ONE VISION. ZERO EMISSIONS.

Reshaping The Grid Through Gas Stewardship:

How Insulating Gas Reconditioning and Recycling Can Lower Your Carbon Footprint

DILO
CERTIFIED GAS

Let’s start with a

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SF_6 – A brief overview

- Discovered in 1901 by Henri Moissan & Paul LaBeau
- Characteristics:
  - **Manmade**
  - **Colorless & Odorless**
  - **Inert**
  - **Dielectrically Strong & Unmatched Arc Quenching**
  - **Thermally Stable**
  - **Self-Healing**

- 100-year Global Warming Potential (GWP) 23,900[1]
- Atmospheric Lifespan of 3,200 years[1]
- 1lb of SF_6 emitted is equal to 10.3 tons CO_2

  - *2.2 Passenger vehicles driven for one year*

    OR

  - *24,786 miles driven by an average passenger vehicle*

1: Source: Climate Change 1995, The Science of Climate Change: Summary for Policymakers and Technical Summary of the Working Group I Report, page 22
Retrieved from: http//unfccc.int/process/transparency-and-reporting/greenhouse-gas-data/greenhouse-gas-data-unfccc/global-warming-potentials

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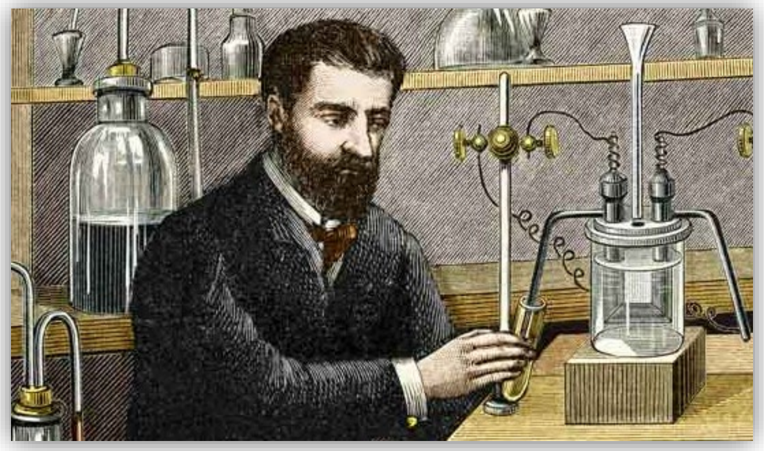
- Manufactured by method of electrolysis
- Manufacturing in North America outlawed by the Kyoto Protocol
  - Currently manufactured overseas in Russia and Asia
- By-products and impurities are a side effect of production
  - SF_4, SF_2, S_2F_2, S_2F_{10}
  - Air, moisture, CO_2
- Contaminants are filtered as a part of the refining process
- Approximately 10,000 tons of SF_6 are produced each year
- Manufacturing process is known source of emissions[2]



2: Source: Hu Jianxin, et al. "Sulfur Hexafluoride (SF6) Emission Estimates for China: An Inventory for 1990-2010 and a Projection to 2020." Environmental Science & Technology, April 2013, Vol. 47, Issue 8, pp 3848–3855.

SF_6 Gas – The Challenge

<u>Initiating a Greener Solution</u>

In Nov 2002, at the **International Conference on SF_6 and the Environment: Emission and Reduction Strategies EPA workshop,** a Technical Paper & Case Study by Solvay Fluor, AGA Gas and AEP, was presented regarding a program launched which provided the opportunity to initiate an SF_6 gas re-use program consistent with environmental awareness and protection. The case study summarized the process to the following highlighted principles:

- Analyze failed SF_6 gas
- Recover & reclaim SF_6 gas into temp storage containers for proper transport
- Transport SF_6 gas
- Perform reconditioning
- Return to the supply stream for use in GIE

They understood that the SF_6 gas needed to meet the requirements for GIE that previously relied on the use of virgin SF_6 gas. The case study also outlined the importance of inventory management. It was very clear that the user needed transparency to ensure that every kilogram/pound of used SF_6 was accounted for and tracked throughout the cycle of the Re-Use Program.

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In reference to the recently updated Intergovernmental Panel on Climate Change (ipcc) document, 2019 Refinement of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, we determined that an estimate of 0.03kg to 0.08kg of SF_6 gas is emitted to the atmosphere per every 1kg (2.2lbs) of SF_6 gas produced.

