SF6 & ALTERNATIVES COALITION

Considerations for Planning an SF_6 Phase-Out

Introduction

Sulfur Hexafluoride (SF_6) has been used for decades around the globe to insulate medium and high-voltage transmission and distribution equipment.[1] SF_6 also has an extremely high global warming potential of 23,500[2]. Given its reference in the Kyoto Protocol of 1997 and its potential material environmental impact – if released into the environment - SF_6 is the subject of regulatory policies in the U.S. and internationally:

United States: In 2009, the U.S. Environmental Protection Agency published a regulation for the mandatory reporting of greenhouse gases (including SF_6) from large emissions. Shortly thereafter, two state environmental agencies (California Air Resources Board and Massachusetts Department of Environmental Protection) promulgated their own respective SF_6 emissions reporting regulations, both of which contained an emission reduction requirement. All three regulations continue in force, though as of July 2020 California is considering a major overhaul to its current requirements.

European Union: In 2006, the European Union passed a regulation with requirements for labeling and recovery of equipment containing fluorinated greenhouse gases: the European F-Gas Regulation EC no. 842/2006. Although this Regulation focuses on hydrofluorocarbons and air conditioning equipment, electrical equipment containing SF_6 is also in scope. The Regulation also delineates requirements for training and certification of gas handlers. A revised regulation in 2014 – the European F-Gas regulation EC no. 517/2017 – includes requirements for leak prevention, detection and monitoring, and a phase-out of selected fluorinated gases on the market. So far there are no application restrictions for electrical equipment containing SF_6 in this Regulation. European regulators have begun discussions for further revisions to the Regulations, with the aim of becoming the first carbon-neutral continent by 2050.

Asia: There are no SF_6 regulations that pertain specifically to transmission and distribution operators. But other programs exist. In Japan, fluorocarbon gas manufacturers and importers are encouraged to reduce production and distribution, and to recycle fluorocarbon gases where possible. South Korea tracks annual emissions of SF_6 in the Energy Sector through a national Greenhouse Gas (GHG) Inventory.

Beyond regulations directed specifically towards SF_6, many countries, some states and local municipalities have committed to reducing carbon footprints within their jurisdictions. In some cases, SF_6 emission reductions are part of this broader effort. Furthermore, in the absence of government mandates, some electric utilities are starting to act voluntarily to reduce emissions of SF_6. The purpose of this paper is to inform decision-makers, whether public or private, about the relevant and material considerations that should factor into a decision about a phase-out or ban of SF_6. This paper will cover different approaches to structuring a phase-out, implications for the gas-insulated equipment (GIE)

[1] For further information on background and use, see the SF_6 & Alternative Coalition's paper entitled "Alternative Insulation Technologies."
[2] Working group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, pg 749: https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_all_final.pdf

market as well as the SF_6 supply chain, availability and viability of SF_6 alternatives, and possible incentives. This paper is not intended to constitute a recommendation for government agencies or system operators to change current policies or practices related to the use of SF_6. We simply offer considerations that should inform that process.

Basis of a Phase-Out Structure

Regardless of whether the phase-out planner is a government agency or a private entity, the first step in the planning process is to define the objective: What do you want to accomplish and over what time period? Once that is defined, there are a range of questions to be answered when structuring a phase-out. The following list of questions will help in defining an appropriate scope by understanding what is possible, what is realistic and what is desirable, and structuring a corresponding framework:

Ratings: What equipment ratings should and could be covered under the phase-out? The availability of alternative insulation technologies depends largely on the maximum voltage rating, continuous current rating, and short-circuit current rating. Other factors may be relevant as well.

Applications: What equipment applications should be covered under the phase-out? This refers to whether the equipment will be indoor or outdoor, pole-mounted, pad-mounted or underground. This determination will lead to further analysis about space and size limitations, severity of temperature and environmental conditions, and applicable standards for safety, reliability and performance. One should also consider specific applications such as shunt reactor switching, shunt capacitor switching and the intended frequency of operation. These applications in particular are becoming more relevant due to the increasing introduction of renewable generation in the power network.

