Green Grids: Tackling SF6 Emissions on GB Electricity Networks

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Grid Edge Policy
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Contents

Executive Summary

A clear commitment from GB networks to tackle SF6 leakage

SF6 is a highly potent, long lived industrial greenhouse gas with a global warming potential (GWP) 25,200 times that of carbon dioxide. Widely deployed over many decades in electrical switchgear, including in electricity networks, it has been favoured by the industry for its technical properties as an effective electrical insulator and in preventing short-circuits.

On climate grounds, a wide-scale reappraisal is under way of the use of SF6 in electrical equipment. Not least, the equipment can leak, adding to greenhouse gas emissions.

The GB networks have made clear commitments to reduce their levels of SF6 emissions from leakage over the next five years. They also have longer-term commitments to eliminate SF6 by 2050, aligning with the UK's statutory requirement for net-zero greenhouse emissions by 2050. Thinking is more advanced on the high-voltage transmission networks, which is important because transmission (as a result of its scale) accounts for 93% of SF6 leakage from the regulated GB networks.

All the GB networks have committed to adopt science-based targets (SBTs) to align their trajectories for greenhouse gas reduction with a global warming potential below 1.5 degrees. Their commitment to SBTs is driven both by strategic considerations, including investor interests, and also by pressure from the regulator Ofgem and wider stakeholders. Ofgem has also put financial incentives on transmission networks to reduce SF6 leakage but they are not particularly effective. In practice, it is their near-term science-based targets which are driving network commitments to reduce SF6 leakage. In particular, National Grid Electricity Transmission and SSEN Transmission have each committed to a one-third reduction in SF6 emissions by 2026 from a 2018/19 baseline.

The well-understood need for the GB networks to control and reduce their business carbon footprint sits alongside unprecedented demand for network growth and system reinforcement in the next 5-10 years. The UK government expects 50 GW of new offshore wind to connect to the transmission networks to deliver on its stated goal of a fully decarbonised grid by 2035 (ie all generation to be zero carbon). Huge expansion of the GB distribution networks is also anticipated to respond to the needs of electrified transport and heat. All stakeholders in GB, including environmental NGOs, presently see the lack of network capacity as a very major barrier to growth of UK renewables and net-zero delivery. With waits of ten-plus years for connections on both transmission and distribution networks, there is widespread agreement that the GB 'connections queue' is unacceptable and must be urgently addressed.

In this context the GB transmission networks are very focussed on what solutions are open to them over the next 5-10 years to allow them to deliver both the necessary network growth and at the same time to meet their SF6 commitments. As such, including through a variety of innovation projects, the networks have been at the forefront of working with manufacturers to trial different SF6-free solutions that are being developed and coming to market.

EU Regulation driving the development of SF6-free alternatives

Notwithstanding UK exit from the European Union, the updated EU F-Gas Regulation remains a key consideration in GB. The EU Regulation is close to being finalised and for the first time will introduce an outright ban on new SF6 equipment being installed, with backstop dates depending on voltage. In the latest version of the text these dates range between 2026 and 2032.

Globally, there are effectively two categories of alternatives to SF6 – those using a synthetic gas and those based on natural origin gases.

The synthetic gas products are closest in performance to SF6. Hence they are seen by the industry to offer a readily-used like-for-like alternative (including for retro-fill of existing equipment). However, synthetic gases still have a global warming potential, albeit significantly lower than SF6. There are also differences between the nitrile-based products (GWP > 2000, but less when blended) and those that are ketone-based (GWP<1). In addition, and importantly, the synthetic gases also fall into the category of PFAS ("forever chemicals") which are pervasive, break down slowly in the environment and carry health and environmental risks.

The natural origin gas products are safe (for both the environment and health) but typically require more space in terms of their physical footprint (in particular at transmission level) and hence are not necessarily suitable in every case.

The updated EU F-Gas Regulation is expected to set a GWP limit of 10 for alternative gases. This effectively limits the market for high voltage switchgear to natural origin gas solutions. However, there is currently only one EU manufacturer at transmission level (275kV / 400kV in GB) and not all types of equipment are yet available. Clearly, all major manufacturers will actively look to develop compliant products going forward although there are technical challenges with active switching equipment at higher voltages (where the requirement is around preventing arc-ing and short circuits). Although there are derogations in the Regulation if suitable alternatives are not available, the GB networks are uncertain about how these derogations would work in practice and what the best route forward is in the interim.

Following on from the EU F-Gas Regulation, Defra and the UK devolved administrations are considering how far to mirror these requirements in GB legislation. The EU Regulation is crucially important, first because it removes the historic exemptions for use of SF6 in new switchgear and second because it forces the pace on approaches to SF6 elimination in equipment maintenance, repair and replacement. The EU Regulation will therefore re-shape equipment being sold into the EU, and therefore very likely into the UK also. If UK rules were different in practice, global markets might provide alternatives, at least in the interim. Ultimately, this is a decision for the UK government but it would be a matter for regret if, over time, the UK ended up with lower climate and environmental standards for electrical switchgear than the EU.

Separately the EU is looking at introducing a blanket ban on all PFAS products ("forever chemicals") given their potential health and environmental impacts (already proven for some PFAS) and following the precautionary principle. This would preclude the use of synthetic gas-based alternatives to SF6. While policy in this area is at an early stage the uncertainty is already impacting the supply chain – and again Defra will need to consider how far to mirror any provisions in GB.

Given the proposed F-Gas Regulation and potential PFAS restrictions, manufacturers are reportedly pulling back on further development of the synthetic gas alternatives. In particular they are likely to be reticent to develop products to meet some of the niche requirements of the GB market (eg for 275kV equipment) until the policy landscape is clearer.

Stringent regulation (on F-Gases and PFAS) is key to the longer-term aim of driving the market in safe switchgear alternatives and supports the networks longer term commitments on eliminating SF6. At the same time, there are widely-reported near-term supply-chain disruptions for electrical equipment, especially high voltage – whether for cables, transformers or switchgear. This is partly due to the global slow-down but also due to the massive increase in international demand, including

in the US and EU. Faced with long lead-times on equipment procurement plus higher costs, GB networks have understandable concerns about how to square near-term supply chain challenges, including for non-SF6 alternative equipment, while at the same time securing delivery of hugely increased network capacity in accelerated timescales. If they fall short, they cannot unlock current network constraints on renewable growth which are key to the UK's 2035 grid de-carbonisation goal.

GB networks face tensions around meeting their near term SF6 targets

Given this context, how achievable the network company's near-term SF6 leakage targets are then varies by network.

National Grid Electricity Transmission (NGET) is by far the largest network, covering the whole of England and Wales, and accounts for 90% of transmission leakage. It has the oldest and leakiest asset base and as such has significant room for improvement by replacing the worst of its equipment (which Ofgem has provided funding for) and improving its asset management practices. It has been testing alternative gases for a number of years. The availability of alternatives (or the continued ability to procure SF6 equipment) is a concern for NGET in terms of maintaining existing network resilience and also to deliver the network growth required. However, these concerns do not seem critical in terms of it meeting its 2026 SF6 leakage reduction target. NGET has also been looking actively at the use of retro-filling with synthetic gas as a way to reduce its substantial SF6 bank in its existing equipment. Its ability to do this is reliant on like-for-like products being allowed in the future.

In contrast SSEN Transmission (in the North of Scotland) is starting from a strong position with a much smaller, relatively new network and low leakage rate. It also has proportionately the highest network growth rate. It is therefore heavily dependent on being able to procure suitable SF6-free equipment to meet both its near term SF6 emissions target and its network growth obligations, with Scotland a particular focus for offshore wind.

Scottish Power Energy Networks (in the South of Scotland) is again smaller with relatively high growth and sits somewhere between the other two transmission networks in terms of its leakage rate. Again it is heavily dependent on being able to procure suitable SF6-free equipment to meet its targets.

For all three transmission networks there is strong focus on their near-term goals through the current price control which runs to 2026. Medium and longer-term pathways through to 2050, and full elimination, remain unclear.

On the local distribution networks there has generally been less historic focus on SF6, with leakage targets hard to compare as they all use different baselines and formulations. The challenges here are also different with around 200,000 items of equipment that typically contain small amounts of SF6 in sealed units with extremely low reported leakage rates. There is no proposal currently to require removal of existing equipment but it is worth noting that, should DNOS need to remove all SF6 from their networks before end-of-life, this would likely be extremely disruptive, costly and deliver a limited environmental benefit in terms of emissions.

In summary, with a continued focus there are good prospects that the companies' near-term targets for reducing SF6 leakage will be met. However, there may be some companies – in particular at transmission level - where there is a real tension between delivering network growth in required timescales and meeting their near term SF6 targets. Given the UK government goal for a fully decarbonised grid by 2035 (and the Labour opposition's stated aim to bring this forward to 2030) it is

likely that the networks may focus on network growth. There are no financial penalties on the networks for failure to meet their science-based targets, the impact is purely reputational.

Conclusions – navigating a path through

GB networks

Given these tensions and trade-offs our view is that there should be two priorities for the companies:

- place a laser like focus on reducing leakage rates - and at the same time -
- collaborate with manufacturers to support the development of natural origin gas solutions that avoid any future risks around PFAS.

Continuing to innovate and share knowledge across networks is key to making progress on leakage rates. A greater emphasis on monitoring and digitalisation would open opportunities for AI and other tools to predict and better manage leakage – and allow more informed decisions about longer term pathways.

Ofgem

There is also a need for Ofgem as sector regulator to be more proactive, to put in place stronger incentives on leakage reduction and require greater transparency from the transmission networks. Ofgem should scrutinise company performance in this area as it would in others – not simply leave it to environmental and other stakeholders to hold companies to account.

Government

At a policy level, environmental regulations are key in driving the industry and manufacturers to find safer and better solutions. As a priority, in considering a future UK F-Gas Regulation, Defra and DESNZ must coordinate and chart a route through that balances the requirement to radically reduce SF6 emissions while at the same time taking account of the need for the GB networks to plan, procure and invest over the next 5-10 years to deliver on the network growth necessary to achieve 2035 grid de-carbonisation.

Consideration of wider health and environmental impacts of PFAS use in electrical switchgear is important. It is also complex given the trade-offs involved. Early work by Defra / the EU to examine the actual impacts of the particular PFAS compounds used in SF6 alternatives should be a priority, especially in light of long development and procurement lead-times and the relatively high cost and long life of energy network assets (40-years plus). If the risks of this particular PFAS compound turned out to be low it would open up more options for SF6 elimination.

In putting together this report it is clear that there is low awareness among GB stakeholders of the issues at stake. The discussions we had have been valuable in and of themselves in raising their profile. However, we are aware that this is a fast-moving area and are keen to explore ways of keeping the debate alive, in particular as Defra looks to consult on revising the UK F-Gas Regulation.

There is also a clear need for a wider debate involving networks, policy makers, environmental and other stakeholders on how transmission networks in particular should balance the tradeoffs in their investment decisions over the next 5-10 years. We hope that this report will provide a stimulus for that debate.

1. Introduction (context)

The GB networks

In this report, funded by the ClimateWorks Foundation, we were asked to address the extent to which National Grid will meet the commitments that it has made around elimination of SF6 emissions. In looking to answer this question we have looked more broadly at all the GB electricity regulated networks recognising that National Grid Electricity Transmission (NGET) is only a part (albeit a large part) of the picture. Looking at the plans and performance of these other networks also provides a helpful comparator for judging NGET's approach.

In GB the electricity grid essentially comprises:

- Transmission networks carrying electricity across the country at high voltage (275kV and 400kV, together with 132kV in Scotland)
- Distribution networks taking electricity from connection points with the transmission network to homes and businesses at lower voltages (33kV, 11kV and low voltage, together with 132kV in England and Wales).

The transmission network is provided by NGET in England and Wales, with Scotland being covered by Scottish Power Electricity Networks (SPT) and SSEN Transmission. NGET is by far the largest of these networks but with the explosion of renewable generation in Scotland, the Scottish networks are seeing enormous growth.

There are then six distribution network operators (DNOs) covering distinct geographical areas including National Grid Electricity Distribution (NGED) which is the largest of the six distribution networks.

As well as the regulated transmission and distribution networks there are a range of other networks that form part of the GB system – independent distribution networks, offshore networks (connecting offshore windfarms to the shore) and interconnectors (enabling import and export of power from other countries). All these networks also use equipment containing SF6 but there is much less information on them and they are outside the main scope of this report, although we discuss them briefly in Section 5.

Ofgem's approach to network regulation

The transmission and distribution network companies are all regulated by Ofgem which sets the revenues that they are allowed to earn as well as certain outputs that they are expected to deliver. This is done through the RIIO[1] price control process. Following engagement with their stakeholders the companies submit Business Plans for the upcoming period (typically 5 years) setting out details on their proposed investment plans and operational costs. Following further engagement, benchmarking and consultation on its draft proposals, Ofgem sets out its final decision on baseline revenue allowances and how these can be adjusted within period to deal with uncertainty. Ofgem can require specific outputs to be delivered or provide financial incentives for improved performance in key areas. Companies then report to Ofgem on an annual basis.

[1] RIIO: Revenues = Incentives + Innovation + Outputs

The most recent transmission price control RIIO ET2 covers the period April 2021-2026 with the distribution control ED2 running from April 2023-2028. The various submissions made by the companies, together with Ofgem's decisions, were a key resource in preparing this report.

Section 2 sets out the ways in which Ofgem's regulatory framework deals with SF6 as context for the companies' individual plans which are summarised in Section 5.

