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SF_6 IN THE ELECTRIC INDUSTRY, STATUS 2000

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Greenhouse effect is a real concern for the future of our life on earth. Electricity industries are leading players for the control of greenhouse gases, mainly through the generation of electricity and the related CO_2 production, less known SF_6 widely used in the electricity industry, has a rather strong 'global warning potential' and has been put in the list of the 'greenhouse gases' of the Kyoto Protocol. It is therefore important to know the most accurate figures concerning this gas and its emissions in the atmosphere, for to-day and for the mid-term. It is the purpose of the work carried out by a CIGRE Working Group 23.02 reported in the following paper.*

* The paper can be downloaded from the CIGRE web-site.

ABSTRACT

A survey is given of the present situation concerning the environmental implications of SF_6 used in electric power equipment. Recently published data on global SF_6 production and emission are critically evaluated and extrapolated to the future. They show that the efforts of the electric industry, namely, original equipment manufacturers (OEM) and users of electric power equipment (utilities) to reduce SF_6 emissions are being successfully implemented and that a substantial further emission reduction can be expected.

It is also shown that the environmental impact of SF_6 cannot be judged by its global warming potential (GWP) alone, but that several other factors, which are reviewed in detail, have to be taken into consideration. Recommendations are made for providing a basis for a rational discussion of the issue.

INTRODUCTION

The high global warming potential of SF_6 became known in 1995, as a consequence of which the gas was put on the list of greenhouse gases in the Kyoto protocol 1997 [1]. The high GWP of SF_6 triggered various efforts to reduce its emissions from SF_6-insulated transmission and distribution (T&D) equipment. These efforts range from improved sealing of equipment over improved gas handling procedures, systematic gas reuse and voluntary emission reduction programs in the electric industry, to governmental regulatory actions. Key issues in the ongoing discussion on the environmental impact of "electric" SF_6 are the *quantitative* facts of atmospheric SF_6 emissions, the efficiency of ongoing SF_6 emission reduction efforts and the role of the SF_6 used in the electric industry in a more general environmental context. This note summarises the presently known facts, tries to extrapolate them into the future and presents, as conclusion, suggestions for supporting a rational discussion of the SF_6 issue.

FACTS AND TRENDS OF ATMOSPHERIC SF_6 EMISSIONS

Key information for an evaluation of the environmental impact of the SF_6 used in the electrical industry (OEM and utilities) is the global SF_6 balance, which is controlled by production, banking of gas in newly installed electric equipment and release into the atmosphere by leakage and handling.

The **global SF_6 production** can be inferred from the annual SF_6 sales world-wide, which were compiled by the major SF_6 producers world-wide in two surveys [2] [3]. These data do not include the SF_6 production in Russia and China and the losses at the SF_6 producers themselves. The production in Russia and China was estimated in [4] to be 400 t/y in 1992 and 880 t/y in 1996. For lack of proper data we tentatively extrapolate these figures to 400 t/y before 1995, a linear rise from 1995 to 1998 and a constant value after 1998. As the gas producers claim to have SF_6 release rates 0.5 % to 8 % of their sales [5], we will account for these by adding an average of 3 % to the sales. The thus corrected total production is represented as the uppermost curve in **figure 1**.

The annual rate at which SF_6 is **banked in newly installed electric power equipment** was estimated to be 2000 t/y in 1995 [4]. This figure is roughly consistent with an estimate of the banking rate in GIS, which has recently been evaluated by the CIGRE WG 23.02. The rate at which electric power equipment is being installed world-wide has been approximately constant over the last decade and is expected to stay constant during the next decade [6]. The banking in newly installed equipment is assumed to slowly decrease since 1997, because the quantity of SF_6 required per installation goes down due to improved design and other factors. We assume the banking rate to decrease from 2000 t/y in 1996 to 1500 t/y in 2000 and to 1200 t/y in 2010.

