prices	18/19 prices
			Resource NG				Resource 3rd Party		actor Hardware / Equip		Other / Ancillaries				Total	
Intervention	Description	Duration (weeks)	SAP (364.50)	CE (433.50)	Development (inc. Survey) (415.80)	PM (415.80)	Contractor Resource	Competent Person	Other (inc. Gas Handling)		Scaffolding	MEWP	Crane	Total		
Wrap	3 Phase		[redacted]	N/A	[redacted]	[redacted]	[redacted]	[redacted]		[redacted]	[redacted]	[redacted]	N/A	[redacted]	[redacted]	[redacted]
Refurbishmen	Small - 3 Phase	8	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Refurbishmen	Medium - 3 Phase	12	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Refurbishmen	Large - 3 Phase	20	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Bushing Repla	3 Phase	6	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Figure 14.2

The cost model above was derived from NG cost libraries (extracted from historic work), NG internal cost book (for internal resource costs) and supplier quotations. A selection of Supplier quotations are given below.

Project Delivery Key Milestones

Below are the high-level milestones for each site.

Key:

(blue)	Optioneering
(green)	Development & Design
(gold)	Delivery

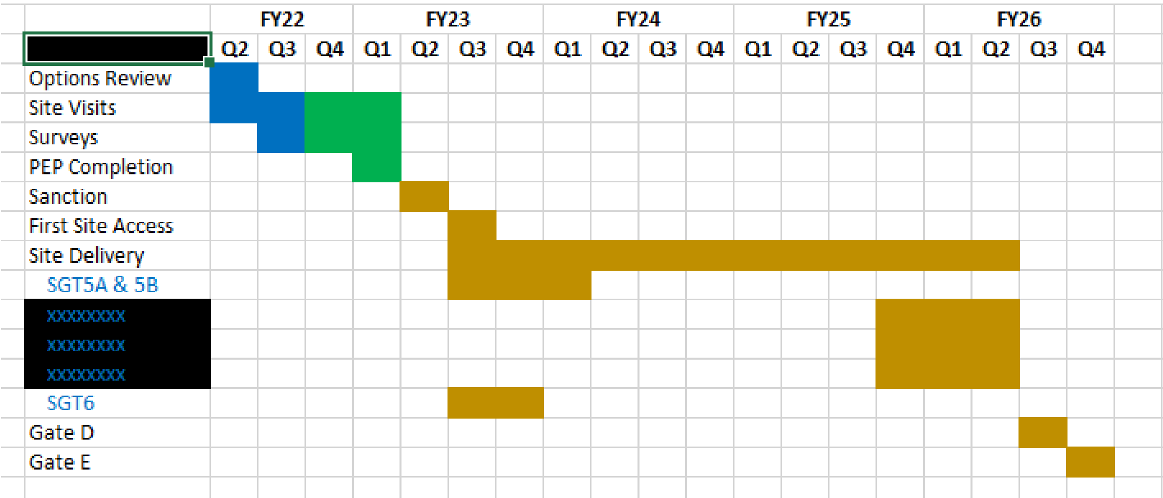


Figure 14.3

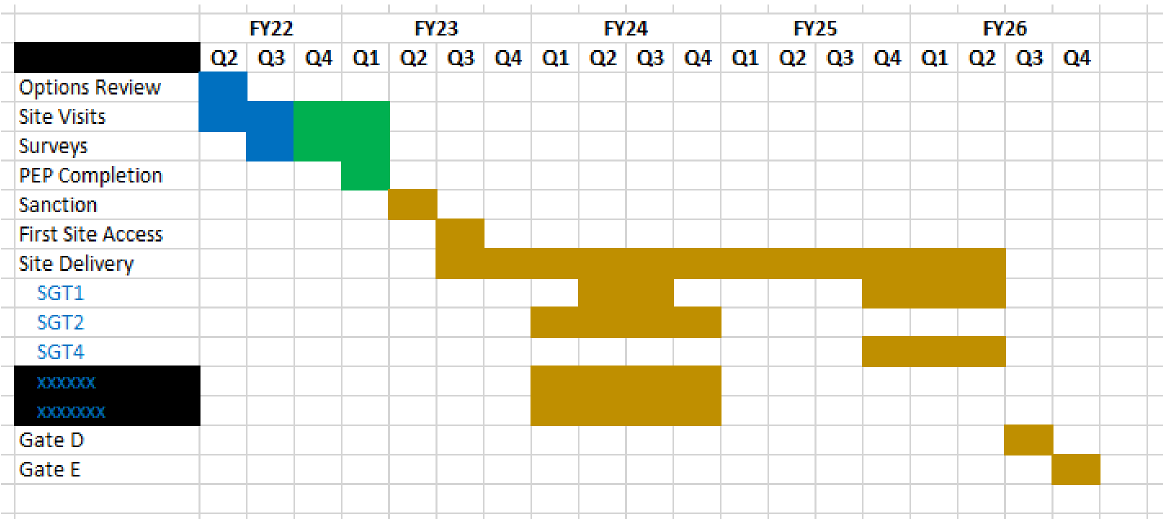


Figure 14.4

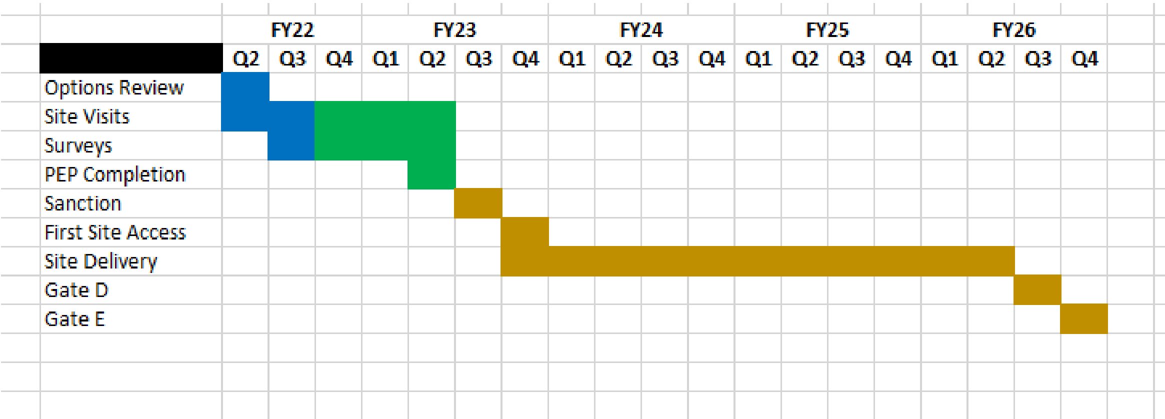


Figure 14.5

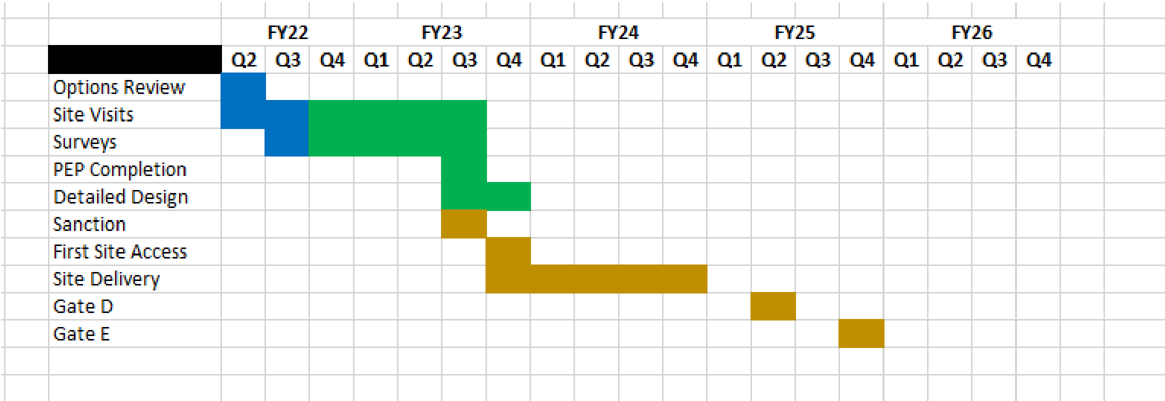


Figure 14.6

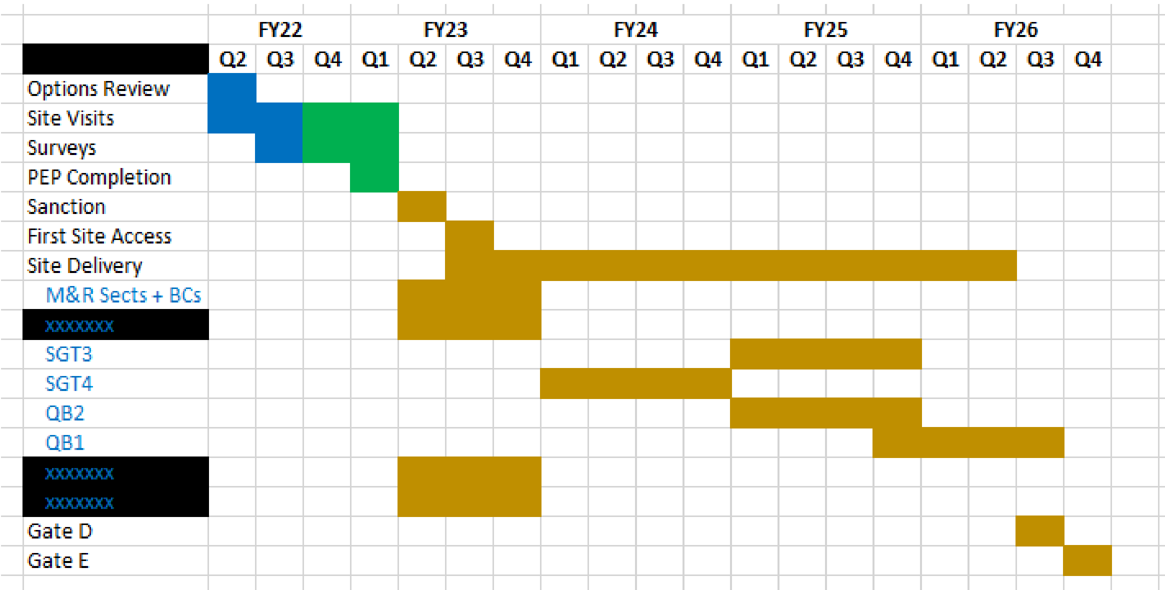


Figure 14.7

External references

Below is a list of external reports and references which have supported the detail within the re-opener.

Climate Change Committee - the sixth carbon budget on F gases – https://www.theccc.org.uk/wp-content/uploads/2020/12/Sector-summary-F-gases.pdf

Energy Networks Association explanation of SF_6 - https://www.energynetworks.org/industry-hub/resource-library/environment-briefing-01-sulphur-hexafluoride.pdf