SF6 – What it is and why it matters

SF6 is a potent greenhouse gas with a Global Warming Potential of 25,200[2] based on the latest IPCC figures (looking at the effect compared to CO2 over a 100-year period). SF6 is also stable which means it is a very long-lived gas with an atmospheric life of 3200 years. With growing awareness of the impacts of SF6 emissions and the imperative to tackle climate change, there is increasing focus on reducing and ultimately eliminating SF6 emissions.

The stability of SF6 also means that it has been widely used in electricity networks because it has good insulating properties and helps prevent arc-ing (or short circuits).

The scale and type of equipment involved varies by voltage level as set out clearly in the 2020 EU Commission review[3]. At transmission level the equipment is on a large scale including GIS (gas insulated switchgear) at sub-stations where there are interconnections between transmission lines or power is being stepped up / down between voltages. Here SF6 is used as an interrupting gas within the switching components and circuit breakers where it plays a vital safety role in extinguishing any electric arcs that can be created when circuits are switched. Larger volumes of SF6 are used for insulation in busbars, (to which electrical connections are made throughout an installation) and other gas insulated lines (GIL) that are in effect large pipes containing the connectors and insulating gas. Small amounts of SF6 are also used as insulation in current transformers.

On the distribution network, as well as smaller versions of these substations, the companies will each have many tens of thousands of items of equipment such as pole mounted transformers (atop wooden poles in rural areas).

While the equipment is designed to be as secure as possible, SF6 can and does leak, in particular from larger non-sealed equipment as it gets older. It is this SF6 leakage that is the immediate concern from a climate perspective but there is also a need to think longer term about how to safely eliminate SF6 from the networks to avoid any risk of future greenhouse gas emissions in a net zero world. End of life disposal is also a significant issue that is under-explored.

In the past, the lack of suitable alternatives meant that electricity networks were exempted from the requirements under the 2014 EU F-Gas Regulation which banned the use of such gases. However, this is now set to change. A new EU Regulation is close to being finalised which will bring the networks into scope. This in turn may have a knock-on impact on GB networks and their ability to meet their near-term SF6 leakage commitments and deliver the network growth needed over the next 5-10 years to support the government ambition for growth in renewables.

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[2] This is the latest figure from the IPCC AR6. DESNZ greenhouse gas reporting requirements (June 2023) still use the IPCC AR5 figure of 23,500.

[3] Report from the Commission. 'Assessing the availability of alternatives to fluorinated greenhouse gases in switchgear and related equipment, including medium-voltage secondary switchgear'. Brussels, 30.9.2020 - C(2020) 6635 final - https://climate.ec.europa.eu/system/files/2020-09/c_2020_6635_en.pdf

As the UK is no longer a member of the EU, Defra will be bringing forward its own Regulation which could in theory deviate from the EU requirements, although EU rules will still shape what EU manufacturers offer and hence what is available for GB networks to procure.

The EU and Defra F-Gas Regulations are explored more fully in section 3 below and the implications for the networks' near-term SF6 targets are explored in section 5.

Current levels of SF6 emissions from GB networks

Total SF6 emissions from the GB networks in 20/21 are shown in the table below which shows that transmission accounts for 93.2% of leakage and NGET accounts for 90% of transmission emissions. A focus on National Grid ET's actions is therefore justified.

Network	SF6 leakage (kg)	% of total leakage
NGET	11700	84.2%
SP T	775	5.6%
SSEN T	476	3.4%
Total transmission	12951	93.2%
Total distribution	940	6.8%
Total networks	*13891*	100%

Source: 20/21 – Ofgem ET1 / ED1 annual reports – supplementary data tables – published Sept 22

Of the distribution networks total, National Grid Electricity Distribution (NGED) accounted for 40% of leakage and 27% of bank. Bank figures are not provided for transmission in the Ofgem ET1 report.

Together NGET and NGED accounted for 87% of network SF6 emissions in 20/21 – a total of 12081 kg or 284k tCO2e.

Although SF6 is highly potent, the volumes involved are small compared to CO2 emissions. Overall SF6 emissions from switchgear accounted for around 2% of UK F-Gas emissions in 2016[4] and total SF6 emissions account for around 0.4% of UK greenhouse gas emissions[5]. However, for the networks SF6 accounts for the vast majority of their business carbon footprint and is therefore a focus for them. The long-lived nature of SF6 in the atmosphere provides a further reason for a strong focus on the issue[6].

What commitments have the transmission networks made on SF6 as part of their RIIO Business Plans?

The transmission company Business Plans in relation to SF6 are explored more fully in section 5. In headline terms they all have both near term commitments to reduce leakage and, except for SPT, a longer-term commitment to remove all SF6 from their networks by 2050. Specifically, for transmission:

[4] Source – Ricardo Energy report for the CCC

[5] DESNZ Final UK greenhouse gas emissions national statistics 1990-2021

[6] For climate reporting the impacts of SF6 are calculated using the GWP over a 100 year period. The impacts of its longer life are not taken into account as highlighted by Kristjan Jespersen of Copenhagen Business School who talks about "3100 years of environmental harm unaccounted for".

NGET has an ambition to eliminate all SF6 from its infrastructure – and therefore reduce SF6 emissions to zero – by 2050, with an interim target of reducing emissions by 50% over this decade. They have a specific target to achieve 33% reduction in annual emissions by 2026 from a 2018/19 baseline in line with their science-based target.

SSEN Transmission's ambition for T2 is to significantly reduce leakage as part of their contribution to a 33% reduction in carbon (linked to their science-based target) – made more challenging by the growth in the network envisaged for T2. They aim to reduce leakage to 0.15% by the end of T2 and to remove all SF6 from their network by 2050.

Scottish Power Energy Networks Transmission (SPT) note that modern assets are designed with inherent leakage of 0.5% (international standard) - and commit to procuring equipment with half this rate of leakage. They also commit to only use SF6 where alternative solutions are not viable. They do not have a specific leakage reduction target as they manage their science-based targets at a group level.

Wider GB net zero context

Grid de-carbonisation driving transmission investment: UK government has set a target to decarbonise the electricity grid by 2035 ie to reach a position where all generation is renewable / zero carbon[7]. To support this, they have set a target for 50 GW of offshore wind by 2030 with significantly increased levels of onshore wind, nuclear and solar as well. To connect all this new generation requires extensive new offshore connections and massive investment to upgrade and extend the onshore network to carry the power to where the demand is located.

Following an assessment by the Electricity System Operator of the network upgrades needed to support the 50GW of offshore wind, Ofgem has now agreed additional transmission network investment of £19.8bn through its Accelerated Strategic Transmission Investment programme (on top of the £8.8bn baseline allowances agreed as part of the normal RIIO price control process). In GB, around four times as much new transmission network will be needed in the next seven years as was built since 1990[8]. With generators now facing connection delays of 10 years or more the task of reinforcing the grid is seen by all stakeholders, including key environmental groups,[9] as increasingly urgent.

2050 net zero goal driving distribution network investment: Similar challenges arise at distribution network level where the required move to electric vehicles and heat pumps again requires massive investment at all levels of the distribution network to cope with the increased loads involved. In Scotland the net zero target date (set in legislation) is 2045.

[7] The Labour party have ambitions to bring this forward to 2030 if elected next year
[8] Electricity Networks Commissioner Companion Report (June 2023) - here
[9] See for example Greenpeace - https://www.greenpeace.org.uk/news/pool-party-at-rishis-sparks-law-promising-upgrades-to-grid-for-renewable-energy/

2. Ofgem's approach to network regulation including SF6

Treatment of SF6 in RIIO ET2

Ofgem's RIIO ET2 framework, which determines the revenues and deliverables for the transmission networks, includes a number of elements which encourage and support a focus on SF6: the requirement for science-based targets and for companies to have an SF6 strategy, annual reporting requirements, a financial incentive to reduce leakage, specific funding for major investments and innovation funding. These are discussed in turn below.

Science-based targets

One of the new requirements that Ofgem placed on companies (in both ET2 and ED2) was that they should have science-based targets relating to their own emissions. Given that SBTi requires companies to have separate targets for scope 1 and scope 2 emissions and with SF6 accounting for up to 98% of scope 1 emissions for transmission, this has been the main driver of the stretching targets that the transmission companies have set themselves for reducing emissions through to 2030.

While the prompt for companies to set science-based targets was that it was a requirement of Ofgem, the fact that these are externally accredited gives them a wider resonance and investors in particular can be expected to help in holding companies to account for delivering against these commitments (which will also be covered by new requirements from the Taskforce on Climate-Related Financial Disclosures). This is important as there is nothing in the Ofgem framework (or more widely) that imposes any penalties if these ambitions are not met.

Environmental Action Plans and SF6 Strategies

The other "reputational" element in the RIIO ET framework was a requirement on companies to produce an Environmental Action Plan, including an SF6 strategy. The quality of the SF6 strategies varied considerably between companies.

They then have to produce an Annual Environment Report (AER) for stakeholders setting out their progress against this Action Plan. Again, these reports have been a valuable resource in producing this report. However, for transmission there is no standard framework for the AERs (beyond overall leakage figures) and companies all look to highlight the positive aspects of their performance, which makes objective comparisons difficult.

IIG Incentive

Since 2007 there has been an incentive on transmission networks to reduce SF6 emissions. This is known as the Insulation and Interruptions Gas (IIG) Incentive. In ET2 this provides a financial incentive (reward / penalty) for the networks to reduce emissions below a baseline level set by Ofgem.

While a helpful part of the overall package, the IIG incentive on its own would no longer be enough to drive the scale of change required. It under-values the emissions savings that are delivered (as it is based on an outdated cost of carbon) and there are complex interactions with the wider SF6 actions that companies are undertaking which make its workings less transparent. Further details are given in Box 1 below.

Box 1: The mechanics of the IIG Incentive

For ET2 the baseline was set based on the company leakage % in the previous price control (2013-20) and an agreed improvement rate, as follows:

SHET	0.38%	
SPT	0.79%	(based on 4% improvement)
NGET	1.18%	(based on 10% improvement)

This leakage rate was applied to the bank at the end of ET1 to derive a baseline leakage level (in kg) against which actual performance is compared.

The incentive rate (reward / penalty per kg) is set based on the non-traded cost of carbon and taking account of the GWP of SF6. However, when the price control was set the cost of carbon used was only £74/tCO2 – a third of what it is now - which means actions to reduce SF6 are under-valued[10].

The baseline is also adjusted on an annual basis to take account of any new installations, removals or work that is funded in other ways through the price control. These adjustments will become increasingly important going forward and make the incentive more complex and less transparent.

Companies are also allowed to apply for adjustments for what are termed "exceptional events" where there is a significant leakage that is considered to be outside of their control. In 2022 SHET were allowed an adjustment following the sudden failure of a new item of equipment which resulted in the leakage of 34 kg. In 2019 NGET had applied for an exceptional event for a major leak which they argued was a manufacturing flaw but where Ofgem took the view that earlier detection of low level leakage would have avoided the major failure. Ofgem therefore did not allow this as an exceptional event. Overall this is a proportionate approach, which still encourages lessons to be learned from these major events, with manufacturers held to account through contractual arrangements.

Investment funding

The final important strand in the RIIO framework is the approach that Ofgem takes to deciding whether or not to allow expenditure on asset replacement or other actions aimed at reducing SF6 emissions. This was a particular challenge for ET2 as the companies started to work through what would be required for them to meet their science-based targets in this area. The companies varied in how much SF6 specific investment they were seeking and ultimately Ofgem did not allow all the funding that was requested but did create mechanisms for companies to come back mid-period if they could justify additional expenditure. Again, the CBA framework that Ofgem prescribed for ET involved the use of a now out-dated cost of carbon (which made the task of justifying expenditure more challenging). However, our understanding is that companies are now able to use the government's updated figure that aligns with net-zero if they are submitting additional proposals in-period.

Further detail on what the companies included in their plans and Ofgem's decisions on those plans are set out in Section 5.

[10] The licence wording refers to using Treasury Green book values so it may now be updated but Ofgem were unable to confirm when we spoke to them

Innovation funding

One feature of the RIIO regime (for transmission and distribution) is that it provides funding for innovation projects in support of the transition to net zero with requirements for learning to be shared across network. Innovations in this area could include partnering on establishing viable SF6 alternatives or methods for improving asset management (monitoring, data-handling, leak-detection, sealing, capping).

Treatment of SF6 in the ED2 Framework

In part reflecting the lower levels of emissions on the distribution networks, SF6 has not had the same focus given to it in the ED2 Framework as there was in ET2. Despite arguments made by the charity Sustainability First, Ofgem did not introduce an equivalent to the IIG incentive for distribution. The distribution companies are required to have science-based targets but this provides a weaker driver in distribution (because SF6 is a smaller element of their carbon footprint which is dominated by losses where emissions will naturally fall as the grid decarbonises). The companies were required to have SF6 Strategies but as Sustainability First highlighted these were of very variable quality ranging from a few paragraphs to standalone documents. However, most of the companies are now starting to look at options for SF6 alternatives – in particular faced with the significant network growth they expect over coming years.

While the companies typically requested some additional funding in their Business Plan for the incremental costs of using SF6-free equipment this was either not allowed or it was unclear if it was.

In particular SSEN-Distribution included a proposal in its Business Plan to replace some of its most leaky assets. This was initially rejected by Ofgem, but then allowed at Final Determination. Sustainability First raised concerns about Ofgem's use of the out-dated cost of carbon which meant that projects that could have been justified were not included in the company plans. And unlike in transmission there is no equivalent of the MSIP mechanism for proposals to be put forward mid-period unless there is a change in legislation.