Unlike for electric applications, the gas used for non-electric applications is usually not recoverable. Most of this gas is immediately released (e.g. cover gas in the magnesium industry, semiconductor industry, military applications) and a smaller fraction of it is released with some delay (e.g. tires, sport shoes, insulation in double-glazed windows). For simplicity, we approximately assume **immediate release of all "non-electric" SF_6**. We then obtain the **calculated global atmospheric release rate** as the difference between the total production rate (upper- • • •

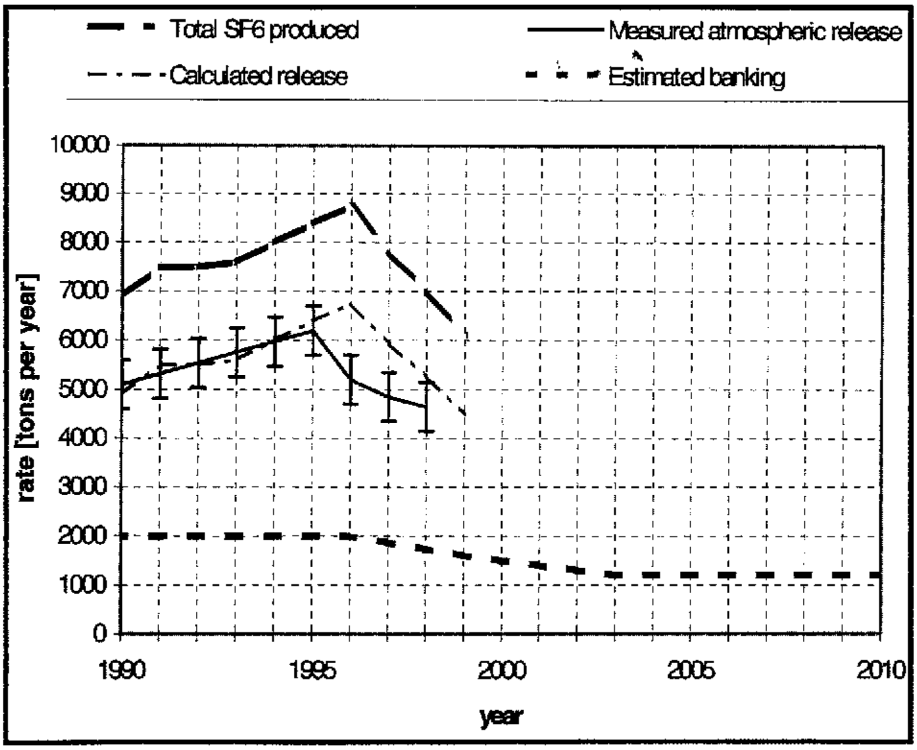

Figure 1: Elements of global SF_6 balance: The total atmospheric release rate (dot-dashed curve) can be calculated as the difference between the total production rate (uppermost curve) and the estimated rate of banking in newly installed electrical power equipment (lowest curve). This calculated release rate is seen to roughly coincide with the measured atmospheric emission rate (solid curve with error bars).

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most curve in figure 1) and the banking rate in newly installed electrical power equipment (lowest broken curve in figure 1). This calculated release rate is represented by the dotted curve in figure 1 and can be checked against the **measured atmospheric SF_6 emission rate** represented by the curve with attached error bars. This curve is determined from the increase of the SF_6 concentration in the atmosphere, which is monitored by various atmospheric research institutions (e.g. [7]). It is seen that this measured emission rate roughly coincides with the calculated release rate, which confirms the approximate consistency of the assumptions that had to be made above.

In their global annual SF_6 sales data [2] [3] the major SF_6 producers also declare the fractions of the total production, which were sold to the utilities and original equipment manufacturers. These data will be referred to as **"sales"** to the electric industry and are shown as the uppermost (broken) curve in **figure 2** (data from the RAND study [3]). As the data in [2] and [3] are partly contradictory it is important to cross-check them with an independent data source, namely, the purchases recorded by the electric industry (OEM and utilities). Such data have been published for Japan [8], The European Union (EU 15) [9] [10] and the US [11]. As these regions cover the vast majority of "electric" SF_6 purchases world-wide they can be completed by estimates for the "rest of the world". The "bottom-up" data thus obtained will be referred to as **"purchases"** by the electric industry. Their total (OEM + utilities) is represented by the dot-dashed curve in figure 2. It is seen that the sales data substantially overestimate the purchases till about 1998. Possible reasons for this discrepancy were discussed in detail in [4]. Around 1999 the data become approximately consistent.

The purchases by the OEM are partly banked in newly installed equipment and partly lost during testing, manufacturing and commissioning. Note that the banking of gas in new equipment at commissioning is normally handled under the responsibility of the OEM. The purchases by the utilities essentially cover leakage and handling losses during equipment operation and are therefore all released. Subtracting the gas banked in newly installed electric equipment (see broken curve in figure 1) from the total purchase by the electric industry one obtains an estimate for the **total release from the electric industry**, represented by the solid curve in figure 2.