Based on this estimate it may be determined that for every 100lbs (45.35kg) of Virgin SF_6 gas received into North America, an estimated 3.0lbs to 8.0lbs. of SF_6 gas is emitted into the atmosphere during production.

During the reconditioning process we estimate that for reconditioning of 100lbs (45.35kg) of SF_6 gas that starts at 95% pure and is reconditioned to 99.0% or greater, <0.64lbs of SF_6 gas is emitted into the atmosphere.

When proper handling is performed in the field during recycling, < 0.05lbs of SF_6 gas is emitted.

The document goes on to further state, "*In addition to the compounds being intentionally produced, a variety of fluorinated GHG by-products can be emitted from fluorochemical manufacturing processes. Emissions of these other fluorinated GHGs can exceed emissions of the compound being intentionally produced.*"

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100Lbs of Virgin SF_6 Gas produced

100Lbs of Reconditioned SF_6 Gas
(95% purity to >99.0%)

100Lbs of Recycled SF_6 Gas
(>97.0%)

*0.12kg (0.05lbs) emissions can be less and are dependent on handling processes and practices.

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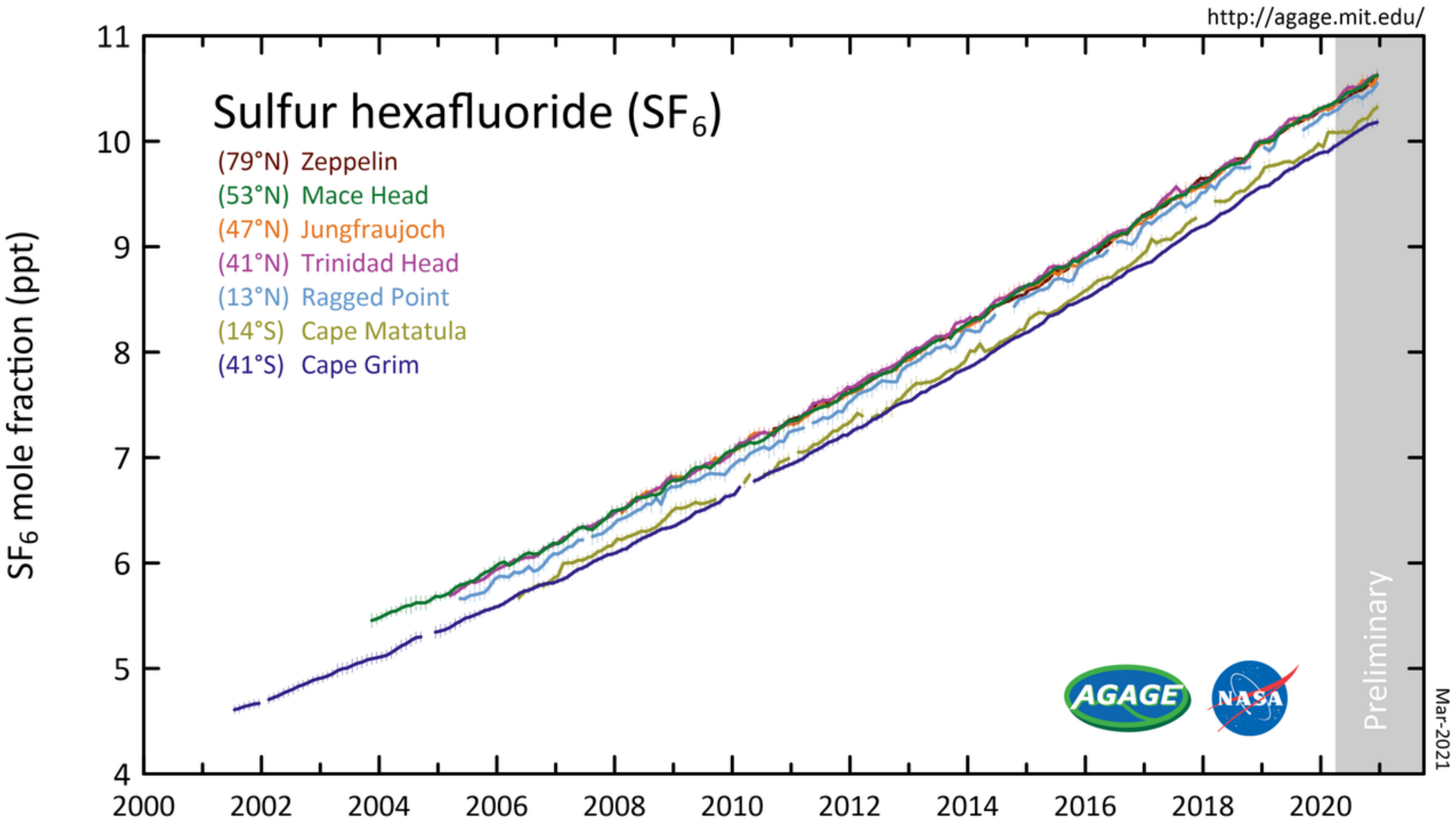
http://agage.mit.edu/
Sulfur hexafluoride (SF_6)
(79°N) Zeppelin
(53°N) Mace Head
(47°N) Jungfraujoch
(41°N) Trinidad Head
(13°N) Ragged Point
(14°S) Cape Matatula
(41°S) Cape Grim
SF_6 mole fraction (ppt)
11
10
9
8
7
6
5
4
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
Preliminary
AGAGE
NASA
Mar-2021