The big issue for the DNOs is around the asset management challenge of dealing with around 200,000 individual items of small-scale equipment, mostly sealed, that may ultimately need to be removed and which none of their strategies addressed (but which needs thinking about in terms of cost, operational impacts, disposal).

One strength of the ED framework compared to transmission is that Ofgem has been much more prescriptive about what has to be included in the Annual Environmental Reports including information on the number of assets, the bank of SF6 and leakage broken down by voltage level with narrative descriptions around arrangements for disposal etc. While the first reports are not due until autumn 2024, they should help shine a light on these issues.

3. Current state of F-Gas Regulations and manufacturer offerings

EU F-Gas Regulation

The EU is currently finalising its far-reaching update to the earlier 2014 F-Gas Regulation. Having been considered by the Commission, European Parliament and Council of Ministers the Regulation is now going through the Trilogue negotiation process with the final text, expected later this year.

Based on the latest text at the time of writing (the Council text of 5 April 2023[11]), the Regulation introduces a series of timetabled bans on the use of SF6 – plus alternative fluorinated gases with a global warming potential (GWP) over 10 - for new electrical switchgear at both transmission and distribution voltages. The prohibitions will start from January 2026 and vary by voltage - as set out in Article 13 - and summarised below:

Voltage	**Primary / Secondary**	**End-Date[12] for GWP > 10 - – but also see derogations.**
<24 kV	D	**1 Jan 2026**
>24kV - <52kV	D (primary / secondary)	**1 Jan 2030**
>52kV - <145kV	D (primary) T in Scotland – ie up to 132kV	**1 Jan 2028**
>145 kV	T	**1 Jan 2032**

Stringent regulation is key to the longer-term aim of driving the industry and the market to develop safe SF6-free alternatives. As such, the updated F-Gas Regulation is a measure likely to align with the longer term targets of the GB networks to eliminate SF6 (and other greenhouse gases).

At the same time, in a GB context, there are issues around the near-term impacts. The choice of back-stop dates draws on the Commission 2020 report (and its associated studies) about the likely market availability of alternative technologies. Our discussions with industry actors raise some specific questions about current availability of alternatives and how the market will develop.

At high voltages on transmission, alternatives are being tested but are still some way off mainstream production. There are presently no manufacturer offerings at 275kV (which is GB specific) and the limit of a GWP of 10 restricts the market for equipment at 400kV to only one EU manufacturer. For

[11] [11] 8162/23 ENV 357. CLIMA 189. CODEC 572. 'Proposal for a Regulation of the European Parliament and of the Council on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014 - Mandate for negotiations with the European Parliament'. Swedish Presidency text. 5 April 2023 - https://www.consilium.europa.eu/media/63509/st08162-en23.pdf
Since this report was completed, a revised text has been agreed between the Council and the European Parliament but we have not reflected those revisions here.

[12] The end-date in the Regulation is currently expressed in terms of when the equipment is brought into operation rather than when the equipment is purchased. Given the long lead times for commissioning high voltage equipment this would significantly bring forward the effective end date.

GB, this would preclude the switchgear technologies that have been the subject of major pilots at transmission level over the past 5 years.

At distribution level there are more options but some questions about the full availability of products that are suitable for the GB market. This operates at different voltages from the EU, including at low voltage [13]. Physical space was a particular concern where distribution equipment is located in an enclosed or constrained space.

A key message is that this is not simply a question of the voltage level. Rather, there is a range of equipment-types at every voltage. Some equipment-types are easier to address with alternatives than others. For example, at transmission-level the insulation function in busbars is easier to deal with than the safety protection requirements around electrical arc-ing in the switches themselves. With a relatively small market for certain GB-specific equipment, manufacturers are unlikely to prioritise work to develop SF6-free alternatives for that equipment. Pole-mounted transformers at low distribution voltages was one example we were given, 275kV equipment was another.

There are derogations to these end dates. In particular the Regulation has time-bounded carve-outs for equipment procurement if alternatives are not commercially available. There are also derogations for energy efficient equipment – with lower lifecycle CO2 emissions from operations than alternatives (5d). At this stage questions remain around how these derogations would work in practice. Further, there is a natural reticence by industry to pursue options that look to be subject to future bans. Given long procurement lead-times, this creates some very difficult near-term choices.

As part of their annual environmental reporting of their scope 3 emissions, the GB networks are now also required by Ofgem to report on embodied carbon. Therefore, in assessing alternatives to SF6 the GB networks must now also take account of the embodied carbon costs of the equipment. For example, with larger equipment the embodied carbon in the increased steel and other materials may outweigh the carbon benefit of moving to that alternative despite a relatively lower GWP. Accounting for embodied carbon in the scope 3 emissions of the electricity network supply-chain is an evolving area, and standardised approaches are still some way off.

There are also other aspects of the Regulation that may have direct impacts for the asset-management approaches of the GB transmission and distribution companies – especially should Defra choose to mirror these provisions directly in their own update of the GB F-Gas Regulation[14]. These relate to:

1. **Spare parts** - future access to spare parts containing SF6 is again date-limited (Article 11) where the current Council drafting includes spare parts albeit with a complex derogation which allows for their use provided it does not increase the capacity of F-Gas. The wording here is important. Stringent regulation on spare parts could perhaps result in stepping-up equipment replacement. At the same time, it may also reduce flexibility to repair or refurbish leaking equipment where that is a better near-term solution.
2. **Gas recycling** - a ban from 2035 on use of 'virgin' SF6 gas for maintenance / servicing / top-up of existing equipment (Article 13) meaning that only recycled or reclaimed SF6 can be used in the maintenance, service and repair of <u>existing</u> switchgear equipment. Currently, recycled gas is more expensive than 'virgin' but the 2035 ban could create a market for recycled gas which could potentially support the case for replacing older, larger items of SF6 equipment (and recycling the gas). It could also provide a route for maintaining and / or life-extending newer equipment.

[13] In particular 11kV at distribution is GB specific

[14] The EU F-Gas Regulation will apply directly in Northern Ireland

3. **GB as a third country** – although the updated F-Gas Regulation will not directly apply to the UK, we will nonetheless be impacted through the rules around the basis of trade, import/ export certification etc. Where there are additional responsibilities for reporting it is assumed that the competent authority would be the Environment Agency (or equivalents in Scotland / Wales) as now.

One point to stress is that although the new F-Gas Regulation introduces an end-date for installation of new SF6 equipment, it does not introduce an explicit bar on the continued operation of existing equipment that contains SF6. Of course, rules around replacement parts or refill, for example, could ultimately force the pace on the need to remove and replace existing equipment. But, absence of a requirement for SF6 removal in existing equipment allows flexibility and enables the networks to plan for meeting their long-term targets on SF6 elimination at reasonable cost.

The process of developing the updated EU F-Gas Regulation has involved extensive debate including the networks (through their trade body Eurelectric), manufacturers and environmental groups.

A group of 10 environmental NGOs in their Position Paper[15] published last year, emphasised that bans are the most effective way to reduce F-Gas emissions and drive the development of alternative solutions. In particular they called for a 2030 end-date, a low GWP threshold and also for an earlier ban on the use of recycled and reclaimed gas. They highlight the issues with PFAS (discussed further below) and argue, on the precautionary principle, for PFAS not be used as an alternative to SF6.

Manufacturers have different positions dependent on their current portfolio. In particular a coalition of manufacturers of natural origin gas equipment (led by Siemens Energy but otherwise all at distribution level) are actively supporting a zero emissions, zero PFAS approach and also highlighting the operational benefits these products bring. Their claims around product availability and the future product roadmap have given confidence to those looking for more ambition in the Regulation.

We return to these issues in Section 6 in our discussion of the barriers to the networks' near term commitments on SF6 being met.

Defra - GB F-Gas Regulation

In December 2022, Defra, the Scottish and Welsh Governments published their 126-page GB assessment of the 2014 F-Gas Regulation.[16] This touched only minimally on the power sector and use of SF6 in electrical switchgear, simply noting that SF6 is widely used and that here are no prohibitions or legislative mechanisms in the 2014 F-Gas Regulation to reduce the use of SF6 in new equipment in this sector, although leakage prevention, gas recovery and technician training requirements are applicable.

Defra have separately been engaging with industry on how they might update the F-Gas Regulation and how far they might mirror or diverge from the EU Regulation. They are planning to publish a more formal consultation later this year or early next. One key consideration in any new UK

[15] https://eia-international.org/wp-content/uploads/NGO-Position-on-EU-F-Gas-Regulation-Proposal-27-June-2022.pdf

[16] F-Gas Regulation in Great Britain. Assessment Report. DEFRA, Scottish and Welsh Governments. December 2022. Pages 71-72. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1126230/F_gas_regulation_in_Great_Britain.pdf

Regulation will be how far there are specific requirements of the GB market and the implications, including trade-offs, for the 2035 grid de-carbonisation commitment and ultimately the 2050 net zero target. It is unclear whether government will need primary legislation to introduce a new Regulation but if so that would extend the timescales.

How far divergence from the EU Regulations would have any practical impact depends in part on UK treatment as a Third Party. EU manufacturers will wish to retain their GB customers but will not want – and indeed probably would not be able – to offer different solutions into the GB market. GB networks could of course look to a wider global market if the particular needs of the GB market are not being met in the phase-out timeline set out at EU level. Indeed, EU manufacturers may also look to diversify outside the EU if they see a wider market opportunity.

The Committee on Climate Change in its most recent progress report to Parliament argued that Defra should implement Regulations that are at least as strict as the EU. While this ambition is important, and ultimately we would not want to see lower standards in GB, the near-term implications for network growth and the 2035 grid de-carbonisation target will also need active consideration. The derogations linked to availability of alternatives are important in managing this trade-off.

Alternative technologies – manufacturer offerings

Manufacturers and research institutes have worked to develop alternatives to the use of SF6 in the power sector and as a result there are now a number of options available. One of the challenges with finding suitable alternatives to SF6 is its effectiveness as an insulating gas enabling a smaller footprint than many of the present alternatives.

The alternatives available are broadly broken down between in-kind and not-in-kind technologies as set out in the Defra document.

In-kind options (or "technical gas alternatives") use lower GWP insulating gases, which function in a similar fashion to SF6. This includes fluorinated ketones and fluoronitrile (C4-FN) blends, which are lower GWP F-gases not explicitly covered by the current F-Gas Regulation (but whose use is likely to be curbed by the proposed new EU Regulation on the basis of their GWP).

In-kind options are available on the market for certain high voltage applications (at 132kV and 400kV), which can also work at lower voltage. Options include:

- GE's g3 Green Gas for Grid (that uses 3M's Novec 4710[17] - a C4-FN product)
- Hitachi's EconiQ (a C4-FN solution which can also be used for retrofill).

These solutions, which have been the focus of the major pilots at transmission level over the past 5 years, have a GWP that is a fraction of that of SF6 (in particular once blended with air) but above the GWP limit of 10 in the current version of the F-Gas Regulation.

At distribution level there is a wider range of options (as the lower dielectric strength[18] of fluorinated ketones is less of an issue at lower voltage). As well as the products listed above these include:

[17] Novec 4710 and 5110 were produced by 3M who have pulled out of the market for all PFAS products (although their switchgear use was only a small element). Alternatives are being sought.
[18] Which is what matters in terms of prevent arc-ing / short circuits

- ABB's SafePlus (using Novec 5110 a fluorinated ketone) offered at 24kV with a GWP of less than 1.

In most cases the solutions being installed today are still seen as pilots and solutions for some particular equipment types are still not available. Manufacturers' roadmaps suggest they should be available as commercial offerings within the next five years. However, the uncertainty around the future acceptability of these solutions (from both an F-Gas and PFAS perspective) is reportedly having a chilling effect on the market. From the GB networks perspective their advantage is that they offer a like-for-like replacement with less disruption and can avoid the embodied carbon costs of replacement with new or larger equipment.

The range of different gases used by different manufacturers creates some challenges for the networks in terms of operational handling but this is a challenge they accept.

Not-in-kind technologies (based on vacuum and "natural origin gases) are also being developed for medium and high voltage, with the vacuum used for arc-quenching on circuit breakers and compressed natural air products (eg O2, CO2) typically used for insulation. As a "world first" Siemens Energy has installed a clean air ("Blue") 420KV busbar on SSEN's transmission network and also has offerings at medium voltage. "Active switchgear" (GIS, circuit breakers) is currently only available upto 145kV but Siemens Energy say they expect to extend the range to higher voltages in years to come. The EU Regulation should help drive this development but the technical challenges with arc-quenching at higher voltages will require innovation and close working with the networks to commission and test any new products. While the market can be expected to develop, the timescales for commissioning transmission equipment – and the safety testing required - place limits on how quickly this can happen.

At distribution level there are more options. As well as Siemens Energy, Schneider Electric has a clean air product for distribution networks that uses vacuum interrupters – and other manufacturers are starting to bring forward products as well and to address the concerns around the footprint of the equipment.

Clean air solutions offer significant benefits in having zero GWP, no PFAS and no operational safety issues. However they are still not available across the product range – with particular issues at high voltage where they are a long way from being available at scale. Moreover space constraints mean they are not suitable for all locations (as acknowledged in the EU 2020 report).

All alternatives are more expensive than SF6 now, but are expected to come down the cost curve to converge with SF6 in the next 5-10 years against a background of rising prices for all equipment.