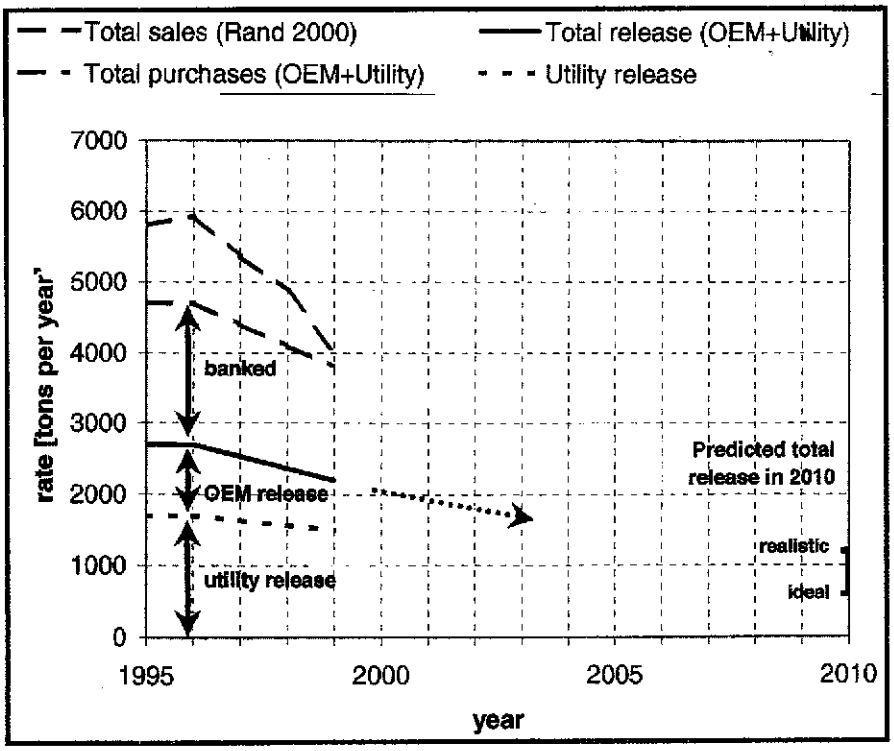


Figure 2: Global SF_6 balance of the electric industry: Total sales to (uppermost broken curve) and total purchases by the electric industry (dot-dashed curve). Total release by the electric industry (solid curve) as difference between purchases and banking rate as shown in figure 1.

From figures 1 and 2 the following **conclusions can be drawn for the present (1999) situation:**

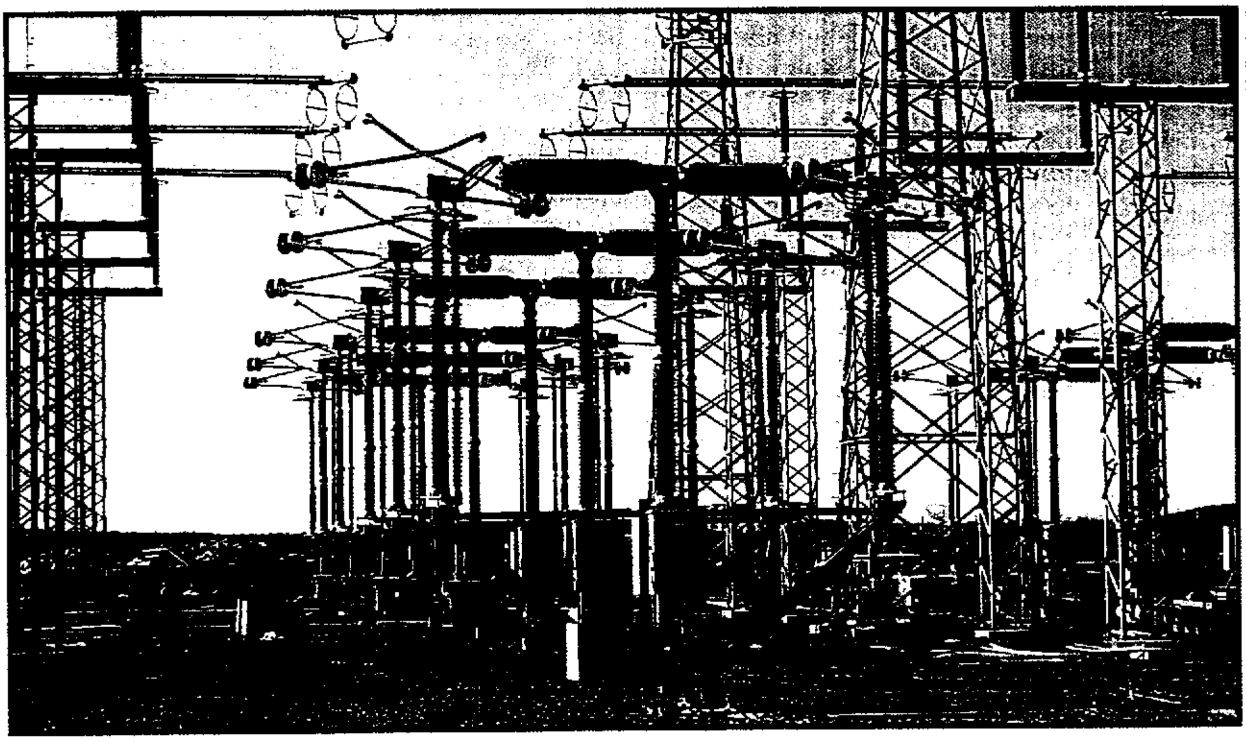
- A substantial fraction of the annual SF_6 production is not used in contained form (as it is in the electric industry) but in applications with immediate or eventual release to the atmosphere.