Task Force on
National Greenhouse Gas Inventories

ipcc
INTERGOVERNMENTAL PANEL ON climate change

IPCC web sites

Home IPCC
IPCC-TFI Home
Organization
Publications
2019 Refinement
Wetlands Supplement
KP Supplement
2006 IPCC Guidelines
GPG-LULUCF
Degradation of Forest
GPG2000
Revised 1996 IPCC Guidelines
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Presentations
Support to Inventory Compilers
Emission Factor Database (EFDB)
Inventory Software
Meetings
FAQs
Links
Electronic Discussion Group (EDG)

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IPCC honoured with the
2007 Nobel Peace Prize

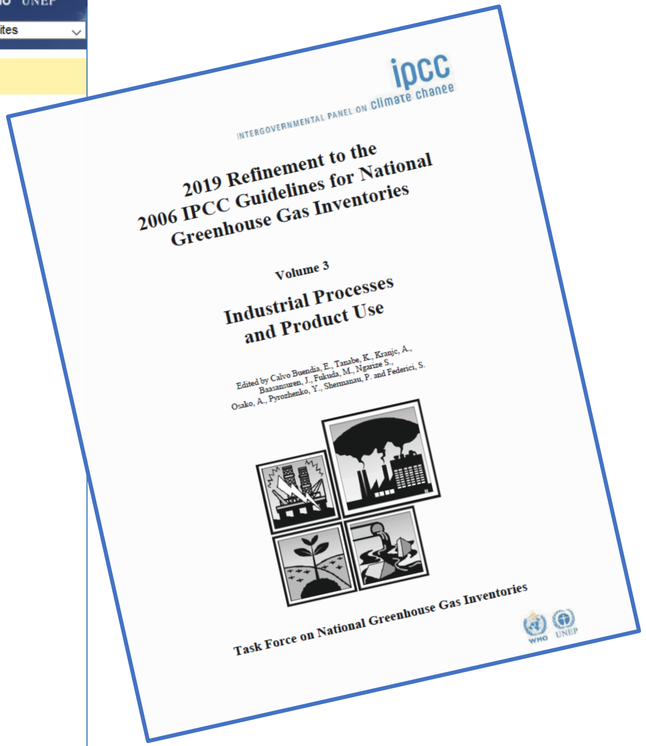
Publications

2019 Refinement

Top | Vol1 GGR | Vol2 Energy | Vol3 IPPU | Vol4 AFOLU | Vol5 Waste

2019 Refinement to the
2006 IPCC Guidelines for
National Greenhouse Gas Inventories
Volume 3
Industrial Processes and Product Use

Chapter	Chapter Name
-	Cover Page of Volume 3 PDF
1	Introduction PDF
3	Chemical Industry Emissions PDF
4	Metal Industry Emissions PDF
6	Electronics Industry Emissions PDF
7	Emissions of Fluorinated Substitutes for Ozone Depleting Substances PDF
	Calculation Example for 2F1 (Tier 2) (MS-Excel)
8	Other Product Manufacture and Use PDF
Annex 1	Worksheets PDF
Annex 4	Glossary for Industrial Processes and Product Use Sector PDF
Annex 5	Mapping Tables PDF
Appendix 1	Possible Approaches for Estimating Fluorinated Compounds Emissions from Textile, Carpet, Leather and Paper Industries: Basis for Future Methodological Development PDF



https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol3.html

What about the alternatives?

