SF_6 End-of-life Recycling for Medium and High Voltage (MV & HV) Equipment

by Jean-Marc Deux

Executive summary

Sulphur Hexafluoride (SF_6) is a greenhouse gas that is widely used as an insulator and breaker medium within switches, circuit-breakers, and other MV and HV electrical transmission and distribution equipment. During the equipment life cycle, use of SF_6 helps improve human safety, reliability, and ease of maintenance. However, at end-of-life, governments require strict adherence to equipment disposal regulations. This paper offers guidance on safe, legal methods for MV and HV equipment disposal and recycling.

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Schneider Electric

Introduction

When MV and HV electrical equipment insulation or breaker component materials contain Sulphur Hexafluoride (SF_6) and the equipment is near end-of-life, special care must be taken in the recycling process. SF_6, at the time of disposal, is recognized by numerous government organizations as hazardous waste. Since the 1990s it is known that 1kG of SF_6 vented into the atmosphere corresponds to roughly 23 tonnes of CO_2.

As a result, SF_6 gas is regulated at the local, state, federal, and international levels. The myriad of compliance legislation that exists must be adhered to. Fortunately, owners of power equipment technologies that contain SF_6 don't need to concern themselves with the risk and complexity of disposal and recycling if they involve knowledgeable, legitimate partners when retiring obsolete electrical equipment. Schneider Electric, for example, purchases and uses hundreds of tonnes of SF_6 per year as part of its manufacturing process. Therefore, a detailed end-of-life program has been put in place across the globe to help support customers who are confronted with SF_6 equipment end-of-life recycling issues.

Users of electrical equipment need to familiarize themselves with the legal status of their equipment and with the operational procedures for disposal. A failure to do so can result in penalties and can cause harm to the environment. As SF_6 use within the electrical industry is forecast to grow approximately 50% by the year 2030[1], (see **Figure 1)** most organizations will have to establish policies that allow for safe disposal and recycling of their electrical equipment.

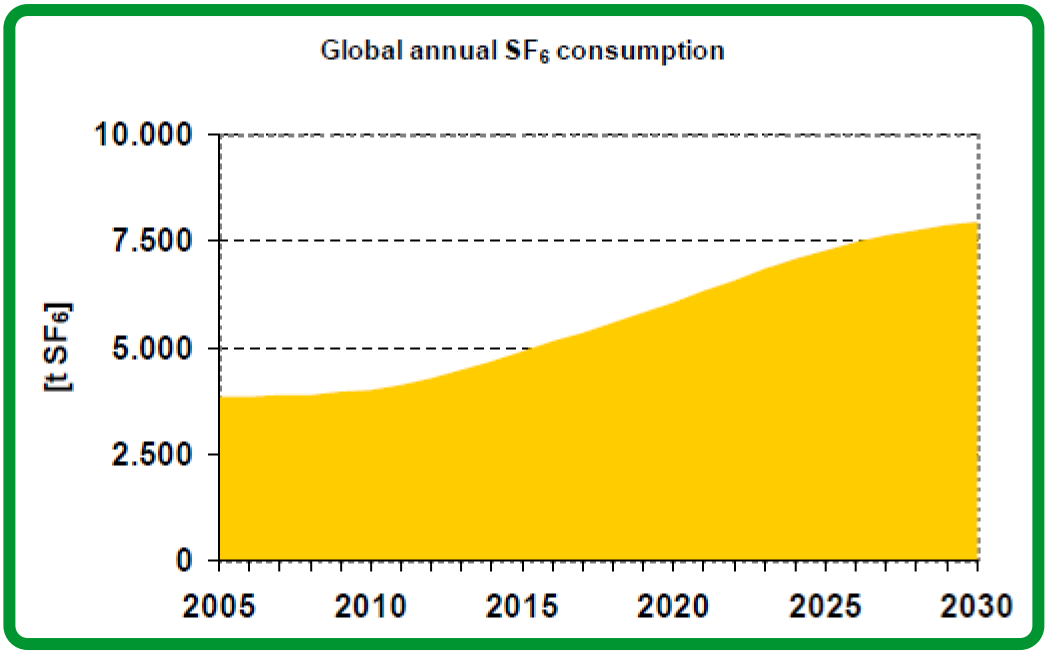

Figure 1
Projected growth of SF_6 global consumption including HV & MV electrical equipment

Life cycle analysis of SF_6 and SF_6-free technologies has shown that both have very similar carbon footprint profiles. However, SF_6-based technology has demonstrated advantages in terms of safety, ease of maintenance, and operational continuity. This is why consumption of SF_6 is growing year after year. This white paper provides guidance for how users of electrical equipment containing SF_6 can properly dispose of and recycle their equipment.