Timing: Over what time period should and could the phase-out take effect? This goes beyond an assessment of the availability of alternative insulation technologies. Length of time required to develop purchasing specifications, pilot various technologies, solicit quotes from multiple vendors, and order and install new equipment must all be taken into account. In addition, engineering, maintenance and operation personnel must be trained on the design, application, and alternative gas handling processes (where applicable) for safety and quality assurance of new equipment. The training must go beyond initial installation and commissioning of the equipment, but also include operation and maintenance of the equipment over its full lifetime.

This timetable must then be replicated for each piece of equipment across the system that will ultimately need to be replaced and set against system parameters that dictate how often and for how long portions of the system can be out of service. This includes assessing the availability of service manpower, financing, access to sites, etc. while ensuring continuous and reliable power supply.

Equipment Scope: Will the phase-out require the replacement of existing equipment or only impact the installation of new equipment? How do replacement parts, themselves insulated by SF_6, factor into the approach?

Emission Scope: Is the phase-out directed specifically at SF_6 or part of a broader effort to reduce the carbon footprint of a specific jurisdiction or operating territory? If the latter, what latitude will regulated entities have to determine how to meet the regulatory requirements?

Scope Exceptions: What exceptions will the framework include, taking into account factors such as cost (CAPEX and OPEX), safety (for personnel and assets), reliability, performance, spacing constraints, and product and power network availability?

Emissions Reduction: Should the framework include procedures/requirements to curb emissions from existing GIE (i.e. comprehensive leak detection/repair, reuse of existing SF_6 gas inventories, reconditioning of SF_6 gas, etc.)? These can be just as effective to reduce a carbon footprint as phasing out SF_6.

Answering each of the above questions in a way that is consistent with the defined objective will form the basis for structuring an SF_6 phase-out for its applicable market or system or application. The remainder of this document discusses various considerations about likely impact (intended or unintended) of a phase-out. Decision-makers should, at the very least, anticipate these and, to the extent possible, develop plans to address them.

Replaced GIE and its SF_6 Contents

In any framework, decision-makers must consider how to dispose of the SF_6 GIE being replaced, along with the gas contaminants, if any. For the SF_6 equipment, refurbishment/resell has historically been an option. However, in the case of a phase-out, refurbishment will not be an option (unless GIE can be sold and shipped to a non-phase-out geographic market). Nor is it viable in most cases to convert SF_6-insulated technology to an alternative insulation by retrofitting the equipment. One option that will be available in a phase-out is to sell the equipment into the scrap metal market. Along those lines, if utilities decide to phase-out SF_6-insulated technology in a short time period, the increased supply in scrap metal could result in a decrease in price, further diminishing utilities' ability to recoup investment. For reasons previously mentioned, large scale scrapping of older equipment could reduce the supply of second-hand equipment that potential purchasers rely on for low-cost, quality products or for replacement parts for existing equipment.

Another example of an impacted adjacent market is the SF_6 supply market. The demand for virgin SF_6 would likely fall in the event of a phase-out, which could impact price of available supply for other industries in the same geographic market that require virgin SF_6. Among these would-be impacted industries and sectors including: the defense industrial base, medical equipment applications, semiconductor manufacturers, and magnesium producers and processers.

SF_6 from GIE being replaced by alternative technologies could be reclaimed and re-conditioned to supply needed SF_6 for new GIE (in ratings/applications allowed by the phase-out) and for replenishment of SF_6 used for general maintenance, leakage and handling emissions in existing GIE. The re-conditioned SF_6 market is already well established, and re-conditioned SF_6 is able to achieve a level of purity that is effective and appropriate for use in most utility and power equipment applications.[3] Accordingly, a phase-out might grow the re-conditioned gas market temporarily. But ultimately, this market would decrease as the phase-out framework expands.