While it is clear that the product range is extending, GB networks are still some way from having sufficient supply of suitable equipment to meet fast-growing demand, compounding existing, wider supply-chain issues (driven by Covid, Brexit and the war in Ukraine). The proposed end dates in the EU F-Gas Regulation provide an additional impetus to manufacturers to build production capacity for eligible alternatives but significant challenges remain for the GB transmission networks in terms of the options open to them over the next 5 years.

Where previously the transmission networks had been expecting to be able to use synthetic gas alternatives – and have carried out major pilots of those technologies – this no longer looks like a viable strategy.

International action on SF6

The need to reduce SF6 emissions was reiterated in a post-meeting communique from the G7 meeting in April 2023[19]. The EU's legislation puts it in the lead on outlawing the use of SF6 but some countries have formal or informal initiatives that are worth being aware of in terms of opportunities for learning or as indicators of where the global market may be heading – see Box 2.

Box 2: International action on SF6

USA : The US Environmental Protection Agency (EPA) mandated reporting of large SF6 emissions in 2009.

In 2018 the SF6 Emission Reduction Partnership for Electric Power Systems launched as a voluntary programme developed jointly by the US Environmental Protection Agency (EPA) and the electric power industry. The SF6 & Alternatives Coalition is an industry organisation for discussion of SF6 and alternative insulation technologies and a forum for industry interaction with public officials on emissions reporting and reduction regulations.

There are also examples of restrictions at state level. For example, the California Air Resources Board (CARB) has set a goal for utilities to stop buying any SF6-insulated products by 2033. However, all existing SF6 installations would be allowed to operate until their end of life. California's regulations also call for the utility to maintain a leak rate of less than 1%.

Japan: Japan has no laws that restrict the use of SF6 in the power sector, or that require emissions tracking and reporting. But by 2000 it had adopted the Closed Cycle Concept, a focus on minimising leaks of SF6. A joint industry-academia "SF6 Alternative Gas Study Committee" has compiled guidelines to evaluate SF6 alternative technologies.

Any alternative solutions must be fully compliant with the "7 requirements" including practicalities around size and ease of handling as well as cost and availability. This has resulted in new products such as Toshiba's Aeroxia (natural origin gas) range, which it is considering for export.

China: Over the last ten years, China is said to have begun to transition away from using SF6 in the 12 kV voltage range. While first generation SF6-free switchgear initially consisted of solid insulated switchgear, currently the trend is reverting to gas insulated switchgear that use SF6 alternative gases. China is now said to be considering new regulations or standards to further reduce SF6 usage and emissions and some tenders require low-SF6 equipment.

Note that the transmission voltages are not standard across jurisdictions and this has implications for availability of alternative equipment, which is more problematic at higher voltages. For example, US transmission voltage is 360kV, UK 275kV/400kV (and as low as 132kV in Scotland), China is 550kV.

[19] Communique is here – see para 62

4. PFAS

What are PFAS and why the concern?

In some alternative solutions, SF6 is being replaced by a mix of gases including PFAS. PFAS (per and poly fluoroalkyl substances) refer not to single chemicals but to a class, within which there are thousands of different chemicals with different structures. Conceptually they are like hydrocarbons but with fluorine rather than hydrogen atoms.

PFAS as a class include thousands of synthetic chemicals that are used widely across industries for their properties such as water, oil and dirt repellency; thermal and electrical insulation; and durability under extreme conditions. Everyday uses of PFAS include the manufacture of non-stick cookware, water-repellent clothing, stain resistant fabrics and carpets, some cosmetics and some firefighting foams.

The bond between a fluorine and carbon atom is extremely strong, and that means PFAS do not readily break down in nature. They accumulate in water sources and traces can be found in populations across the globe. The persistence of PFAS in the environment have led them to be dubbed 'forever chemicals' and clean environment campaigners have strongly challenged their use.

Several major chemical companies have been subject to litigation by water companies in the USA and in Europe over water contamination from PFAS and on 23 June 3M agreed a deal, to contribute up $10.3 billion, payable over 13 years, to support PFAS remediation for public water suppliers that detect PFAS. It has also announced that it will exit all PFAS manufacturing by the end of 2025.

The actual timescale for breakdown and the effect of individual PFAS-types varies but studies of particular PFAS substances[20] have raised concerns around their impacts on fertility, reduced foetal growth, reduced immune efficiency, liver disease and increased risk of cancer in humans. There are also concerns about the compounding effect of different PFAS.

PFAS Legislation - EU

At EU level a European Chemicals Agency consultation was launched in March 2023 on a project to ban all PFAS[21] with the possibility (supported by the member states who developed the proposal) of time limited derogations for certain products and some exemptions for specific uses, dependent on the availability of suitable alternatives.

The ECHA report highlights the very high persistence of PFAS and their degradation products and also sets out their position on the health and environmental risks:

"Although for most PFASs there are insufficient data to adequately assess their effects on human health and the environment, increasing research efforts that progressed beyond PFOS and PFOA [the initial products studied] reported similar adverse effects for other PFASs. Hence, there is a growing concern for the harmful effects of the complete PFAS family, given that concerns similar to the well-studied PFASs may be also expected for the currently less studied substances. Adverse effects

[20] See eg FT Big Read The crackdown on risky chemicals that could derail the chip industry May 2023; Guardian Forever chemicals linked to fertility problems in women; le Monde The massive contamination of Europe by "forever chemicals" (Feb 23)

[21] https://www.erm.com/insights/eu-reach-restrictions-how-to-prepare-for-the-proposed-pfas-restriction/

resulting from 'combined exposure' to complex mixtures of PFASs are likely for both humans and wildlife."

Following the precautionary principle and to avoid a situation where a banned product is simply replaced by a new product that has not yet been considered, the case is made for a ban of all PFAS.

For the energy sector, the ECHA consultation proposes a 5-year derogation for high voltage switchgear. Following the consultation, a draft opinion is expected at the end of the year with REACH restrictions coming into force in 2025.

The ECHA report[22] notes the issues with higher voltage switchgear but (as with the F-Gas Regulation) sees fewer issues at lower voltages:

"*Clean air technology has been introduced to replace both SF6 and fluorinated gases as insulating gas in electrical equipment, together with dry air (mix of nitrogen and oxygen) and vacuum. However, for high voltage switchgear the technology is still in development. A full fluorinated gas free portfolio up to 145 kV is already available and in operation. For high-voltage switchgear >145 kV, alternatives are not yet on the market".*

The consultation report acknowledges that the derogation would cause limited emissions due to low leakage rates.

The restriction would cover manufacture, placing on market and use of the restricted substances through the EU REACH legislation. It is unclear at this stage whether existing equipment could continue in use (either because of direct restrictions or restrictions on availability of top-up gas, for example).

There are calls from networks for a tiered approach that takes some account of the toxicity, persistence and mobility of different PFAS products, though given the huge range of products within scope the testing required to do this for all products would not seem practical.

The ECHA proposals are at a relatively early point in the REACH process. Industry is making the case to get the proposals significantly diluted. Environmental groups are urging the Commission to hold firm[23].

PFAS Legislation – UK

The UK is moving more slowly on PFAS.

As with the EU F-Gas Regulation, depending on the ultimate drafting, the EU restrictions will likely shape the market for products containing PFAS and the form of any derogations on switchgear will be important.

Nonetheless, it is fair to say that in our many discussions for this paper there was relatively little awareness among GB actors of the prospective EU ban and its implications for the synthetic gases used in switchgear as an alternative to SF6.

[22] https://echa.europa.eu/documents/10162/f605d4b5-7c17-7414-8823-b49b9fd43aea

[23] https://www.theguardian.com/environment/2023/jul/11/eu-to-drop-ban-of-hazardous-chemicals-after-industry-pressure

In the wake of the UK exit from the European Union, the government continues to evolve its detailed approach to the regulation of pollutants and hazards in the environment and for health, including for food and product safety. Unless or until the UK government introduces a change, EU received law stands. Where EU law and regulation is updated or changed (as with the F-Gas Regulation or the ECHA proposal for a PFAS ban) the UK government will decide on whether or how far to align. The UK government's overall approach to environmental and hazard regulation is beyond the scope of this paper, but these areas are hotly contested with many different stakeholders actively engaged.

In May 2022, the UK government issued a new legally-binding policy statement to embed protections and enhancements for the environment in all government policy making, including explicit reference to the precautionary principle.[24]

However, there are some differences of emphasis in the UK approach as highlighted in a recent government paper on growth[25] (which also set out proposals to give Ofgem a new growth duty):

"Some of the current regulatory standards inherited from the EU are based on an overly restrictive and often disproportionate interpretation of the precautionary principle. Sometimes, this reverses the burden of proof, for example through requiring an innovator to demonstrate the absence of possible harm from an innovation before it can be commercialised. The UK's new approach instead recognises that regulation should be applied proportionately, and there must be sufficient evidence that any identified risk is credible and real".

On PFAS specifically, Defra said in its April 2023 'Plan for Water' : "*They remain in the environment for years after use and move between different parts of the environment, including soil and water bodies. Since they are used in a range of different processes and products, managing continued use, emissions and existing pollution is a significant challenge*". The Plan focuses on reducing the much larger use of PFAS in other industries (aside from switchgear), so that Defra says it will:

- "*reduce the amount of PFAS entering the water environment following the recommendations of the UK REACH Regulatory Management Options Analysis on PFAS through starting to develop a UK REACH restriction proposal on PFAS in firefighting foams this year*
- *undertake further work to prepare for further restrictions on other uses of PFAS, including consumer products such as textiles, cleaning products, paints, and varnishes*"

While PFAS in switchgear may not currently be a priority use case for Defra to consider, there is a strong argument for early work to understand the impacts given the scale of future investment expected in networks, the link to delivery of net zero ambitions and the long lives of the assets concerned. This is particularly important if the UK is taking a different approach to the EU on environmental regulation. More evidence is needed to avoid precluding options if the risks turn out to be low and to enable the difficult choices and tradeoffs to be made on a more informed basis.

[24] https://www.gov.uk/government/news/environmental-principles-policy-statement-published

Precautionary principle - 'where there are threats of serious or irreversible environmental damage, a lack of scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation'.

[25] Smarter Regulation to Grow the Economy (May 2023) - here

PFAS in Switchgear

Two types of PFAS with different functional groups are used in electricity switchgear at present as alternatives to SF6:

- **Fluoronitriles** which are considered to have a GWP of 2100, but lower where blended. The fluoronitrile produced by 3M is NOVEC 4710 and its chemical composition is C_4F_7N. It is used in GE's g3 and Hitachi's EconIQ high voltage switchgear and gas insulated lines.
- **Fluoroketones** which are considered to have a GWP below 1 and are also said to be non-toxic. The fluoroketone produced by 3M is Novec 5110 which, mixed with inert gases is used in ABB's "SafePlus AirPlus" products.

What this means is that some products, acceptable under the EU F-Gas Regulation, could still end up being outlawed under EU PFAS restrictions, with a knock-on into UK supply chains. The positioning of PFAS could also potentially impact public acceptability of new network infrastructure.

The PFAS issue presents a particular challenge in relation to the management of existing SF6 banks in GB (and in particular for NGET). Retro-fill would seem to provide the best opportunity for removing SF6 and significantly reducing the tCO2e from leakage. However, due to physical limitations, retro-fill requires a like-for-like gas which currently means using PFAS.

More generally, the fact that switchgear will typically have a 40-plus year life means that networks and the regulator need to consider the risk of a future ban on new PFAS impacting spares or top-up gas plus potentially a requirement for the safe removal of PFAS ahead of the end of life. Wherever they can networks would be wise to seek natural air solutions, with further innovation and product development required to enable such solutions to be more universally applicable. Manufacturers of natural air products are using "regulatory certainty" as a selling point.

Most networks are now starting to consider the risks around PFAS in SF6 alternatives – but are faced with limited options. Some, including NGET, have also noted that a broad PFAS ban would have much wider ramifications for the sector (not dissimilar to the issues being flagged by the rail industry[26]) and are arguing for a grading system for PFAS that takes account of the risk of particular compounds.

As well as networks, Ofgem also need to better understand the issues and trade-offs on PFAS in SF6 alternatives to inform their future funding decisions.

[26] FT 3 July 2023 EU Rail Industry warns over proposed ban on "forever chemicals" - here

5. Where are the GB networks now?

Actions to tackle SF6 emissions

In reflecting on the companies' plans and progress around reducing / eliminating SF6 emissions, it is helpful to think about the various different actions required for both transmission and distribution:

- **New installations**: given the anticipated growth in all networks to support the connection of renewables, companies need to find alternatives to SF6 for new equipment they are installing. While alternatives are available at 132kV, solutions are not available for all voltages or equipment types. The companies are working in collaboration with manufacturers to develop and test alternatives across the product range. The Energy Networks Association (ENA), the industry trade body in UK, co-ordinates type testing for new equipment.
- **Reducing leakage from existing equipment**: This is effectively an asset management task requiring prevention, early detection and repair. By tracking where leakage arises companies can identify problem makes or types of assets which can assist in prevention and detection. While there is some sharing of information, the companies in each sector all seem to be adopting slightly different strategies on preventative measures, perhaps reflecting the different asset ages and challenges they face.
- **Managing down the existing bank**: While all companies have talked about eliminating SF6 from their networks by 2050 (with varying degrees of commitment), they have not developed programmes to deal with this. Some change-out will take place naturally as equipment is replaced at the end of its life or upgraded for other reasons and "retrofill" options are being actively explored.
- **Safe disposal and recycling**: Looking at the full lifecycle impacts of SF6 is important. Where SF6 is taken off the system (either when equipment is removed or the gas is replaced) then there need to be arrangements for its safe disposal. Looking to the future more use will need to be made of recycling.