[11] ECOFYS, "Update on global SF6 emissions trends from electrical equipment-edition 1.1", page 29, 2010

Effects of SF_6 on the environment

In its pure state, SF_6 is not poisonous to human beings or other forms of plant or animal life. It is also not an ozone depleting substance (ODS). Therefore, SF_6 in its pure state is not a dangerous material according to the local legislations for chemicals. However, SF_6 does pose a threat as an enabler of global warming. Its high Global Warming Power (GWP) classifies it as a greenhouse gas and therefore, it is monitored around the world as mandated by the Kyoto Protocol.

SF_6 has a GWP of 22,800[2] which means that 1 kg of SF_6 is equivalent to 22,800 tons of CO_2. It is the gas with the highest GWP in the world and has an atmospheric life span of 3,200 years. However thanks to effective electrical industry closed cycle re-use processes (recycling for re-use), SF_6 still remains the smallest contributor to global warming of the greenhouse gases (see **Table 1**)[3].

Table 1
Contribution of various greenhouse gases to global warming

Greenhouse gas	Concentration (parts per billion)	Concentration Percentage
CO_2	353.10^3	60%
CH_4	17.10^3	15%
N_2O	310	5%
O_3	10.50	8%
CFC-11	.28	4%
CFC-12	.48	8%
SF_6	.002	.1%

Schneider-Electric continues to utilize SF_6 in its products because, though not ideal, it allows for compactness and perfect insensitivity in harsh environments. In addition, aggressive and robust recycling and end-of-life processes (see **Figure 2**) help to make SF_6 a low contributor to global warming. The use of SF_6 technology in electrical equipment remains one of the least harmful solutions from a global environmental point of view.

When electrical equipment reaches the end of its useful life, the equipment usually contains gaseous and solid SF_6 decomposition by-products which are toxic and corrosive. The main potential gaseous decomposition by-products are HF, SO_2, SO_2F_2 and SOF_2. Their respective concentration can range from a very few parts per billion to a few percentage points of the volume of the SF_6. The existence of molecular sieves placed inside SF_6 equipment compartments help to absorb most of these gaseous decomposition by-products during the lifecycle of the electrical equipment. The by-products result from partial discharges or the process of breaking load during the lifecycle of the electrical equipment.

Sometimes, some solid powder by-product (a few grams) can also accumulate inside the enclosure containing the gas during the equipment's lifecycle. Special care must be taken by the operators extracting the gas in order to prevent the breathing-in or touching of this powder. European Union Directive n°305/2008 states that all personnel handling SF_6 gas must be trained and certified by authorized certification bodies.

[2] Climate Change 2007, Intergovernmental Panel on Climate Change, Working Group 1, Chapter 2.10.2.

[3] Ecofys Emission Scenario Initiative on Sulphur Hexafluoride for Electric Industry (ESI-SF6), "Update on global SF_6 emissions trends from electrical equipment" –, Edition 1.1 01.07.2010

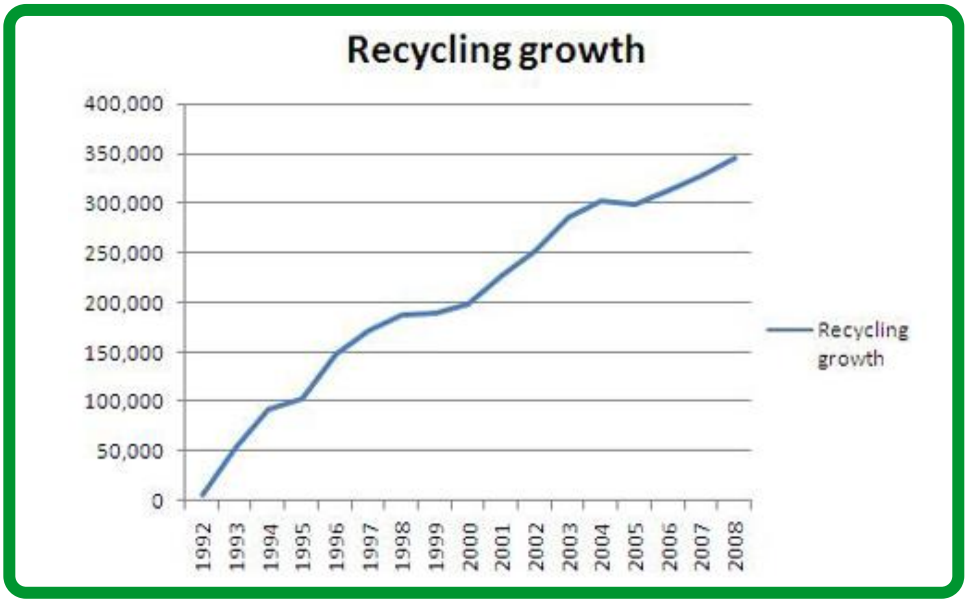

Figure 2
SF6 (kg) recycling growth trend from 1992 to 2008

End-of-life process for MV and HV units

Due to its high GWP, SF_6 is considered a hazardous waste at the moment of its end-of-life by a majority of countries. Therefore, only licensed or authorized hazardous waste managers are allowed to handle, transport, recycle, or destroy the gas according to national or regional regulations and standards. In some countries, the hazardous waste owner must acquire an authorization number after having registered as a hazardous waste producer (even though in most cases he will subcontract the end-of-life process to licensed waste managers). **Table 2** provides an illustration of some global and regional regulations and standards.