		Sulfur-hexafluoride	Clean-Air	Carbon Dioxide and Oxygen	C4-Fluoronitrile	C5-Fluroketone
Base Gas	Chemical Formula	SF_6	80% N_2 + 20% O_2	70% CO_2 + 30% O_2	$(CF_3)_2CFCN$	$(CF_3)_2CFC(O)CF_3$
	$CO2_e$(GWP)	23,500	0	<1	2,210	1
	Boiling Point	-64°C	<-183°C	-50C	-5°C	+27°C
	Dielectric Strength	1.00	0.43	0.77	2.20	1.70
Gas Mixture	Background (gases)	Pure or with N_2 or CF_4	80% N_2 + 20% O_2	70% CO_2 + 30% O_2	~90% CO_2	~90% O_2 With N_2 or CO_2
	$CO2_e$(GWP)	23,500	0	<1	~380	<1
	Lowest Operating Temperature	-30°C *	-50°C	-50C	-30°C	0°C to +5°C -20°C possible
Internal Arc Reaction	Decomposition Products	HF, S_XF_Y, SOF_X, F_2, SO_X, CF_4	If applicable: O_3, NO_X	CO, HF, O_3	CO, HF, C_nF_{2n+2}, other Fluorinated Compounds	CO, HF, COF_2, C_XF_Y, other Fluorinated Compounds
	Toxicity of Decomposition Products	Slightly toxic (Hodge-Sterner)	Typically None	Relatively harmless (Hodge-Sterner)	Practically non-toxic (Hodge-Sterner)	

Alternatives to SF_6 are proving to be a promising advancement in the environmental control of GHG emissions

- However, it is also important to consider the following[1]:
  - No measurable improvements currently exist as it is related to safety for handling of SF_6 alternatives vs SF_6
  - New gas mixtures generate arc byproducts. Compatibility testing with existing switchgear materials have led to acceptable solutions
  - Toxicity of both the base gas and arc byproducts must be considered. Evaluation of these compounds for health and safety is paramount.
  - The interrupting capability of switchgear using SF_6 alternatives is largely based upon CO_2 gas mixtures. CO_2, in orders of magnitude, is more permeable than SF_6 and the sealing technologies of switchgear will be affected.
  - SF_6 alternative equipment using “Technical Grade Air” and vacuum interrupters operates at a significantly higher pressure than SF_6 equipment. The static seals and dynamic seals presently used in switchgear will be challenged to cope with the higher pressures.
  - Vacuum interrupters in equipment using “Technical Grade Air” currently are still limited in their power handling.
  - All the new gas mixtures operate at higher pressures as compared to SF_6 . This presents two challenges; first, the design of pressure vessels which can operate safely and reliably for long periods of time; and second, customer acceptance of switchgear with higher operating pressures. Higher gas pressures can also mean higher leakage rates.

[1](Ref: Alt Gas Mixtures Status and Strategy Considerations – George Becker – Power Engineer)

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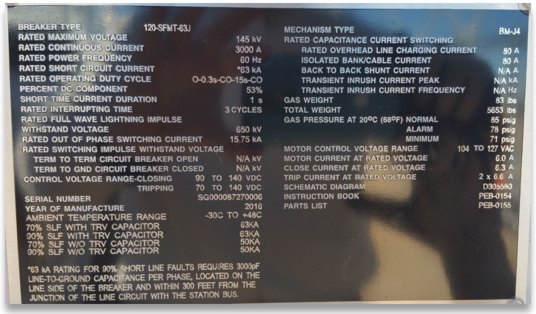
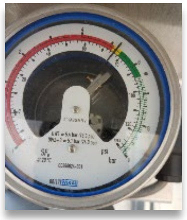
On-Site Gas Processing for Immediate Re-Use

Accountability starts with nameplate value & actual pressure vs temperature (i.e. identifying leaks and/or previous reporting inaccuracies)