In order to make progress in all these areas the networks need to significantly step up some of the basics around asset management including:

- Having a clear understanding of their existing **inventory** of SF6 equipment (by age, manufacturer, voltage and location etc) and the bank of SF6 that they hold;
- Improved **monitoring** of equipment and collection of leakage **data** (not just based on top-ups when a critical level is reached) enabling improved **analysis** around the drivers of leakage and enabling **projections** of future leakage rates for different types of equipment as well as allowing pre-emptive action to be taken on higher-risk equipment;
- Common **reporting** standards are needed in each sector to enable performance to be judged with standardised baselines and clear **targets** and metrics;
- Having clear and transparent **strategies** which are timetabled and costed for how they will deal with both the short-term and longer-term challenges;
- Using **innovation** funding to help address the range of challenges set out above.

Innovation

All transmission networks (but particularly NGET and SSEN) are using NIA innovation funding[27] provided under the price control to develop solutions across the product lifecycle. This funding was

[27] Network Innovation Allowance- funding for small scale projects

instrumental in supporting development of SF6 alternatives and is key to delivery of the long-term ambitions and supply-chain improvement. A requirement of the innovation funding is that results have to be disseminated so that all networks can benefit and details are available on the ENA's Smarter Networks Portal[28].

Box 3: Current innovation projects on SF6

Live NIA projects include:

- NGET: delivering a novel method of sealing harmful environmental SF6 leaks on small-bore pipework;
- NGET: developing a safer method of repairing small bore pipes which does not risk further leakage;
- NGET and SSEN projects looking at monitoring the performance of SF6 alternatives
- SSEN projects to capture SF6 in the event of leakage and also to speed up the process of detecting leaks;
- NGET / UKPN - Working with EPRI to improve management of ageing assets
- NGET studying the performance of C4FN based alternatives and how the chemical composition might change over time with moisture / reaction with equipment
- SPT: looking at whole life cycle emissions for sub-station design

NGET and UKPN are also seeking next phase funding through the Strategic Innovation Fund (SIF) for further exploration of whole life cycle costing of different options for reducing SF6 emissions, including options for disposal at end of life, in partnership with Manchester University.

[28] https://smarter.energynetworks.org/

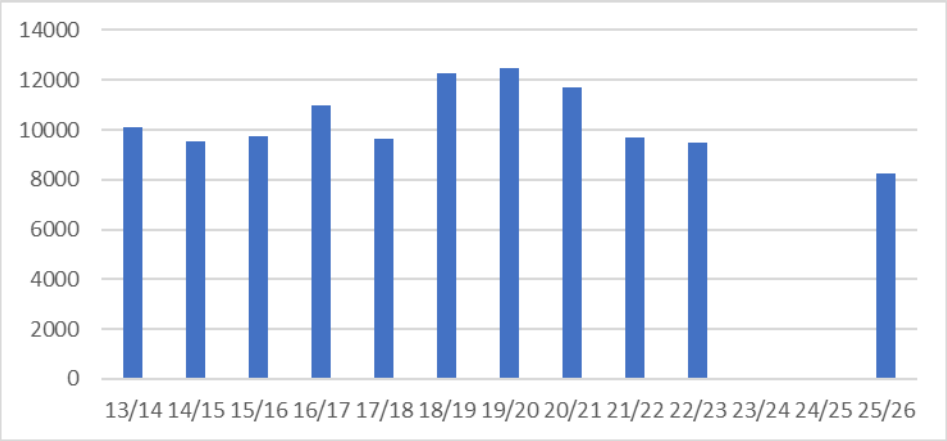
National Grid Electricity Transmission

Targets and performance metrics

NGET committed in its Business Plan to a science-based target, in line with Ofgem requirements. The SBTi confirmed that this meant a 50% reduction by 2030, from a 2018/19 baseline. NGET's interim target for 2026 is calculated as 34% assuming a linear pathway. Given the SBT must be reached by scope 1 and scope 2 independently, and that fleet accounts for only 1.6% of scope 1, NGET's target is for SF6 emissions to be reduced by at least 33% by 2026.

As the graph below shows, 2018/19 (the baseline year) was a relative high point in NGET's SF6 emissions and good progress was made in the first year of ET2 (21/22) but performance has plateaued somewhat in the most recent year.

Figure 1: National Grid Electricity Transmission SF6 Emissions (kg)



Source: Ofgem RIIO ET1 Annual Report 2022, NGET Annual report 22/3 (plus extrapolation for 25/26 target)

NGET has the highest leakage rate across the transmission networks, at least in part because the network is typically much older than the others. Older GIS equipment tends to contain much higher levels of SF6 as well as being more prone to leakage.

NGET say in their 2020 SF6 Strategy that their SBT requires them to achieve an average leakage rate across their asset base of ~0.9% by 2026 compared to the 2018/19 rate of ~1.4%.

As noted in Section 2, the IIG baseline that Ofgem set for NGET (before it earns a financial reward) is to reduce its leakage rate by 10% (compared to the average leakage rate for 2013-20) reflecting what Ofgem judged as current under-performance. The resulting IIG target is 1.18% - against an average performance through 2013-20 of around 1.3%. This IIG target is thus significantly less stretching than NGET's science-based target.

As of 2022 NGET was reporting a 1.05% leakage rate which represents an improvement that will earn it a reward but its leakage rate is still significantly above that of the other networks. Moreover, with the significant network growth envisaged through this decade NGET is to some extent "running up the down escalator" in terms of its efforts to meet its science-based targets (ie although its leakage rate as a % is falling, the fact that its bank is growing means that its total volume of emissions in tCO2e will be slower to decline). In its MSIP application (see below) NGET notes that new installations have a typical leakage rate of 0.25% which means network expansion would help improve NGET's average leakage rate albeit still adding to absolute emissions if SF6 is used.

This complex interplay between the leakage rate (as a %), the growth over time of the bank and the resulting total emissions (whether from old or new kit) makes it hard to forecast future emissions and whether NGET will meet its targets. This big picture story is not clearly set out by NGET (or indeed by any of the networks).

NGET's Business Plan and Ofgem Determinations

NGET's Business Plan talked about the need for "brave action" replacing leaking assets and innovation to find alternatives but included no specific plans. NGET proposed an uncertainty mechanism to cover the costs once it was clearer what was required. They also highlighted that "*These investments are carbon price sensitive and the cost of carbon doesn't currently cover the investments required within this mechanism, with a focus on longer-term benefit".*

NGET said that its SF6 asset intervention programme would include:

- leak prevention and remedial repair works for assets to support their operation to end of life; and
- strategic interventions, such as asset replacement, for assets approaching their end of lives, where emissions levels warrant an alternative to leak management.

NGET provided an initial cost estimate for the asset intervention plan of £150m (subsequently revised to a range of £190m to £325m).

At Draft Determinations Ofgem made clear that it did not think NGET's proposed mechanism would encourage cost efficiency or guarantee delivery. Instead Ofgem wanted to provide an upfront cost allowance for delivery of specific interventions (with the ability for Ofgem to recover costs if these interventions weren't delivered). Ofgem said NGET needed to provide more evidence, including modelling of forecast leakage rates to support the funding it would be looking for.

Hence in its September 2020 response to Draft Determinations NGET included a more comprehensive SF6 Strategy looking at leakage rates by asset age and eg indoor / outdoor. Based on this analysis it asked for:

• Baseline funding for defined interventions at 18 named sites to abate present and future leakage of ageing assets;

• Baseline funding for application of pre-emptive, palliative coatings to assets within the first 20 years of service to prevent future leak evolution;

• A flexible funding element to deliver the remaining interventions required to achieve their science-based target;

• A mechanism to facilitate the adoption of SF6-free retro-fill within existing hardware when these options became available during RIIO-2.

Taken together these elements would result in a proposed upper funding limit of £613m.

The proposed 18 specific site interventions were colour coded to show the extent of cost justification based on a cost of carbon of £74/tco2e. Only about a third were cost justified at that level – others were described as "strategic". Since NGET submitted its proposals, government have reviewed the

cost of carbon to take account of the commitment to net zero and increased it so it is now £252 / tCO2[29]e. On this basis many more of the proposed interventions would have been cost justified.

In its Final Determination Ofgem allowed NGET £87m for site-specific works at 10 sites which were in imminent need of intervention (basically refurbishment). Ofgem will track the emissions abatement for the 10 sites against expected levels of abatement when considering potential adjustments under the Price Control Deliverable mechanism. They will also seek to ensure that funded sites and their expected levels of abatement are considered under the IIG leakage incentive, to reduce the risk of overlap.

Ofgem also approved funding of £2.7m for the palliative works.

In addition, Ofgem put in place a flexible mechanism to allow NGET (or other transmission networks) to bring forward proposals mid-period for funding for additional interventions to reduce SF6 emissions through the MSIP (Medium Sized Investment Programme) re-opener. As a part of this the network has to have a clear and well-articulated long-term plan to reduce not only SF6 leakage from its assets, but its SF6 inventory as well.

In 2022 NGET put in an application for additional funding under the new MSIP mechanism and secured significant further funding – see box 4.

Box 4: NGET's MSIP Bid

In January 2022 NGET put in an application for funding under the MSIP mechanism. Specifically it was looking for funding for an additional 5 site refurbishments (which had been included in its initial Business Plan but where it was now able to provide stronger justification). It also requested funding for replacement of 427 current transformers and repairs to 167 circuit breakers. NGET argued that these additional investments were needed to allow it to meet its 2026 target. It said it would bring forward further proposals under MSIP as it develops its plans to meet the 2030 and 2050 targets which it expects to require the use of retro-filling.

Through MSIP NGET was requesting £54m of additional funding on top of its baseline allowance and from which it expected to save 21,848kg SF6, equating to 513k tCO2e.

The MSIP proposal[30] built on the 2022 SF6 Strategy in providing an overview of NGET's approach. As such it is a valuable source of evidence to help in judging how robust NGET's plans are.

In July 2022 Ofgem consulted on NGET's MSIP proposal, saying that it supported the needs case for the investments but that aside from the 5 sites it considered that NGET was already being funded through other mechanisms for this work. In its response NGET pushed back against this view and in April 2023 when Ofgem published its final decision it agreed to fund the 5 sites and also the current transformer replacements.

Actions that NGET is taking to reduce SF6 emissions

New installations

Like all the transmission networks, NGET is committed to using alternatives to SF6 where these are available and is considering both technical gas and fluoronitrile options. In their Business Plan they

[29] https://www.gov.uk/government/publications/valuing-greenhouse-gas-emissions-in-policy-appraisal/valuation-of-greenhouse-gas-emissions-for-policy-appraisal-and-evaluation
[30] NGET Re-opener Report MSIP – SF6 Asset Intervention - here

committed to stop designing with 132kV[31] SF6 assets in new builds by 2021. Their current policy is that competing SF6 technologies are excluded from procurement activities when two or more technically and commercially viable alternatives are available and offered.

To help develop the market for alternatives, NGET, like other networks, has been undertaking a number of pioneering projects working with equipment manufacturers:

- In 2018 NGET pioneered and energized its first SF6-free 420 kV gas-insulated busbar at its Sellindge substation using **GE's g3** solution (GWP 328).
- In April 2022 NGET announced plans at Littlebrook in Dartford to replace the former facility, which was becoming difficult to maintain. The new substation will again use **GE's g3** solution (but now for active switching gear as well), saving 5.6 tonnes of SF6 gas. The next stage is completing circuit diversions, then SF6 gas from the old substation will be removed safely in stages with the former substation decommissioned and demolished by the end of 2024.
- In December 2022 NGET announced a new SF6-free substation would be built at Bengeworth Road (as part of the £1 billion London Power Tunnels project) where, in a UK first, **Hitachi Energy** will deliver **EconiQ**™ 400kV gas-insulated switchgear (GIS) and gas-insulated lines (GIL) containing no SF6, with work due to start in 2023.

Reducing leakage

For NGET reducing leakage has been a particular focus area given its historically high leakage rate.

In its 2020 SF6 Strategy NGET emphasised the need to move from a reactive approach (where there can be delays in detecting and repairing an asset) to a proactive approach that embodies the need to forecast asset leak performance. This involves using past data and considering factors such as manufacturer, design type, installed location/environment, age, etc. and enables NGET to make timely, pre-emptive interventions.

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. NGET's approach is that any leak rates in-excess of the design value warrant intervention given the environmental impact of SF6.

As NGET highlight, environmental corrosion is a key factor in SF6 leakage. By taking actions to prevent the ingress of moisture and pollution the onset of such leakage can be deferred or prevented. Preventative measures include the application of external palliative coatings to outdoor components of gas insulated substations to prevent environmental degradation of SF6 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.

Careful analysis of where leaks occur can help identify weak points eg leaks are more likely to occur on horizontal joints or flanges (because moisture pools on them) than on vertical joints.

When leaks occur NGET's SF6 Strategy makes clear these can be dealt with through:

- Repairs which involve 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.

[31] Although 132kV is not a transmission voltage NGET will have equipment at 132kV to allow large loads / generation to connect directly to the transmission network

- Refurbishment: Return of the critical SF6 sealing components to "as-new" condition by physical dismantling the equipment, cleaning and re-working damaged components and replacing seals and gaskets, etc. Costs are high and the work requires long outages.
- Replacement: Substitution of the leaking equipment with new equivalent equipment. This may be individual components, partial or full. Costs and outage durations are high. The options need careful analysis to avoid wasteful investment.