- There is a clear decreasing trend in the total SF_6 production and in the SF_6 release from the electric industry since 1996. **From 1996 to 1999 the electric industry has considerably reduced its release with a further falling trend for the future,** although new SF_6 equipment continues to be installed.

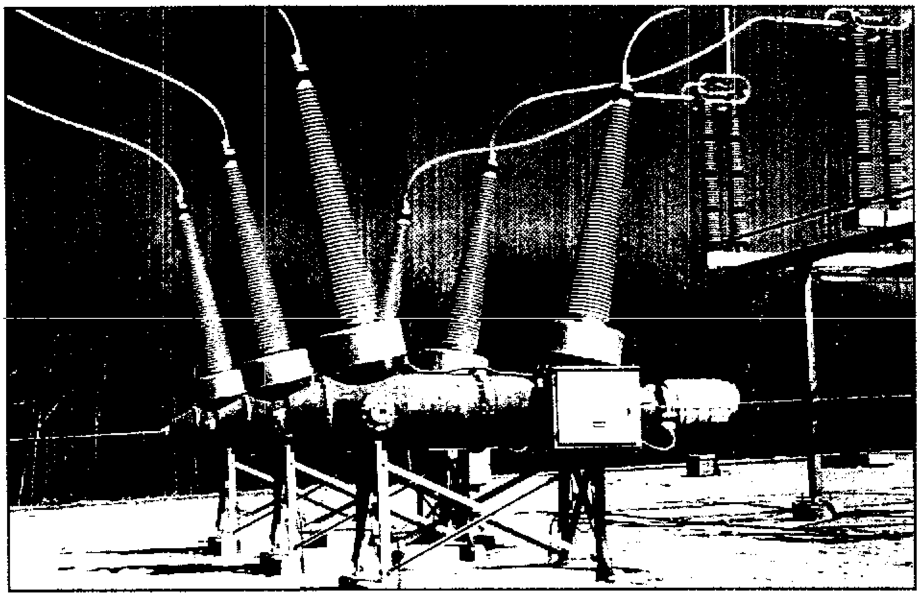
- It should be noted that the **decrease of "electric" SF_6 emissions starts** already after 1996, i.e. **only one year after the high global warming potential of SF_6 became known** in 1995. This indicates a **rapid reaction of the electric industry to the problem.**

- The continuing downward trend of the "electric" SF_6 emissions since 1996 shows that **the electric industry has started to implement environmentally conscious SF_6 handling practice world-wide.** It should be noted that such an implementation is a tedious process, which requires substantial capital investment in handling equipment, time for personnel instruction and world-wide logistic efforts.