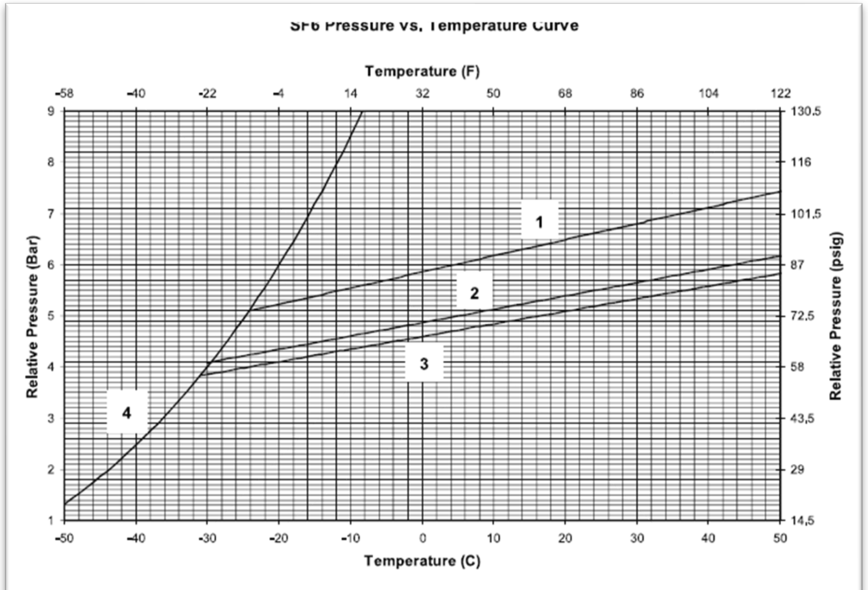


Figure 4 SF_6 Pressure Curves

1. Rated pressure curve 94,1 psig (6,5 bar) at 20 °C (**49,5 g/l**)
2. Alarm pressure curve 78,1 psig (5,4 bar) at 20 °C (**41,6 g/l**)
3. Lockout pressure curve 73,8 psig (5,1 bar) at 20 °C (**39,5 g/l**)
4. SF_6 liquefaction curve

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Key Tools and Resources

Having the proper tools is the key to success…

What size and type gas handling system is required?

What is the quality of the gas?

How much gas storage?

Are adapter fittings needed?

Is additional filtration required?

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- Perform condition analysis of the gas in the GIE
  - Ideally test at least three parameters:
    - **Moisture content**
    - **Purity**
    - **Arc Byproduct**
  - Alternative mixtures may require additional contaminants to be detected
  - This is also a good time to check your service hoses for integrity via the "leak-up" method

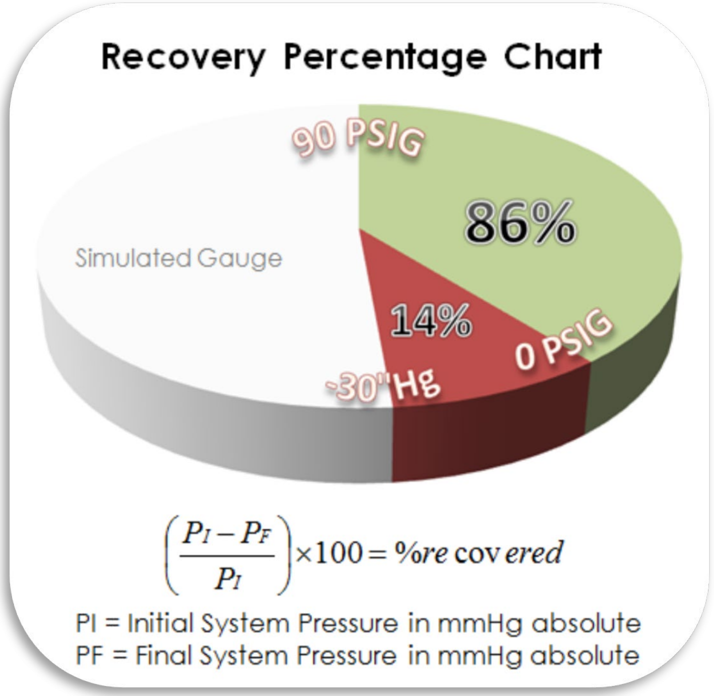
Contaminant	In-service	Re-use
Non-reactive gases (air / N_2)	Up to 3%	Up to 3%
Reactive gases (SO_2, SOF_2)	500 PPM_v	12 PPM_v
Moisture – GCB only	200 PPM_v	200 PPM_v

	IEC 60376 specification for new SF6 gas	IEC 60480 specification for used SF6 gas	IEC 62271-4 SF6 reuse specification
Air / CF_4	Max. 1 vol.-%	< 3 vol.-%	< 30 vol-% air < 5 vol-% CF_4
Moisture (Dew point)	-36 °C* at p_a 1 bar < 25 ppm (mass)	-23 °C* at p_a 1 bar **(medium voltage)** -36 °C* at p_a 1 bar **(high voltage)**	< 1,000 ppm (mass) approx. +4.5 °C at p_a 1 bar
Oil	< 10 ppm (mass)	< 10 ppm (mass)	< 1,000 ppm (mass)
HF, SO_2	< 1 ppm_v	< 12 ppm_v SO_2 < 50 ppm_v total	> 12 ppm_v SO_2 > 50 ppm_v total
* measured at ambient pressure			