During the end-of- life process, the expectation, based on the modern processing tools available, is that less than 0.5% of the recoverable SF_6 volume results in emissions. Pick-up, transportation, and dismantling of the obsolete electrical equipment must be executed in a manner that allows for safe handling. For example, it is recommended that electrical equipment be strapped safely on a pallet and fixed on the truck platform prior to transport.

Since the concentrations of toxic and corrosive substances within SF_6 decomposition by-products remain in most of the cases below the ADR regulation threshold (ADR refers to the European Agreement Concerning the International Carriage of Dangerous Goods by Road), SF_6 gas transported inside spent electrical equipment is subject to United Nations (UN) code 3164. SF_6 gas contained within a bottle is subject to UN code 3163 regulations. Labeling and packaging should therefore adhere to ADR regulation requirements. UN hazardous waste codes concerning the transportation of waste include UN code 16 05 04* [* = hazardous waste] when the SF_6 is contained inside a bottle and UN code 160213* [* = hazardous waste] when SF_6 is contained inside MV electrical equipment (see **Table 2**)

Prior to transportation or shipment of the SF_6, specific transportation tracking documentation must be filled out by the waste owner, the licensed forwarder, and the recycling company. That same documentation must be properly filed by the waste owner after shipment has been completed. This transport tracking document legitimizes the shipment in the eyes of the authorities and serves as proof that the hazardous waste has been transported by an authorized carrier.

If transportation requires the crossing of borders, the authorities of the departure, transit, and destination countries / states must be notified prior to shipment and must issue an approval for such transport. The authorities will request a description of the exact route to be taken and will require proof that only licensed stakeholders are involved in this shipment. In addition, the waste owner is requested to sign a bank guarantee covering the cost of shipment back to the point of origin should any issue emerge during transport.

Table 2
Identification of main global and regional regulations and standards

Geographical jurisdictions	Key regulations	Key technical standards
UN regulations (global)	United Nations (UN) ADR (Agreement of carriage, labeling and packing of Dangerous goods by Road) regulation (and equivalent by sea or air) – UN 3163, 3164 or UN 3308 United Nations (UN) Waste transportation regulation – UN 16 05 04*, 160213*	IEC 60 376 - Specification of technical grade SF_6 for use in electrical equipment IEC 62271-4 Handling procedures for sulphur hexafluoride (SF_6) and its mixtures.
European Union regulations	EU regulation n°305/2008 - Training and certification of all SF_6 handling operators) EU regulation n°842/2006 - Rules of reporting, emissions reductions, labeling	IEC 60 376 - Specification of technical grade SF_6 for use in electrical equipment IEC 62271-4 Handling procedures for sulphur hexafluoride (SF_6) and its mixtures.
USA regulations	GHGRP 2011 - Green house gas global reporting rules SF_6 Emission Reductions from Gas Insulated Switchgear (California), 2007	ASTM D2472 - Specification of technical grade SF_6 for use in electrical equipment and use and handling of SF_6 IEEE C37.122.3 – IEEE Guide for Sulphur Hexafluoride (SF6) gas handling for high-voltage (over 1000Vac) equipment
China regulations	China national climate change program (not specific to SF_6 gas)	GB/T8905-1996 - Electrical Management and Checking Guide of SF_6 Electric Apparatus) GB12022-1989 - Industrial Usage of SF_6 DLT 595-1996 - Rules for supervising SF_6 gas in electrical apparatus

When the electrical equipment begins to be dismantled, copper, aluminum, and iron components (which make up most of the spent electrical equipment) need to be segregated and stored in different, separate containers. The envelope / enclosure containing the SF_6 should also be carefully set aside. This separation of materials facilitates the processing work and improves the efficiency rate of the recycling. A recycling rate of up to 98% can be achieved under the best of conditions.

During the dismantling step, the enclosure containing the SF_6 must be identified and isolated as soon as possible. This minimizes the possibility that an inadvertent dent or damage during the dismantling process allows the SF_6 to escape into the atmosphere.

The main tool used to connect to the enclosure to extract the SF_6 gas is a vacuum pump coupled with specially designed valves (see **Figure 3**). The gas, once extracted, is then stored inside dedicated bottles. The pump must be configured to allow a remaining pressure level of maximum 20 millibar (mbar) inside the SF_6 compartment. This allows for comprehensive quantities of SF_6 to be recovered for later recycling. In this phase, leakages must be avoided and measurement of residual emission must remain below the 0.5% of SF_6 volume recovered.