Green House Gas protocol detailing gases GWP values - https://www.ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf

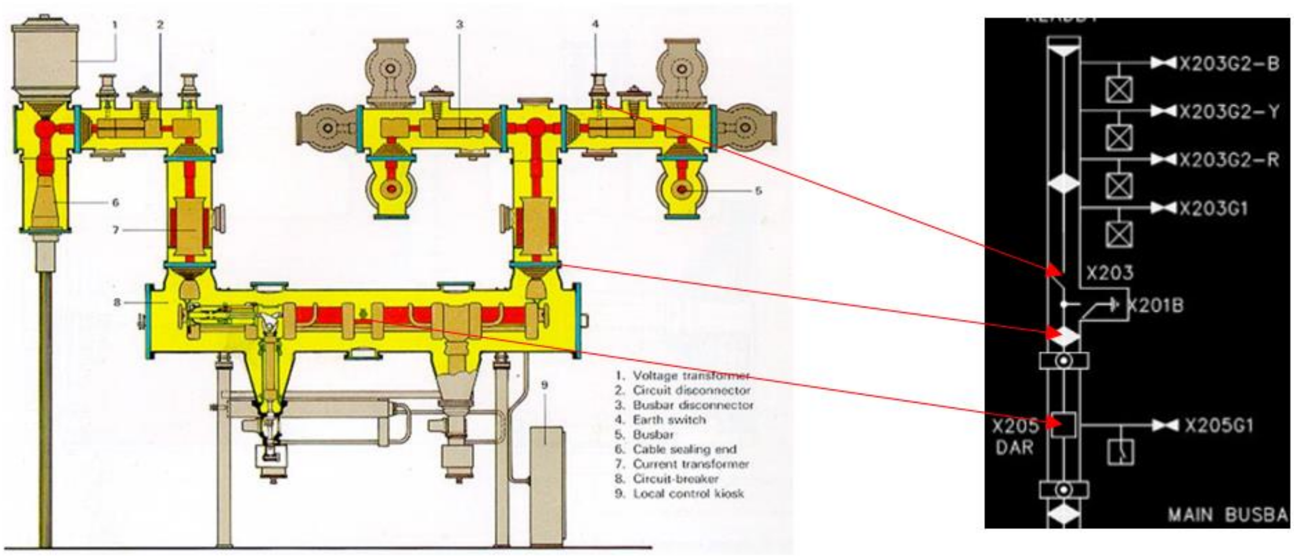
F-gas regulations – https://www.gov.uk/government/collections/fluorinated-gas-f-gas-guidance-for-users-producers-and-traders

Climate Change Act 2008 – https://www.legislation.gov.uk/ukpga/2008/27/contents

5 things about climate change and net zero that matter to the public - https://traverse.ltd/application/files/9816/4181/6289/Five_things_about_climate_change_and_net_zero_that_matter_to_the_public_-_Traverse_1.pdf

Empowering climate action – in brief (ESO report on public view of UK's climate agenda) - https://www.nationalgrideso.com/document/215896/download

Gas Zone diagram



National Grid plc
National Grid House,
Warwick Technology Park,
Gallows Hill, Warwick.
CV34 6DA United Kingdom
Registered in England and Wales
No. 4031152

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