- On-site reconditioning is achieved with filtration systems
  - Pre-filter (external to gas handling cart)
  - On-board filters
    - A combination of both is ideal for best results
- Filtration systems reduce moisture and eliminate by-products
  - Air and other non-reactive gases CANNOT be removed by on-site processes
- Reconditioned gas qualifies for immediate re-use
- Standards for re-use are set by:
  - CIGRE
  - IEC
  - IEEE
  - ANSI

The perfect recovery is achieved with zero emissions

- Determine how much gas is recovered
  - Track the initial and final compartment pressure
  - Track and log weight of the gas recovered
- Different rules apply to leaking SF_6 GIE
  - Recovery prematurely stopped at 1-3 psig
  - Recover remaining gas into separate cylinders
    - Air intrusion is almost certain once in the vacuum stage of recovery
    - Separating the positive & vacuum stages ensures maximum reusable SF_6 on-site
  - C4/C5 mixtures may require complete replacement due to ratio conflicts with partial recovery



FILLING

- Be sure to check the OEM's manual or nameplate for accurate SF_6 capacity information.
- Accidently overfilling GIE could result in an SF_6 emission by engaging a pressure relief valve (rupture disk).
- Tracking gas weights by documenting SF_6 movements and using a cylinder weight scale and/or mass flow meter can aid with preventing both positive and negative emissions.
- Always set regulators in a static environment. Failure to do so may result in excessive pressure settings and potential rupture disk failures.

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Off-Site Reconditioning Process for Insulating Gases

Intake & Analysis of Used SF_6

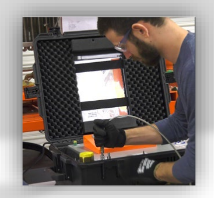
- Low Purity
- High H_2O*
- Presence of SO_2*

Account for weight of SF_6 analyzed and to be reconditioned

* CIGRE ; IEEE; ANSI; IEC; ASTM

Perform SF_6 reconditioning

Analysis of Reconditioned SF_6

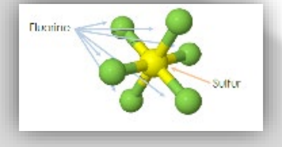


Confirm analysis of reconditioned SF_6 meets/exceeds standards for re-use*

Report#:	S-2975	Service#	0		Date:	1/20/2020	Pallet#	1
AssetTag Number	Cylinder Serial Number	Cylinder Certification Date	Purity (vol %)	Moisture	Decomp (SO_2/SOF_2)	Tare Weight	Gross Weight	SF_6 Weight
	SG862500Y	9/2014+	100.0%	<40 PPMv	PPMv	1,454.0 LBS	2,554.0 LBS	1,100.0 lbs
	6169-33	8/2014+	100.0%	<40 PPMv	PPMv	1,388.0 LBS	2,488.0 LBS	1,100.0 lbs
	4890-26	4/2011+	100.0%	<40 PPMv	PPMv	1,452.0 LBS	2,552.0 LBS	1,100.0 lbs
	4057-0	9/2014+	100.0%	<40 PPMv	PPMv	1,430.0 LBS	2,530.0 LBS	1,100.0 lbs
	4057-17	9/2014+	100.0%	<40 PPMv	PPMv	1,407.0 LBS	2,507.0 LBS	1,100.0 lbs