Environmental Impact and Life Cycle Assessment (LCA)

Decision-makers should consider the environmental impact to retire existing SF_6 equipment in the event of a phase-out, especially if before the end of the expected service life. A thorough assessment of the environmental impact includes analysis of the ratio of recyclable materials to non-recyclable materials from decommissioned SF_6 equipment. While recyclable/recycled materials contribute to a circular economy, thereby mitigating environmental impact, the non-recyclable materials are likely to end up in a

[3] CIGRE SF_6 Recycling Guide

landfill. Some GIE may only contain a low percentage of recyclable materials, while others may have a much higher percentage.

Used SF_6 can be recycled or destroyed, and procedures for both are well recognized. However, the occurrence of the latter will increase as more markets and systems gravitate towards phase-out. SF_6 emissions occur during a commonly used incineration processes for destruction, though they are difficult to quantify.

A thorough life cycle assessment involves not only an analysis of climate change impact but also the complete environmental impact to produce, transport, install, operate, maintain and decommission the SF_6-free asset throughout its intended service life. LCA also includes other significant aspects such as ozone depletion, human toxicity, particulate matter, ionizing radiation, ozone formation, acidification, eutrophication, fresh-water ecotoxicity, water consumption, land usage and resource depletion. These aspects are significantly affected by the material content and mass of the equipment. Decision-makers should note that these categorical dynamics exist for both SF_6 GIE and non-SF_6 GIE, so the same type and level of assessment should be applied to both to attain an equitable comparison.

End of Life Considerations

Apart from selling used equipment and gas into secondhand markets, utilities may choose destruction as an alternative method of disposal. Procedures to destroy SF_6 are fairly well known but not popularly practiced and involve destroying the gas in high-temperature kilns, converting the vapor to a solid which requires neutralization. There are existing service providers that can maximize efficiencies due to economies of scale to perform SF_6 destruction on behalf of utilities. As noted above, SF_6 emissions occur during destruction.

GIE owners also tend to rely on third-party service providers for destruction of the equipment itself. However, there are several steps that must be completed prior to removal of the GIE offsite. These steps include: decontamination of the SF_6 gas chamber (if necessary); disposal of operating mechanism hydraulic/pump oil; de-energizing any operating mechanism pre-charged systems; and, in the case of older equipment, removal of insulation with asbestos. Due to inherent complexities, these steps are also often performed by third parties

The re-conditioning and destruction processes for alternative gases either do not exist or are not well established at this point. Stakeholders are aware of the need to develop environmentally friendly end-of-life plans to address both re-conditioning and destruction challenges where such exist.

Incentives to Accelerate Emission Reductions and Proper Gas Recycling or Conversion

Public agencies are in a position to incentivize parties for meeting or exceeding certain benchmarks. In some cases, an incentive program could be a substitute for a phase-out. Such a program might entail imposing financial penalties on regulated entities if emissions exceed a certain threshold, while at the same time rewarding regulated entities with "credits" if emissions are below the threshold. "Credits" could be in the form of less restrictive reporting requirements, for example.

Another incentive mechanism might be to limit the amount of new or "virgin" SF_6 that a regulated entity can procure. This would allow for the reduction of global emissions and likely lead to greater voluntary internal controls to reduce emissions during insulation, as well as recycling.

Gas Performance Differences

There are a variety of operational considerations when moving to phase out use of SF_6 from a given market or system. A principal consideration is the fully industrialized readiness of alternative gas technologies for given ratings and applications. For example, some alternative gases are only appropriate for medium or high voltages, but not both. When compared to SF_6 some alternative gases do not provide equivalent insulation or arc quenching performance, which means that equipment using alternative gas technologies may be larger than SF_6 equipment and operate at higher pressures. As with SF_6, alternative gas GIE may be designed to operate within the entire spectrum of climates and present no inherent limitations for operation at high temperatures. Operation at low temperature extremes is also possible, though some gases may require additional heating or insulation devices.

Additionally, some alternative gas technologies may require different maintenance and monitoring procedures than SF_6. For example, most alternative gas mixtures on the market presently are comprised of base dielectric insulating gases that do not fully recombine after disassociation from high temperature arcs. This could result in somewhat greater degradation of the gas and its long-term effects on the performance of the equipment as compared to SF_6, but which can also be mitigated with design and maintenance strategies.