Overall, our impression is that NGET are now seized of the challenge they face and have stepped up at an operational level in terms of addressing it. For example, their 2022 report claims performance improved as a result of the new focused SF6 team that was formed with responsibility for SF6 intervention development and delivery.

However, without explicit funding from Ofgem it is not clear how willing they would be to invest. While at one level it is right that the costs of this work need to be covered, there is not a bright line between what should be good practice in terms of asset maintenance (with questions of whether historically that was allowed to slip over time) and enhanced action that is now needed because of the greater focus on climate change.

Inventory management – Retro-fill

In their SF6 Strategy NGET acknowledge that most of their proposed actions are focussed on leak reduction but that the long term science-based targets can only be met by tackling inventory. The one opportunity that they highlight for reducing the inventory of SF6 (as well as helping with short-term emissions) is retro-filling of existing equipment with a like for like gas with a lower GWP.

NGET have led the work in GB (and globally) on the option of retro-filling. They say they expect this option to be viable in RIIO2 for certain equipment like gas insulated busbars.

In December 2021 NGET announced a world first pilot project at Richborough Substation in Kent, to develop and deploy Hitachi Energy's EconiQ™ to replace SF6 at an existing sub-station, avoiding the environmental impact and cost of replacing equipment which is otherwise fit for many more years' service.

Because of the need for this to be a like-for-like replacement gas the only option for retro-filling currently is a blended fluoronitrile based gas with a GWP of c 300 and involving PFAS. However, retro-filling offers a much quicker and cheaper solution than building new assets and also involves lower embodied carbon. NGET's Ofgem funded project with Manchester University on lifecycle assessment should provide an independent view of the value (in overall carbon terms) of alternative approaches to managing SF6, including options that enable the equipment itself to remain in use to the end of its life.[32]

Whether retro-fill is permitted will be subject to decisions on the EU / UK F-Gas Regulations plus any restriction on PFAS. This is probably the biggest determinant of whether NGET meets its 2030 and longer-term SF6 emissions targets.

[32] See also Hitachi's Lifecycle Assessment of Different Concepts of SF6-Free GIS - here

SSEN Transmission

SSEN were the first network to commit to science-based targets, ahead of it being an Ofgem requirement as part of the Business Plan process. Their science-based target requires a reduction in SF6 emissions of 33% by 2026.

Their specific commitments in their Business Plan are to:

- Reduce leakage to 0.15% by end of T2
- Install 19.9t less SF6 in T2 (than if they continued to use SF6)
- Remove all SF6 by 2050
- Innovate to develop new solutions across all voltages

Tracking SSEN T's performance back through ET1 is difficult because of a change in their methodology for reporting leakage to bring them in line with other networks (which is discussed further in Section 6 below).

Their latest Annual Environment Report submitted to Ofgem shows their performance since the 2018/19 baseline year:

	2018/19 SBT baseline	2019/20	2020/21	2021/22
SF_6 tCO2 e	1,925	3,120	2,947	2,777
Leakage rate %	0.21	0.32	0.24	0.19

Historically SSEN T have had the lowest rate of SF6 emissions among the transmission networks (reflected in Ofgem's decision not to impose an improvement factor in setting their baseline for the IIG incentive at 0.38% reflecting their performance from 2013-20). However they are also the network that is seeing the highest capacity growth linked to the massive increase in renewable generation in the North of Scotland. As such they are heavily dependent on being able to use SF6-free equipment for their new installations if they are to meet their targets.

They also note that new equipment can be leak prone in its early days (often linked to problems with manufacture or during installation[33]) and hence will be subject to additional monitoring but they still anticipate this to drive a short-term increase in emissions where they have to install SF6 equipment. They are looking at procurement options to put incentives on manufacturers to minimise early life leakage.

SSEN T have also put significant effort into working with manufacturers. Specifically:

- At Kintore near Aberdeen they are building the world's first 400kV substation (2km of gas insulated line and 9 bays of GIS switchgear) using **GE's g3** (Green Gas for Grid) technology. The first phase is due to complete this year;
- This builds on previous orders for the construction of a 1-km long g3-gas insulated line (GIL) at their New Deer substation, as well as a 145 kV **g3**-gas insulated substation (GIS) and a 420 kV g3 gas-insulated busbar for their Fort Augustus site.
- In 2019 they also installed the first "clean air" 145kV circuit breaker provided by Siemens (using vacuum and a mix of nitrogen and oxygen) at Dunbeath.

[33] This creates what is known as the "bathtub effect" where equipment is more fault prone at the start and end of its life.

- In May 2021 they announced the energisation of the Glen Kyllachy wind farm transmission connection, home to the first SF6 -free Siemens Clean Air Power Voltage Transformers on the GB Transmission network.

They are also focussed on the wider process and other changes needed to support the use of SF6 alternatives on the network and to cope with a mix of gases on the network – each requiring different handling. Safe handling at the end of the product life is also being explored.

Overall SSEN T seem strongly committed to achieving their science-based targets as part of the wider SSE Group ambitions. However they face a real dilemma if suitable equipment is not available – and in the context of wider supply chain challenges - given the level of investment needed over the next 5-10 years to meet GB's 2035 grid decarbonisation goal. This is a real concern given the lack of any offerings at 275kV and the fact that the only options for active switchgear at 400kV are synthetic gas solutions that may be banned in future (with the risks that carries for availability of spare parts etc).

Scottish Power Energy Networks Transmission

SPT provided only a high level SF6 strategy in its Business Plan but, like the other transmission operators, has committed to reductions in SF6 leakage over the ET2 period. It has science-based targets at a group level but it is less clear how far these are driving a focus on SF6 and SPT do not have specific emissions targets in terms of tCO2e or leakage rates.

Instead in their Business Plan they made specific commitments to:

- Procure assets with leakage rates that are half the international standard rate of 0.5%;
- Procure SF6-free assets where they are "technically feasible and market ready";
- Offset any leakage where repairs fail, using high quality offsets[34].

Over the first 5 years of T1 they had average leakage of 0.75% against an IIG target of 0.85% including a big increase (+40%) in 18/19 as a result of repeated leaks at one site. Their performance sits between NGET and SSEN and their associated IIG baseline for T2 is 0.79%.

In the first year of T2 (21/22) they reported that they had reduced leakage by 30% compared to the previous year and that their leakage rate for that year was 0.45%, a very significant improvement. This has been achieved through a strong focus on repair, raising questions (as with NGET) about their previous asset management approaches. The repair plan was derived from thorough analysis of their SF6 filled equipment with a wide range of interventions considered to ensure any leaking assets are either fully refurbished or, if this cannot be achieved, replaced. They have established an internal SF6 working group "performing bi-monthly reviews of SF6 related issues ensuring any leaks are appropriately remedied without undue delay". They are also exploring techniques for encapsulating equipment to prevent leakage.

Given the current state of the market their view is that all their new 132kV installations will be specified SF6-free and where they have GIS installations at 275kV & 400kV, the GIB (busbars / gas insulated lines) associated with these sites may be SF6-free where viable.

Again they are working with manufacturers to explore alternatives including a 275kV substation at Windyhill which is being upgraded using Hitachi's EconiQ™ GIS and GIL as well as a newly developed transformer.

[34] While not central to this report we remain sceptical about the benefits of offsetting and in particular would not want to see that treated as an alternative to direct action on leakage.

Overall SPT appear more focussed on the SF6 challenge than their Business Plan might suggest. They have scope to improve on historic performance through better asset management but are very concerned about the implications of options being limited for replacements or new capacity. They have also highlighted the need to look at whole lifecycle carbon impacts and are concerned about the higher levels of embodied carbon in the vacuum / natural air solutions, recognising that this in turn would impact on their Business Carbon Footprint once scope 3 emissions are properly accounted for.

Distribution Networks

The challenge faced by the distribution networks is very different to that on transmission. Overall they have around 200,000 items of equipment containing small amounts of SF6, <5 kg, mostly in sealed units. This creates a longer-term problem for them in removing SF6 from their networks if they want to avoid all possible emissions.

In the near term the DNOs face a similar challenge to the transmission networks (albeit on a much smaller scale). They had an average leakage rate in 2020/21 of 0.28% (0.42% for NGED). This likely reflects a small number of relatively leaky assets that need to be dealt with given that the majority of smaller assets will be sealed units that it is assumed do not leak (or do so minimally). Indeed, the year-on-year volatility in DNO leakage rates reflects the impact that one individual leak can have.

While the message at EU level is that there are adequate SF6-free alternatives at distribution level, we got a mixed picture from those we spoke to in terms of the GB position. While the manufacturers have plans to fill the main gaps in their portfolio at low / medium voltage over the next few years there may well still be some GB specific niche gaps beyond that point – and certainly there are portfolio gaps today which impact those looking to move ahead more quickly.

As set out above there is no equivalent to the IIG for distribution and the companies' plans in this area are driven by their science-based targets and reputational pressure.

However, compared to transmission, SF6 emissions constitute a markedly smaller proportion of the DNOs' carbon footprints (where they are comparable in scale to those from operational vehicle emissions) and especially looking at scope 1 and 2 together where losses dominate. As a result, they typically have more flexibility over the level of SF6 savings they need to achieve to meet their science-based targets.

The Sustainability First report on the ED2 Business Plans makes clear that the quality of the companies' SF6 strategies varied considerably, from a few pages in the Environment Action Plan to a standalone strategy document (SPT and SSEN). It warned that absent a strong focus from Ofgem – which was not forthcoming – a concerted effort by DNOs in ED2 could not be assumed.

While the companies were required to include a target for SF6 leakage reduction in their Business Plans, these were all presented in different ways with different baseline years making them hard to compare. Ofgem simply accepted the targets proposed with no attempt to increase the stretch required. Ofgem did set out a requirement for the DNOs to develop a common reporting methodology but no real progress has been made on that front. That said, Ofgem's guidance on what DNOs need to include in their Annual Environmental Reports is much more detailed and prescriptive than it is for transmission which will hopefully aid transparency.

Sustainability First in its report sought to compare across the DNO commitments in their Business Plans but noted that "*meaningful cross-company comparison on the targets on the basis of*

information in the EAPs is hard…. Pulling this table together has not been easy. The EAPs do not necessarily set out clear information on initial ED1 SF6 leakage reduction targets – nor on ED1 out-turn performance against those targets in a standard or readily accessible way." There are also problems reconciling some of the leakage rates quoted with figures in the Ofgem annual report. With those caveats, the targets can be summarised as follows:

DNO	ED2 Business Plan Leakage Target
ENWL	Maintain leakage rate <0.3% (a 10% reduction on ED1) Reduce emissions by 340tCO2e pa Review after 2 years
NPG	Reduce leakage by 15% (Plan includes clear trajectory and table of past performance)
SPEN	Reduce leakage by 10% over ED2 compared to ED1 (Plan includes good summary of alternatives available)
SSEN	Aim to reduce leakage by 35% by 2028 compared to 19/20 Begin reducing SF6 holdings (Plan demonstrates good understanding of inventory and leakage by asset type, age etc)
UKPN	Reduce leakage rate to 0.1% by end ED2 – a reduction of 9% against current (strong) performance
NGED	20% reduction in SF6 leakage Drive partners to develop SF6 alternatives

All the DNOs included a level of requested spend to support their SF6 strategies but, as noted above, it is generally unclear if this was provided.

The deliverability of these plans will be dependent in part on the availability of suitable SF6 free alternatives.

For networks like SSEN Distribution expecting significant network growth in the ED2 period to accommodate more distributed generation and other low carbon technologies, and with an ambitious leakage reduction target, the current lack of availability creates a real dilemma. While their policy is to install SF6-free equipment where it exists, supply chain limitations mean that this is not always possible and they are left with a choice between using SF6 to enable connections to go ahead or holding up wider de-carbonisation.

That said, actions are in train to start to pilot the use of SF6 free alternatives at distribution level including:

- 2023: UK Power Networks is installing its first Siemens Energy "Blue" clean air gas insulated switchgear (GIS) operating at 132kV, as part of a substation upgrade in Lewes, East Sussex.
- 2021: SPEN Distribution installed Siemens Energy "Blue" clean air switchgear on an 11kV ring main unit at a substation in Glasgow;
- Northern PowerGrid installed two ABB SafePlus switchgear variants using alternatives to SF6 in indoor substations in Durham. This has the same interface and footprint as other ABB equipment so can readily be substituted and has a GWP of less than 1.

It is also worth noting that 132kV is transmission in Scotland but distribution in England and Wales. There is therefore scope to bring learning across from Scottish transmission for this equipment (which will include larger levels of SF6 than lower voltage equipment).

For all distribution networks there is also some scope to reduce leakage by better asset management. Several DNOs already make use of infra-red leakage detection or special liquids to help in pinpointing leaks and steps are also being taken by some to improve data analytics to understand patterns and causes of leakage (including eg correlation with temperature changes). UKPN are also exploring ways to speed up repairs once a leak is identified, working with NGET on their Raw-water innovation project.

There is only one brief reference in the plans to work on safe disposal at end-of-life which is another area that requires further exploration.

Offshore and independent networks

While this report focusses on the regulated transmission and distribution businesses, there are a number of other network models that serve small but growing proportions of the GB industry (see box 5 below). In most cases these are not subject to price controls, instead being delivered under contracts of varying duration, with little or no apparent oversight of their performance by Ofgem, the Environment Agency or Defra. These networks will be using electrical switchgear but will have no specific incentive to manage leakage beyond requirements in the general F-Gas Regulation or company science-based targets. Major leaks can also attract poor publicity[35]. There is currently no visibility of the scale of their banks or leakage rates.