- In [4] the SF_6 banked in electric power equipment was estimated to have been about 27 000 t in 1995. With the average annual banking rate assumed in figure 1, the SF_6 banked in equipment in 1999 results about 30 000 t. With utility losses of about 1500 t/y this yields a **world average release rate from operating equipment (leakage + handling) of ~ 5 %/y.** This value is higher than the data retrieved by CIGRE for high voltage GIS [12]. These data indicate that leakage losses from high voltage GIS were in the range 0.5 ...1 %/y and handling losses around 1...2 %/y. For medium voltage distribution equipment of the sealed-for-life type, total losses during operation are much lower still. The discrepancy between the CIGRE figures and the world average is most probably due to emissions from regions where SF_6 technologies and handling •••



Life Tank Breaker.



Dead Tank Breaker.

practice considerably below the state of the art are still in use. As an example of such regional differences, the total "electric" emission from the European Union in 1995 was only 3 % of the global emission whereas 15 % of the "electric" SF_6 was banked in this region [13]. More precise and regionally differentiated statements will only become possible after more detailed data become available.

As environmentally conscious SF_6 handling in the electric industry is presently still in the process of implementation, it is justified to **extrapolate the "electric" SF_6 emissions to the future.** For this purpose, we make the following **assumptions,** which are all based on *presently* established power equipment technology and gas handling practice and do not yet account for future improvements:

- We can estimate an **"ideal" lower limit based on what would be technically achievable without regarding cost aspects.** For this we assume that the utilities reduce their emissions to a total (leakage + handling) of ~ 1 %/y. Figures in this range have already been reported in the past from some countries (e.g. [14]). The figure of 1 %/y has also been proposed in the draft of the international electrotechnical standard IEC 60517 [15] and has already been agreed upon in some voluntary emission reduction commitments (e.g. [5] [8]). Under the assumption of a future annual banking rate as shown in figure 1, the quantity of SF_6 banked in electric equipment in 2010 will be approximately 45 000 t. This would result in future emissions from operating equipment of approximately 450 t/y. The original equipment manufacturers (OEM) are assumed to reduce their loss rate to less than 4 % of the SF_6 they install in new equipment. This figure has already been committed to by an OEM association [5]. For medium voltage distribution equipment of the sealed-for-life type even lower losses are already presently achieved. With a prospective banking rate of 1200 t/y this would correspond to an OEM release of about 50 t/y. The ideal lower limit for emissions from the electric industry would thus be about **500 t/y** world-wide.

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- For a more **realistic scenario** we have to consider cost aspects, difficulties to achieve world-wide implementation of efficient gas handling and remaining equipment below state-of-the-art performance. Under these conditions we assume utility emissions of about 1000 t/y and OEM losses of approximately 200 t/y resulting in total emissions from the electric industry would be about **1200 t/y.**

The "ideal" lower limit and the realistic scenario estimates are represented in figure 2 by the two levels marked "ideal" and "realistic" for the year 2010. They specify the range to which the "electric" SF_6 emissions are expec-ted to decrease asymptotically.

With these estimates we come to the following **prospective conclusion:**

- **The electric industry** (OEM + utilities) **has the potential to reduce its SF_6 emissions to about 1000 t/y world-wide which is a reduction of the 1995 value by more than 60 % despite of a considerable increase in gas banked in equipment. This is more than an order of magnitude better than the reduction requirements by the Kyoto Protocol.**

3. ONGOING SF_6 EMISSION REDUCTION EFFORTS

Voluntary programs for the reduction of SF_6 emissions from the electric industry were initiated briefly after the high global warming potential (GWP) of SF_6 had become known. These activities were organised by the electric industry (electrotechnical committees, OEM and utilities), SF_6 producers and manufacturers of SF_6 handling and recycling equipment. They consisted of:

1 - **Promotion of appropriate (state-of-the-art) SF_6 handling by international committees:**

- Issuing of recommendations for environmentally responsible SF_6 handling in the electric industry (e.g. CAPIEL/UNIPEDE [16], IEC [17], CIGRE [18-20])
- Preparation of SF_6 handling guides for the electric industry (IEC [17], CIGRE [19, 20]).
- Ensuring maximal reuse of SF_6 on site and avoiding unnecessary transport (return to the OEM or SF_6 producer) [19] [20] [32].

2 - Activities of **OEM (Original Equipment Manufacturers)**:

- Improved equipment design to reduce the quantity of SF_6 required per installation and to reduce leakage.
- Implementation of appropriate SF_6 handling practice in test laboratories, factories and on erection sites.
- R&D activities to explore the feasibility of SF_6 substitution (e.g. [21-23])
- Environmental evaluation of SF_6 insulated electric power equipment by environmental lifecycle assessment (LCA) [24] according to the standard ISO 14040 [25].