Fill into clean (non-contaminated) SF_6 storage containers

Account for weight of SF_6 analyzed and reconditioned



Introduce into SF_6 supply stream

IEC specifications (standards) for sulphur hexafluoride

	IEC 60376 Specification for new SF_6 gas	IEC 60480 Specification for used SF_6
SF_6	> 98.5 vol.-% For gas mixtures: > 99.7 Vol.-%	> 97 Vol.-% For gas mixtures: ±5 % from the nominal value
Air/CF_4	Air: < 10.000 µl/l (i.e. 1 Vol.-%) for pure SF_6 gas For gas mixtures: < 2,000 µl/l (i.e. 0.2 vol.-%) CF_4: < 4,000 µl/l (i.e. 0.4 Vol.-%) for pure SF_6 gas For gas mixtures: < 800 µl/l (i.e. 0.08 vol.-%)	< 30,000 µl/l (i.e. 3 % vol.) For gas mixtures: SF_6/N_2 mixtures: < 30,000 µl/l (air and/or CF_4) SF_6/CF_4 mixtures: < 30,000 µl/l (air and/or N_2)
Moisture (dew point)	< 200 µl/l (.i.e. 200 ppm_v; -36 °C frost point @ atm)	< 200 µl/l (i.e. 200 ppm_v, -36 °C frost point @ atm.)
Oil	< 10 mg/kg (i.e. 10 ppm_w)	< 10 mg/kg (i.e. 10 ppm_w)
HF, SO_2	< 7 µl/l (i.e. 7 ppm_v) total	< 50 µl/l total (i.e. 50 ppm_v) or 12 µl/l (i.e. 12 ppm_v) For (SO_2+SOF_2) or 25 µl/l (i.e. 25 ppm_v) HF

Substance	DILO Certified Gas	IEC 60376:2018* (Virgin gas)	ASTM D2472-15
SF_6	> 99 Vol.%	> 98,5 Vol.%	≥ 99,8 wt%
H_2O	≤ 8 µl/l	< 200 µl/l	≤ 8 ul/l
Frost point (100 kPa)	≤ -62 °C	-36 °C	-62 °C
Total acidity (HF equiv.)	< 0,1 µl/l	< 7 µl/l	≤ 0,3 ppm_w
Air	< 500 µl/l	< 10.000 µl/l	≤ 500 ppm_w (≙ 2500 µl/l
CF_4	< 500 µl/l	< 4.000 µl/l	≤ 500 ppm_w (≙ 830 µl/l)
Oil mist	< 1 mg/kg	< 10 mg/kg	–
SO_2	< 0,1 µl/l	–	–

*For use in mixtures with N_2/CF_4, SF_6 purity of 99.7 % by volume is recommended.
µl/l = ppmv; mg/kg = ppmw, wt% = percentage by weight

Off-site reconditioned SF_6 gas should come with the following report information for accurate recordkeeping:

Report#:	AIR#191017	Service#	S-2878		Date:	10/17/2019	Pallet#	1
AssetTag Number	Cylinder Serial Number	Cylinder Certification Date	Purity (vol %)	Moisture	Decomp (SO_2/SOF_2)	Tare Weight	Gross Weight	SF_6 Weight
EHR603	N-339679	07/17*	99.9%	<40 PPMv	PPMv	119.0 LBS	233.8 LBS	114.8 lbs
GTE931	419416	11/16+	99.9%	<40 PPMv	PPMv	121.8 LBS	236.3 LBS	114.5 lbs
HLY311	73251805	11/17+*	99.9%	<40 PPMv	PPMv	110.7 LBS	225.3 LBS	114.6 lbs
FKN258	SG2095B	7/14+*	99.9%	<40 PPMv	PPMv	123.0 LBS	238.3 LBS	115.3 lbs
HLY301	U36035	11/17+	99.9%	<40 PPMv	PPMv	117.4 LBS	232.7 LBS	115.3 lbs
HKV358	32	03/17+	99.9%	<40 PPMv	PPMv	118.0 LBS	233.2 LBS	115.2 lbs
GTC978	OX-4-408947	12/16+	99.9%	<40 PPMv	PPMv	114.0 LBS	228.8 LBS	114.8 lbs
FKP274	C6657014	08/16+*	99.9%	<40 PPMv	PPMv	121.0 LBS	235.9 LBS	114.9 lbs
HAW447	179273	08/17+	99.9%	<40 PPMv	PPMv	127.0 LBS	242.2 LBS	115.2 lbs
DJT090	N-278340	07/14+	99.9%	<40 PPMv	PPMv	118.0 LBS	232.9 LBS	114.9 lbs
JCU279	X-379544	07/18+	99.9%	<40 PPMv	PPMv	113.6 LBS	228.9 LBS	115.3 lbs

Example of Outgoing Report for over 1,200 pounds of reconditioned SF_6 gas in 115 Capacity Cyl's

Report#:	S-2975	Service#	0		Date:	1/20/2020	Pallet#	1
AssetTag Number	Cylinder Serial Number	Cylinder Certification Date	Purity (vol %)	Moisture	Decomp (SO_2/SOF_2)	Tare Weight	Gross Weight	SF_6 Weight
	SG862500Y	9/2014+	100.0%	<40 PPMv	PPMv	1,454.0 LBS	2,554.0 LBS	1,100.0 lbs
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	4057-0	9/2014+	100.0%	<40 PPMv	PPMv	1,430.0 LBS	2,530.0 LBS	1,100.0 lbs
	4057-17	9/2014+	100.0%	<40 PPMv	PPMv	1,407.0 LBS	2,507.0 LBS	1,100.0 lbs

Example of Outgoing Report for 5,500 pounds of reconditioned SF_6 gas in 1,100 capacity tonners

What else can you do?