In all of these network models the focus on competition means that there will be a strong emphasis on minimising the upfront costs with less regard to, for example, environmental impacts. Unless they are part of a wider group with a strong commitment to science-based targets there is nothing driving these networks to reduce SF6 leakage or manage their bank of assets. Understanding the scale of the issue in this part of the market is important to feed into wider policy making.

As with the regulated networks we would expect the levels of SF6 leakage to be greater on the offshore and interconnector networks. Where there are major leaks it is assumed that these would need to be reported to the Environment Agency[36] but beyond that there is no information on the scale of the issue.

[35] See coverage of leak at Seagreen windfarm - here

[36] In Scotland the relevant body is the Scottish Environmental Protection Agency (SEPA) and in Wales it is Natural Resources Wales

Box 5: Other categories of networks in UK

At transmission level there are two current and one future additional types of network:

- Interconnector licensees operate transmission lines that link GB with neighbouring markets, usually via subsea cables. Ofgem lists 23 such licensees, not all of which have built assets at this stage.
- Offshore transmission network operators (OFTOs) are granted a 25-year licence to own and operate direct links between offshore wind farms and the onshore network. Two dozen such licensees are listed.
- Competitively awarded transmission operator (CATO): this approach, which Ofgem is looking to take forward, would apply the OFTO model to new onshore networks and would see large, separable assets owned and operated by third parties under long-term licences, taking them out of the incumbent networks' price controls.

Incumbent distribution networks are geographically specific but within their areas are smaller areas that are owned and managed by other parties. In some cases (such as rail networks) they can span several DNO areas. The models include:

- 'Behind the meter' networks, which may be at high voltage level and are often used for complex mixed sites such as airports or trading estates.
- Independent DNOs. Utility connections (gas, electricity, water, telecoms) for new developments is a competitive activity in GB and 'last mile' connections are delivered by independent companies that connect to the incumbent DNO. While the connections may be 'adopted' by the local DNO, increasingly they are retained by the connections company operating as an independent DNO with prices set based on the DNO price control.

6. Reflections on progress and plans

This section draws on all the evidence we have gathered and that is set out in earlier sections to answer some of the specific questions that we were asked to address.

Is there enough transparency around progress?

Transparency is important to enable stakeholders to track progress. While all the regulated networks publish an array of different reports which all touch on SF6 (including the Statutory Report and Accounts, Annual Regulatory Report, and Annual Environmental Report) it remains extremely difficult to bring together a complete picture of what progress is being made. This is primarily because the companies have discretion in the format of their reports and in their narrative will often quote % changes against different base years, for example.

While Ofgem has published guidance on certain information that has to be included in the Annual Environment Report, for transmission this is very limited as noted above (and eg does not even include information on the bank of SF6). For distribution the required information is much more comprehensive but until we see the first reports next year it is unclear how easy they will be to understand.

In RIIO 1 Ofgem itself used to publish an annual summary of performance looking across the companies on a range of factors (including SF6 leakage). However, the last such report for transmission looked at the period 20/21 and it is not clear if Ofgem will continue to publish such reports going forward (although Sustainability First have highlighted the importance of Ofgem doing so rather than simply relying on stakeholders to try to unpick what is happening).

In ED1 Ofgem had been publishing a RAG rated league table of performance on leakage rates. While it was given little profile (being buried in supporting Excel spreadsheets) it did provide at least a basic level of cross-company comparison.

To really understand the challenges and extent of progress much more granular data is needed – highlighting the types of assets where leakage is highest, at what voltage, and reporting not just on the number but also the nature of "interventions" undertaken, showing new assets installed separately from existing assets, for example. Ofgem's requirements for the distribution AERs should help fill this gap but significantly more transparency is needed on transmission.

The networks do share some of this information among themselves through the ENA who have produced a report as part of their work on the F-Gas Regulation. However, the information is seen as commercially confidential. A de-sensitised version of the report is understood to be in hand, but we have not been able to gain access to it. To improve transparency (and to support learning between companies) it would be helpful for the ENA to share such information and provide regular updates from an industry perspective.

As well as questions about what gets reported there are also important issues about the metrics themselves. Ofgem is quite prescriptive about how leakage should be reported under RIIO. This helps with consistency but there are concerns that the metrics used may be systematically under-reporting levels of SF6 emissions (see box 6). Ofgem should review these metrics to ensure they present an accurate picture.

Box 6: Potential issues with the way SF6 emissions are reported to Ofgem

Leakage is not the same as top-up: In reporting to Ofgem SF6 leakage is defined as being the amount of top-up added. This will therefore pick up on the most significant leaks. However, the low level of underlying leakage in new equipment (well under 0.5% pa) would not require top-up and hence would not be counted. In their Business Plan SSEN T flagged that they had previously been reporting leakage as the sum of top-up and the boiler plate leakage rate but were moving to only report top-up to avoid double-counting and to be consistent with the other networks. This appears to have resulted in a drop in their leakage level to around a quarter of what had previously been reported, suggesting that across GB networks relying purely on top-up data may be significantly under-stating the actual leakage level. This should not matter if there is accurate reporting of SF6 levels when equipment is installed and when it is ultimately removed – but at best that creates a significant lag in reporting. Better monitoring (as required under the F-Gas Regulation) would also be helpful in picking up early problems – and indeed many of the networks are monitoring leakage levels for this purpose so data should be available.

Leakage from equipment that is removed: Ofgem requires transmission companies to report leakage from assets that were in situ at the end of the year – thus excluding leakage from assets that have been replaced (which are likely to be the most leaky assets). In their SF6 Strategy NGET say "*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*"

Updating the GWP: In converting to tCO2e Ofgem requires the companies to use a GWP of 23500 (in line with the IPCC figures from the Fifth Assessment report) but the latest IPPC Report now puts the figure at 25200. Ofgem should ensure the companies are using the latest figure to avoid under-reporting. For other reporting (eg to DESNZ for international comparisons) the companies sometimes use an earlier IPCC figure of 22600. This is generally explicit but can add a further complication when comparing data from different sources.

Will commitments be met?

As described above, all companies have generally set out in their Business Plans specific short-term commitments aimed at reducing SF6 leakage over the price control period through to 2026 (Transmission) or 2028 (Distribution). These vary in terms of the level of ambition and the challenges are primarily practical ones around equipment availability.

The biggest issue here is linked to the F-Gas Regulation currently being finalised at EU level. As things stand the EU is pursuing stringent regulations in terms of the cut-off dates for purchase of new equipment and the level of GWP allowed in alternative gases. PFAS restrictions would further limit the options available.

Stringent regulation (of F-Gases and PFAS) is key to driving the development of safe switchgear solutions and supporting the networks in meeting their 2050 targets on elimination of SF6 (and other greenhouse gases). However, in the near term there is a risk to delivery of leakage targets given that alternative equipment is unlikely to be available on time at the scale required and installing new SF6 equipment (even with much lower leakage rates) will be harder to justify. There is currently only one

manufacturer offering a clean air solution at transmission level (and then not at all voltages or all types of equipment). The focus of pilots at transmission level over the past 5 years has been on synthetic gas solutions which would not be available going forward.

For distribution, space constraints may limit the options for some types of equipment at present, albeit these are being developed.

Our assessment of the position for each of the transmission networks against their short-term science-based targets on SF6 leakage is set out in section 5 and summarised in Box 7 below.

Box 7: Will short-term SF6 leakage targets be met?

For **NGET** the target of a 33% reduction should be relatively achievable. As a poor performer currently in terms of the basics of detecting and rapidly repairing leaks they have plenty of room for improvement. They have funding to replace / refurbish equipment at their most leaky sites. None of these actions are dependent on the availability of alternatives although wider supply chain pressures could cause a problem for them. While they do have plans to use SF6 alternatives for new installations, at least at 132kV, our sense is that achieving their 2026 target is not heavily dependent on access to these alternatives.

In contrast, for **SSEN Transmission** as a strong performer there are few low hanging fruits in terms of improving performance. Despite their strong commitment to this agenda, they have significant capacity growth planned over this period to support the GB's wider de-carbonisation goals and in particular the connection of offshore wind. For their size they have put significant effort into helping build the supply chain for alternatives, reflecting the degree to which they are dependent on those alternatives to meet their targets. In particular they have looked at both forms of solution and would be concerned if overly prescriptive legislation (on either F-Gas or PFAS) limited their options. Ultimately, if necessary, they will have to continue to invest using SF6 while they can and look for other ways to address their short-term science-based target.

SP Transmission has not set itself a specific leakage reduction target. While it has a commitment to use SF6-free equipment this is caveated as being dependent on availability. As such its ET2 targets are not at risk. However, it remains determined to reduce leakage as a contribution to group level emissions targets and, like SSEN T, is very concerned about legislation limiting its options.

In **distribution** the picture is even more mixed with companies demonstrating very different levels of ambition. Looking back over ED1 there was very patchy performance against the targets the distribution companies set themselves and there were no repercussions. Whether DNO 2028 SF6 emission targets are met will depend to a large extent on how undemanding they are but also how much focus is given to them.

As regards the long-term goal of removing all SF6 from the networks by 2050, which most of the companies aspire to, little thought has been given to how it might be achieved either at transmission or distribution level. Not all of the distribution networks yet have detailed SF6 strategies. And none of the companies – transmission or distribution - have costed investment and asset management plans for how they will do this. The operational challenges are greatest for distribution given the many equipment items involved.

Clearly the F-Gas Regulation can be expected to play an important part in driving longer-term elimination as one might expect that all distribution equipment installed post 2030 and all transmission equipment post 2032 will be SF6 free (unless derogated). Given also an expectation of continued expansion of the network one would expect that in the natural course of events SF6 will

be less prevalent by 2050. However, the typical asset life is around 40 years so even by 2050 there will still be a significant amount of SF6 equipment on the networks, absent specific action to address it.

Full SF6 removal before or by 2050 would therefore require a major programme of asset removal and replacement. At distribution level this would be relatively costly and the amounts of SF6 are comparatively very small. Questions may therefore arise around the cost-benefit case for early replacement of these distribution assets if they are sealed and have minimal leakage, absent a regulatory ban on their continued use. This is not envisaged at present but perhaps cannot be completely ruled out.

What are the barriers? - Economics

Aside from the issues around product availability and particular product characteristics (space requirements, like-for-like replacement), the other major barrier is cost. We have not received any specific cost information from the network companies or from manufacturers but it clearly is a consideration.

The EU Commission 2020 report suggested that alternative GIS technologies could have a price premium of up to 200% over SF6 equipment, in part because of larger dimensions, although this may reduce with economies of scale and manufacturers expect some convergence with SF6 equipment. The Commission also indicated that medium voltage switchgear was expected to be between 5 and 30% more expensive, even with scale. The networks we spoke to all expressed concern about the major current squeeze on the global power-sector supply chain and therefore equipment costs. But, in addition on SF6 replacement they were facing a significant additional price premium on all the alternatives. They were also concerned that if regulations had the effect of limiting the number of competing manufacturers in the short term, this would put further upward pressure on prices.

As regulated monopolies, whether the networks can incur the higher costs of alternative technology or carry out early replacement of very leaky equipment is dependent on them being able to make the case to Ofgem. Ofgem has ultimately agreed to most of the spend proposals put forward by the companies at transmission level even if it has not always been immediately persuaded of the case and companies have had to provide further evidence.

A particular concern is that for the transmission price control and in its CBA template for distribution Ofgem was using a cost of carbon of only £74/tCO2e when the government figure, updated for the net zero commitment, was around three times that. As a result, it was much harder to justify expenditure to reduce carbon emissions. Although Ofgem now appears to be allowing the networks to use the updated figure in any proposals they bring forward, in distribution there is no reopener mechanism for companies to go back with projects that they could now justify. On transmission the IIG incentive does not adequately incentivise companies to reduce leakage because it is based on the outdated cost of carbon.

Another element of the analytical framework that Ofgem could usefully think more about is how it might treat the risks around equipment needing to be replaced ahead of the end of its useful life if future PFAS regulations outlaw the use of a particular product or if type-fault problems emerge after a number of years of operation. Reassurance that Ofgem understands the costs and asset-management risks of alternatives would give the networks confidence to move ahead more quickly in adopting alternatives for new installations.

Linked to this, another important methodological point that is relevant to policy makers and to networks themselves is the need to look at whole life costs in considering different options. NGET and SSEN are working on a SIF innovation project with the University of Manchester[37] to develop a methodology for looking at replacement, retro-fill and repair options for different age assets, including looking at how to get better data on leakage and improved approaches for SF6 disposal. Taking account of embodied carbon costs of replacement equipment makes sense but can be complex where the origins of raw materials are unclear, for example.

Given the high costs of energy at present, GB policy makers, together with Ofgem, will be reluctant to see further costs added to customer bills. Being able to demonstrate that a proposed intervention is the most cost-effective solution helps address that – and getting the analytical framework right is an important part of that.

Ultimately the costs of eliminating all SF6 by 2050 may prove not to be justified for small equipment with negligible leak rates. Having better data and a robust analytical framework will be essential for making these calls in due course.

Does use of PFAS mean we are creating a future problem?

There is growing awareness of the very high persistence of PFAS and their degradation products, their mobility and the health and environmental risks. The proposed EU restriction which would ban all PFAS is still at an early stage in the policy process and the nature of any GB restrictions is unclear. However, there is a clear risk that in using them in new switchgear we are storing up a potential problem for the future.

In the UK, Defra seem unlikely to pursue a complete ban on PFAS in the near term. However, as with the F-Gas Regulation, the EU PFAS restrictions will shape what equipment is available in GB from EU manufacturers. Public acceptability, potential liability and litigation concerns on use of PFAS chemicals will also be considerations for the networks.