Figure 3
Example of a typical vacuum pump used to remove SF_6 gas

Once the bottles are full of recovered SF_6, they are transported with care to a recycling facility in order to be purified. A battery of filters removes water, air and the remaining small quantities of toxic and corrosive by-product materials. At the end of this recycling step, a certificate of recycling showing the quantity of SF_6 recycled (in kg) should be issued by the recycling company and archived by the waste owner. This certificate serves as proof that the SF_6 has been properly recycled and that the liability of the waste owner is at an end. In most cases, 98% of the recovered SF_6 can be reclaimed for further re-use in electrical equipment.

The enclosure that originally held the SF_6 has to be opened with care because it may contain a white powder which consists of solid SF_6 decomposition by-products. Gloves, goggles and a mask should be worn by the operators during this neutralization step which consists of spreading a basic solution in order to neutralize the acidity of this power and to render it non-toxic and non-corrosive. After neutralization, the former white powder that has absorbed the neutralization solution is gathered and placed in a special bag marked for safe destruction. **Figure 4** summarizes the SF_6 recycling steps.

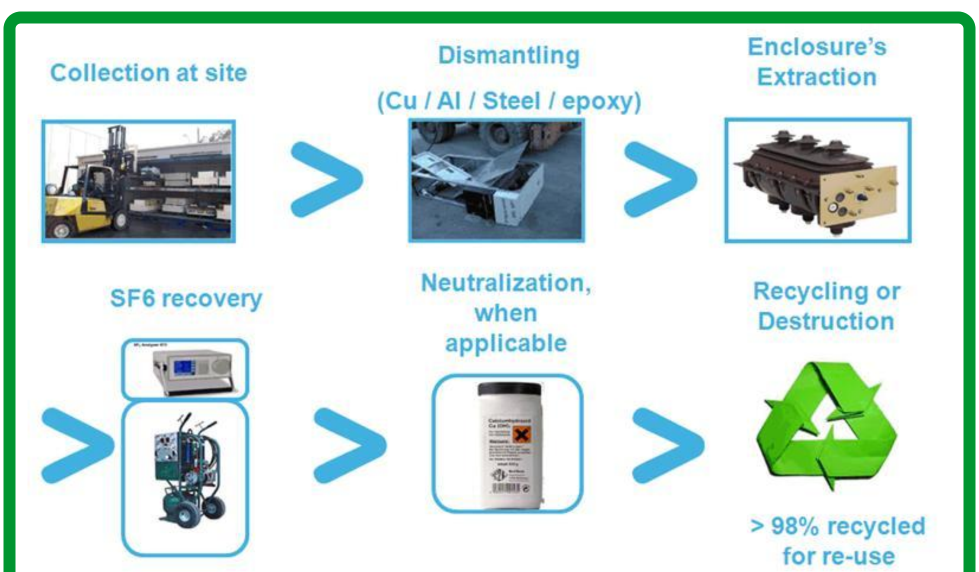

Figure 4
The recycling of SF_6 has evolved into a very efficient system having minimal impact on the environment

Conclusion

The SF_6 technology imbedded in electrical equipment represents no threat to the planet as long as the SF_6 is properly handled, recovered, recycled and re-used in a closed cycle. SF_6 recycling is highly regulated at the local, national, and international levels and penalties for non-compliance are severe. SF_6 end users are not expected to be familiar with the large volume of regulations that affect the recycling process, but businesses must be cognizant of the issues involved. By working with reputable licensed and authorized partners, most SF_6 technology MV and HV electrical equipment owners can safely dispose of their spent equipment.

In addition to peace of mind for the individual responsible for equipment disposal, compliance to the regulations will contribute to carbon emission reduction. Recycling 1 kG of SF_6, for example is equivalent to the removal of 133.000 kilometers worth of automobile emissions. The launching of a SF_6 disposal initiative begins with an audit of equipment that is near end-of- life. Once the quantity of equipment has been identified, a plan can then be developed with the appropriate partner to begin the formal disposal and recycling process.

About the author

Jean-Marc Deux is the Field Services End-of-Life Program Manager at Schneider Electric. He holds 2 Master's degrees in Electrical Engineering from the University of California Los Angeles, USA and the Institut National Polytechnique de Grenoble, France. He also holds an Executive MBA from the Ecole Supérieure de Commerce de Paris, France. He has worked in multiple areas spanning from logistics and supply chain to projects and order execution with specialization in MV electrical equipment. He is a member of the SF_6 task force at T&D Europe Group and actively lobbies European institutions for safe disposal of SF_6 and its by-products.