3 - Activities of **electric utilities** including:

- Improvement of gas handling procedures.
- Introduction of SF_6 inventories.
- Signing memoranda of understanding for emission reduction with a government authority (e.g. USA [26], Japan [5]). •••

4 - Activities of the **SF_6 producers**:

- Establishment and updating of global SF_6 production inventories [2] [3]
- Offering take-back services for used SF_6

5 - Manufacturers of **SF_6 handling and recycling equipment**:

- Performance improvement and cost reduction of SF_6 handling and recycling equipment
- Support of personnel instruction.

4. SF_6 IN A GENERAL ENVIRONMENTAL CONTEXT

Although SF_6 is one of the strongest greenhouse gases by its molecular properties, it is important to put it into a general environmental context and to do this in a *quantitative* way. In this respect, the following aspects are of particular importance for electric power equipment:

SF_6 is one of many other man-made greenhouse gases and is emitted in comparatively small quantity. Its contribution to global warming can be approximately assessed in terms of CO_2 - equivalent emission rates. A CO_2 - equivalent emission rate is the actual emission rate multiplied by the global warming potential (GWP) of the gas. At present (1999), the SF_6 emission from the electric industry is about 2200 t/y (see figure 2) which, with a GWP of 22 500 for SF_6 [33], corresponds to 50 Mt/y CO_2 equivalent. The total equivalent emission of the other man-made greenhouse gases is presently 43 000 Mt /y CO_2 equivalent [6]. **The present share of "electric" SF_6 in man-made greenhouse gas emissions** is therefore:

50 Mt/y (CO_2 equivalent) /
43 000 Mt/y ~ $1.16\ 10^{-3}$ ~ **.1 % (1999)**

As estimated above, the full implementation of appropriate SF_6 handling in the electric industry will reduce the "electric" SF_6 emissions to about 1000 t/y corresponding to ~ 23 Mt/y CO_2 equivalent. Considering that the global emission rate of all man-made greenhouse gases will have increased to approximately 50 000 Mt/y CO_2 equivalent in 2010 [6], the share of the electric SF_6 emission in relation to the total greenhouse gas emissions will then be

23 Mt/y (CO_2 equivalent) /
50 000 Mt ~ **0.04 % (2010)**

It can thus be concluded that the **"electric" SF_6 emissions, which are already now quantitatively insignificant, will become irrelevant in the future despite the ongoing installation of SF_6 insulated power equipment**. This conclusion may seem against intuitive expectation, which considers only the *molecular* property GWP and does not account for the *quantitative* emission SF_6 data.

It has to be noted that the above estimates do not yet account for the ***positive* environmental value of SF_6** when it is **viewed in the context of an *integral* environmental evaluation.** Because of its high functional efficiency SF_6 allows to design very compact equipment. This allows the saving of materials and energy losses, both of which substantially contribute to the integral environmental impact. These savings have to be balanced against the negative impact of the SF_6 losses. The procedure for such a balance is **LCA (environmental life-cycle assessment)** according to the international standard ISO 14040 [25]. LCA evaluates the integral environmental impact of a technology and allows, in particular, the assessment of the relative contribution of SF_6. Applying LCA to a regional electric power supply system [24] has led to the result that the use of SF_6-insulation *reduces* the environmental impact of the overall system. Material savings, lower energy losses and other features enabled specifically by SF_6 over-compensate for the negative impact of the SF_6 emissions. It has therefore to be concluded that **SF_6, in spite of its high GWP, may even reduce the integral environmental impact of electric power equipment due to its extraordinary functional performance.**

In contrast to many other greenhouse gases, the SF_6 used in electric power equipment is, by its very function, enclosed and is practically always handled by expert personnel. In contrast to consumer products, it is therefore relatively easy to implement conservative gas handling, once the necessary investments in gas handling equipment and personnel instruction have been made. **The electric industry has proven that it has started to implement appropriate SF_6 handling world-wide.**