That said, the EU proposal for an outright ban on all PFAS on a precautionary basis would create further supply-chain challenges for the GB networks in the near term, in particular at transmission level, even if a time- limited derogation were allowed. Manufacturers of PFAS based SF6 alternatives will be less likely to develop their product ranges in line with their original roadmaps if a ban is anticipated even if the end-dates are some way off.

Examining the specific PFAS compounds used in switchgear is not a priority for EU REACH or for Defra. However given the wider zero impacts of a ban and the long lives of the assets involved there is a strong case for them to be prioritised for review.

While there is significant overlap between those products that would fall foul of the stringent F-Gas GWP requirements and also PFAS, there are some products that would meet the F-Gas Regulations but fail on PFAS.

There is then a risk that installed PFAS might ultimately have to be removed in the same way as we have seen with PCBs.

There would therefore seem to be real merit in active pursuit of vacuum / natural air solutions (on climate, environmental and safety grounds) and we would hope that F-Gas Regulation and PFAS

[37] See Youtube video (from 30 minutes marker)

concerns will lead to more manufacturers exploring these and looking to overcome the practical barriers that currently limit their use in GB.

However, in the interim there is a real concern that further limiting the options available will jeopardise the UK's ability to meet its 2035 grid de-carbonisation goals. Retaining an aggressive near-term focus on managing leakage levels, including on new equipment, would help and indeed, continued use of SF6 (with tightly managed leakage) might actually be preferable to PFAS solutions, given the risk of future bans on their use. However, these near-term choices and tradeoffs (between SF6, PFAS and network investment delays) are difficult for the networks to make and need wider debate.

For the networks their SBTs push them to use PFAS alternatives in the near term (to reduce SF6 emissions) absent a clear policy steer on how to balance the risks involved between SF6 and PFAS ahead of suitable natural origin gas solutions becoming available across the product range.

Moves to curb PFAS chemicals both in the US and EU need greater visibility, including with Ofgem and government, given the wider implications for the net zero agenda and the difficult trade-offs involved.

7. Conclusions and Recommendations

Our overall conclusion is that there has to be a twin-track approach involving, first, an immediate laser-like focus on reducing leakage but in parallel (given the long-lead times) turbo-charging the industry's actions working with manufacturers to bring forward acceptable SF6-free, non-PFAS alternatives.

We set out below the steps that the different actors – government, Ofgem, networks, manufacturers – need to take to deliver on this.

Regulate to drive new switch-gear product development but don't jeopardise net zero (EU and UK government)

While the best solution from an environmental point of view would appear to be an early ban on SF6 given its high GWP, there are difficult trade-offs involved in the GB context. In particular, achievement of 2035 grid de-carbonisation targets requires a huge increase in network capacity over the next 5-10 years which in turn requires the availability at all voltages of suitable alternative technologies at sufficient volume, that are not prohibitively expensive.

Trying to second guess when suitable solutions might be available is currently very challenging – and setting aggressive targets helps focus minds and drive development of alternatives. What matters in the EU Regulation – and the subsequent Defra Regulation - is that the derogations on the timeline provide the necessary "safety valve" (at distribution and transmission level) so that lack of supply chain availability does not hinder the network growth we need to meet wider climate goals, without creating a loophole so large that it ceases to drive innovation. The priority is that this derogation is workable in practice, recognising cost and practical considerations (including embodied carbon) and allowing case by case decisions to be taken.

Similar considerations apply to potential PFAS restrictions. The prospect of regulation should drive manufacturers to focus on developing natural origin gas alternatives. But in the interim there need to be suitable exemptions linked to the availability of suitable alternatives, to avoid jeopardising the network investment required.

For PFAS it would be helpful to have an early scientific assessment of the risks of the particular compounds used in switchgear to inform UK decisions under UK REACH and to give clarity to the sector about the risks involved in what are long-lived assets.

To navigate these trade-offs in the near-term, joined-up thinking is required across UK government as responsibility for net zero sits with DESNZ while environmental protection sits with Defra.

Put the focus on leakage rather than the bank of installed gas (networks, policy makers)

Ultimately it is the emissions that matter in terms of climate change and all networks, at transmission and distribution levels, should have aggressive leakage management strategies. For NGET in particular there would seem to be significant opportunities to reduce emissions through better leak prevention, detection and repair. Better monitoring to provide better data should allow more sophisticated analytics and a more proactive approach to managing emissions. Even with new equipment monitoring is important to keep leakage to the absolute minimum. This is an area that is ripe for innovation.

Much tougher penalties are needed for significant SF6 leaks and more attention needs to be paid to the arrangements for safe disposal (to ensure that is not a hidden source of emissions).

While eliminating all SF6 from the electricity system would, obviously, eliminate all associated greenhouse gas emissions it is likely to be a slow and costly approach. Collecting data and understanding much better the causes and patterns of leakage will allow more informed policy decisions to be taken in due course on long-term removal.

Ofgem to give SF6 more concerted focus with stronger incentives and increased transparency

Reflecting their new net zero duty, Ofgem should be placing a greater focus on SF6 as the primary source of scope 1 carbon emissions from the electricity networks. The companies will (in large part) take their lead from Ofgem in terms of the importance they attach to the issue.

We need a regulatory regime which addresses the issues raised in section 6 and in particular that:

- Appropriately values investments aimed at reducing leakage and appropriately rewards (or penalises) companies for their operational performance in reducing leakage;
- Provides for greater transparency – in particular at transmission level - through consistent, robust and comprehensive reporting;
- Uses improved data to ensure better-targeted / better-designed regulatory incentives and interventions;
- Holds companies to account for meeting their commitments, comparing performance across the sector, rather than relying on stakeholders to do this company by company.

A continued emphasis on the issue by wider stakeholders will be important in getting Ofgem to take the issue more seriously (as well as in helping hold the companies to account).

Closer working is needed between the Environment Agency[38] and Ofgem given their respective roles – as well as engagement with government more broadly on this issue.

Turbo charge cross-industry collaboration and support a plural supply chain (Networks)

While there are examples of networks working together on innovation projects and there has been an ENA working group on SF6, there is a need for a significant step-up in the sector approach to collaboration given the scale of the challenge now being faced.

Formally the ENA take the lead on inputting to legislation (in particular at EU level via Eurelectric) and providing “type approval” for new switchgear. However there is a valuable role they could play encouraging wider cross industry collaboration and knowledge-sharing as improved monitoring and data analytics allow for better understanding of causes of leakage, for example. With SF6 alternatives being adopted there will be significant learning which should be shared to allow take-up to be accelerated across the industry (and any issues flagged early). A more proactive approach to sharing learning from innovation projects is needed and is, we understand, being facilitated at the transmission level through the Energy Innovation Centre.

Given the supply chain challenges, all the GB network companies need to become expert purchasers of SF6-free equipment and more active in developing close collaboration with the supply chain.

[38] Plus SEPA in Scotland and Natural Resources Wales

There is a need to develop new forms of contractual arrangements to cover maintenance and support services and to cope with potential new liabilities. There are opportunities for networks to share international market intelligence / experience and ultimately, potentially, for a wider collaboration working with government on joint procurement[39] to address supply-chain issues on behalf of GB plc. As sector regulator Ofgem also needs a better grasp of the supply-chain position and the risks involved.

Fill the gaps in knowledge through further work (various)

End of life recycling / disposal (Networks)

This is an area that is currently under-explored. At present most SF6 that is recovered from equipment being replaced is incinerated but the carbon impacts are seemingly not counted in network company reporting. With the new F-Gas Regulation the ban on the use of "virgin" SF6 may create a market for recycled gas with, for example, Celtic Recycling, now offering that service. This should be encouraged. There are questions around other toxins that may be in used SF6 and there is a clear need, as part of any full lifecycle assessment, for end-of-life treatment to be considered. Properly tracking these gases from cradle to grave is also important in ensuring that all leakage has been recorded. The NGET SIF innovation project with Manchester will hopefully explore some of these issues.

Offshore and independent networks (Ofgem)

While this report focusses on the regulated transmission and distribution businesses, as set out in Section 5, there are a number of other GB network business models that serve small but growing proportions of the GB industry – potentially having the opportunity to own and operate all new network assets valued over £100 million and delivering most new low-voltage connections - with little or no oversight of their performance by Ofgem or other regulators. These networks will not have any incentive to manage leakage beyond requirements in the general F-Gas Regulation and there is currently no visibility of the scale of their banks or leakage rates. Further work is needed, ideally led by Ofgem who have the powers to request information and ultimately to introduce standards on leakage rates if necessary.

Keeping up with a moving picture

It has been clear from our work that this is a shifting landscape and this report can therefore only provide a snapshot of the progress and challenges at this particular point in time. The process of interviewing people for this report has, of itself, helped raise the profile of the issues discussed. Updating this report in a few years would help to keep the companies and others focussed on the SF6 challenge and build a broader understanding across all parties of the issues at stake.

Wider debate involving industry, policy makers and environmental groups is important as networks look to navigate through some of the difficult choices and tradeoffs they face over the next 5 years as the market evolves to meet new tougher standards that will put us on a better course longer term.

[39] Subject of course to any competition law restrictions

Resources

Ricardo and Gluckman Consulting: Assessment of the potential to reduce UK F-gas emissions report for CCC (2019) - https://www.theccc.org.uk/publication/assessment-of-potential-to-reduce-uk-f-gas-emissions-ricardo-and-gluckman-consulting/

2020 Report from the EU Commission. 'Assessing the availability of alternatives to fluorinated greenhouse gases in switchgear and related equipment, including medium-voltage secondary switchgear'. Brussels, 30.9.2020 - C(2020) 6635 final - https://climate.ec.europa.eu/system/files/2020-09/c_2020_6635_en.pdf

EPA - SF6 Emission Reduction Partnership for Electric Power Systems (US) - https://www.epa.gov/eps-partnership

Ofgem RIIO ET2 Final Determinations (inc company annexes) - https://www.ofgem.gov.uk/publications/riio-2-final-determinations-transmission-and-gas-distribution-network-companies-and-electricity-system-operator

Ofgem Guidance on ET2 Annual Environment Reports (2021) - https://www.ofgem.gov.uk/publications/riio-2-environmental-reporting-guidance

Ofgem Guidance on ED2 Annual Environment Reports (2023) - https://www.ofgem.gov.uk/publications/decision-riio-ed2-annual-environmental-report-guidance-document-and-template

Ofgem Re-opener Guidance (see Appendix 5 for MSIP SF6) - https://www.ofgem.gov.uk/publications/re-opener-guidance-and-application-requirements-document-version-3

NGET Business Plan SF6 Strategy (2019) - https://www.nationalgrid.com/electricity-transmission/document/131776/download

NGET 2020 SF6 Strategy (in response to Draft Determination) - https://www.nationalgrid.com/electricity-transmission/document/134666/download

NGET MSIP SF6 Asset Intervention Re-opener report (2022) – https://www.nationalgrid.com/electricity-transmission/document/140901/download

NGET Annual Environment Report 2021/22 - https://www.nationalgrid.com/electricity-transmission/document/146001/download

SSEN T Business Plan Strategy for the Management of Insulation and Interruption Gases (2019) - https://www.ssen-transmission.co.uk/globalassets/documents/a-network-for-net-zero/supporting-evidence/our-strategy-for-the-management-of-insulation--interruption-gases-.pdf

SSEN T Annual Environment Report 2021/22 - https://www.ssen-transmission.co.uk/globalassets/documents/sustainability-strategy/aer1---new.pdf

SP T Business Plan Environmental Action Plan (inc SF6 Strategy) (2019) - https://www.spenergynetworks.co.uk/userfiles/file/RIIO-T2_Annex_7_Environmental_Action_Plan.pdf

SP T Annual Environment Report 2021/22 - https://www.spenergynetworks.co.uk/userfiles/file/39727_Transmission_Annual_Environmental_Repor_2021-2022_final_online_version.pdf

Sustainability First Review of ED2 SF6 Strategies (2020) - https://sustainabilityfirst.org.uk/images/Sustainability_First_-_Commentary_-_DNO_ED2_SF6_STRATEGIES_-_final09022.pdf

Manufacturer websites:

Hitachi – Products: https://www.hitachienergy.com/products-and-solutions/high-voltage-switchgear-and-breakers/econiq-eco-efficient-hv-portfolio

ABB – Products: https://new.abb.com/medium-voltage/switchgear/gas-insulated-switchgear/iec-gis-rmu-for-secondary-distribution/iec-gas-insulated-compact-switchgear-safeplus-airplus

Positioning: https://new.abb.com/news/detail/93332/how-to-migrate-to-an-sf6-free-future-ahead-of-impending-f-gas-regulations

Siemens Energy* – Products: https://www.siemens-energy.com/global/en/offerings/power-transmission/innovation/blue-high-voltage-products.html

SF6 Positioning: https://www.siemens-energy.com/global/en/news/magazine/2022/industry-initiative-to-reduce-f-gases.html

PFAS Positioning: PFAS White Paper - here

General Electric (GE) - Products: https://www.gegridsolutions.com/hvmv_equipment/catalog/g3/

Positioning; https://www.gegridsolutions.com/products/applications/hvmv/g3-the-sf6free-solution-in-practice-gea33137.pdf

Schneider* – Products: https://www.se.com/ww/en/work/products/product-launch/sf6free-mv-technology/smairset/

*= member of the Switching Gears for Net Zero Alliance - https://www.switchinggearsfornetzero.com/

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