Over time, the market for alternative gases will likely evolve to address some or all of the above issues, though we make no projection regarding the timeline of that evolution. In the interim, regulated entities and regulators must consider the real (fully industrialized) readiness and range of alternatives for specific applications and ratings.

Operational Considerations of Alternatives

Another critical consideration is human exposure to alternative gases. For example, the U.S. Occupational Safety and Health Administration (OSHA) has established an 8-hour time-weighted average permissible exposure limit (PEL) of 1,000 ppm for SF_6, meaning this level of inhalation over this time period is safe for humans.[4] Some alternative gases do not yet have OSHA PELs, but producer analyses yield much lower exposure limits.[5] Given that human exposure to these gases in reality is not likely to approach the eight hours used in the OSHA model, we are not suggesting a specific level of risk to employee health; we only recommend that this information be considered by decision-makers.

Some alternative gases on the market are really mixtures comprised of several different gases. Dealing with gas mixtures, as opposed to a single gas like SF_6, creates additional handling complexities. For example, some gases (e.g. mixtures) can only be procured as separate components and therefore require mixing and homogenization in the field to ensure that molecules are thoroughly and equally spread throughout the equipment. With these gases, on-site mixing apparatus may be required to manage the weight and ratio of each component gas. While this requirement does not apply to alternative gases that come pre-mixed, auxiliary equipment may still be necessary to pre-heat and homogenize gas mixtures before filling the GIE. Further, additional gas equipment such as analyzers and leakage detection equipment are required for handling.

Potential leakage rates highlight an additional complexity: over time the constituent gases of a mixture may leak at different rates, resulting in a change in the gas composition. Design and maintenance strategies exist to address this.

Some GIE containing alternative gases may also require use of higher filling pressures as compared to SF_6. This may be an operational consideration for decision-makers who would need to revise their

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[4] https://www.osha.gov/dsg/annotated-pels/tablez-1.html

[5] See 3M Novec 4710 Insulating Gas Health & Safety Bulletin: https://multimedia.3m.com/mws/media/1132124O/3m-novec-4710-insulating-gas.pdf; see also 3M Novec 5110 Insulating Gas Health & Safety Bulletin: https://multimedia.3m.com/mws/media/1812232O/3m-novec-5110-insulating-gas-health-safety-bulletin.pdf

operating procedures to account for the change in filling pressure. For example, it will be important to ensure that handling/maintenance equipment in use is designed for the increased pressure.

Summary

The SF_6 & Alternatives Coalition has no position on SF_6 market or system phase-outs. We only recommend that decision-makers conduct a thorough analysis of the numerous factors that inform the decision and timeline to phase out SF_6. These factors range from operational considerations to environmental ones; and from supply chain availability to downstream market impact to total life cycle impact. Though the driving factors are often environmental, and other commonalities do exist, there is no "one-size-fits-all" approach to a phase-out, meaning that structure and timing can and should vary from system-to-system and jurisdiction-to-jurisdiction.

About the SF_6 and Alternatives Coalition

Formerly named *The Electric Transmission & Distribution SF6 Coalition*, the SF_6 & Alternatives Coalition is comprised of 18 members who are producers and distributors of SF6 and SF6 alternatives, manufacturers of gas-insulated equipment, a California utility, and other SF6 stakeholders. Our mission is to:

1) provide a forum for equipment manufacturers using SF_6, SF_6 producers and distributors, and transmission and distribution equipment owners for discussion of environmental concerns of SF_6 as a greenhouse gas;

2) develop best practices and recommendations related to sustainable SF6 usage in electric power transmission and distribution;

3) advocate the Coalition positions to federal, state, and local policymakers;

4) educate public and private stakeholders on SF6 alternatives; and

5) maintain liaisons with government and industry groups such as U.S. EPA, Institute of Electrical and Electronic Engineers (IEEE), EEI, IEC, CIGRE, and EPRI.