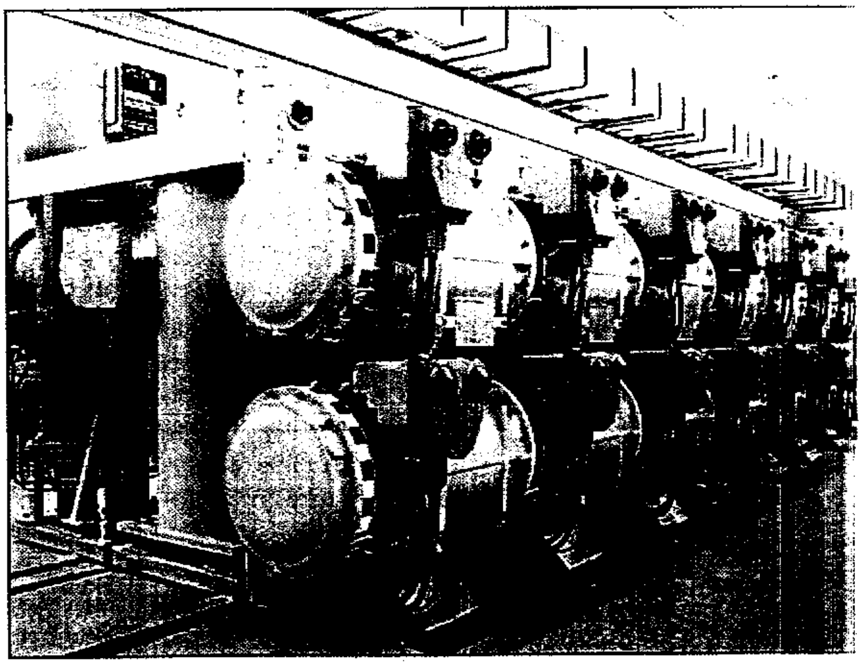
Several decades of intense and comprehensive research have shown that **a functionally equivalent substitute gas for SF_6 does not exist** for physical reasons (e.g. [21]). As a consequence, **SF_6 substitution, if enforced, would become technically difficult, economically unacceptable and environmentally disadvantageous, particularly for high voltage transmission equipment.** Nevertheless,the OEMs are continuing research and development work to identify performance niches (mainly lower voltages and currents) in which SF_6-free equipment might eventually become feasible. The 1997 **Kyoto protocol** for the reduction of greenhouse gas emissions [1] explicitly lists SF_6 as the gas with the highest global warming potential. This **obliges all participating countries to achieve SF_6 emission reduction.** The methods by which governmental institutions try to achieve this goal and the reduction levels they have as targets are at the choice of the countries. Presently, three major concepts of governmental action can be recognised:

a) Establishment of national SF_6 inventories (e.g. in Brazil [14], EU [27], D [28] [29], Japan [5]).

b) Voluntary agreements on SF_6 emission reduction between government and electric industry (e.g. in US [26], Japan [5], D [30]).

c) Straightforward taxation of SF_6 as greenhouse gas and/or programmed phase-out (e.g. DK [31]). Whereas the establishment of national SF_6 inventories is necessary and voluntary emission reduction agreements have already proven to be efficient, **straightforward taxation and/or phase-out call for remarks:**

- Such measures are solely based on a material specific property (the global warming potential) and disregard functional aspects, the role of the gas in the context of an integral environmental impact assessment (LCA) and the economic consequences.
- Such measures will have several (probably unintended) counterproductive consequences. ● ● ●



Gas Insulated Substation.

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They will cause a cost increase for maintaining and retrofitting existing SF_6 power equipment. They will enforce technologies with increased cost and (integral) environmental impact. They may even make it impossible to provide certain vital functions in the T&D system, which can not be realised technically without SF_6, without reverting to historical technologies which were phased out decades ago, not only for economic but also for safety and environmental reasons.

5. RECOMMENDATIONS

Based on the facts and figures presented in this paper it is recommended that:

(1) Information of the kind presented in this document is made available on the CIGRE SF_6 web-site and regularly updated, with free access for CIGRE members and non-members.

(2) CIGRE includes instructions on the establishment of SF_6 inventories in the planned practical SF_6 handling guide presently in preparation. These instructions could be based on the CAPIEL Inventory Methodology which is based on the Tier 3b Mass Balance Methodology according to IPCC Good Practice [10].

(3) CIGRE develops a sample form for a voluntary SF_6 emission reduction agreement between government and electric industry. This form could be based on existing documents of this type (e.g. US [26], Japan [5], D [30]).

(4) Background information of the kind presented in this document is made available to governmental institutions and their consultants and to all relevant international and national organizations in order to provide information on the **quantitative** aspects of SF_6 use in the electric industry. This is expected to help putting the ongoing SF_6 discussion on a rational basis.

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