TRAINING

According to the Environmental Protection Agency:

"Training raises awareness of emissions, environmental and health impacts of SF_6 and by-products, and potential reduction options, but training also enables employees to follow procedures and protocols properly." [3]

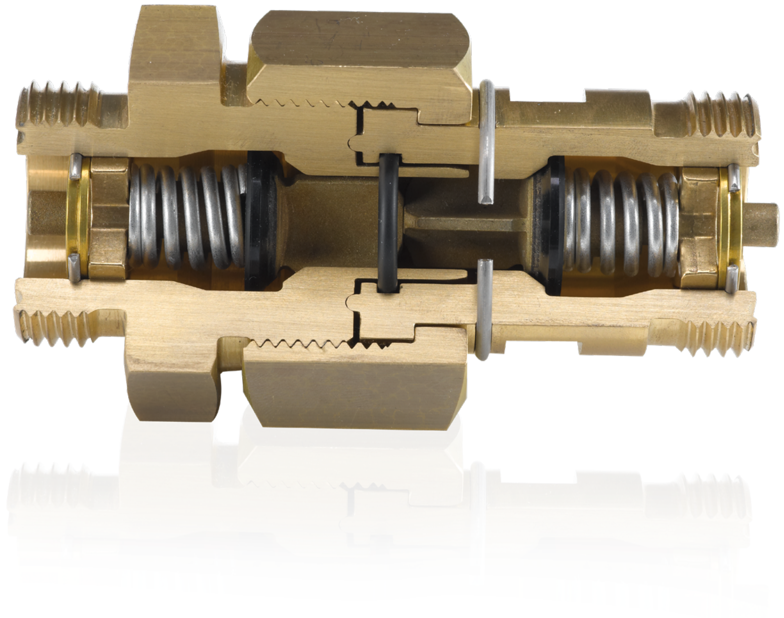
... And in most cases with equipment ownership, ***IT'S FREE!***

... at least with DILO, it is. ;)

3: Source: (August 2018) Overview of SF_6 Emissions Sources and Reduction Options in Electric Power Systems.

Gas Connections & Material Replacements

- Check to see that fittings used for connection to GIE and other accessories (manifolds, analyzers, cylinders, etc.) are leak tested.
- Refrain from using threaded connections, which are prone to leak over time:
  - NPT (Taper)
  - JIC (Flare)
  - Compression (i.e. Swagelok, HyLok, etc.)
- Identify and replace rubber components, such as hoses and diaphragms, every 5 years, if possible.



Cylinder Consolidation

- Ensures all gas is accounted for throughout your locations.
- Ideally, all partial cylinders should be returned to a single inventory point, such as a dedicated bottle shop.
- Can also help to identify poor quality gas that will require reconditioning before being put back into service.

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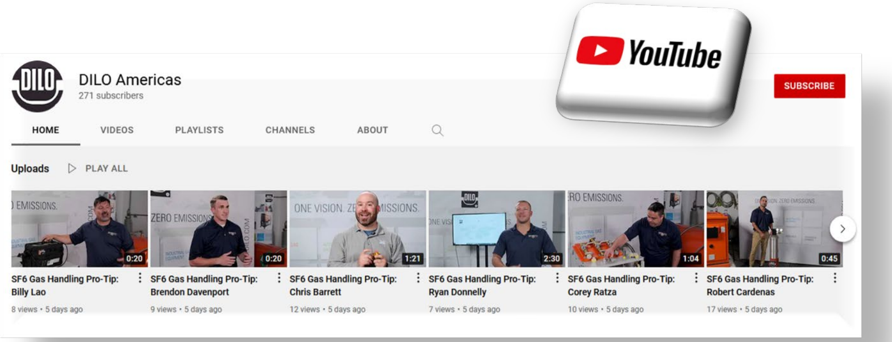

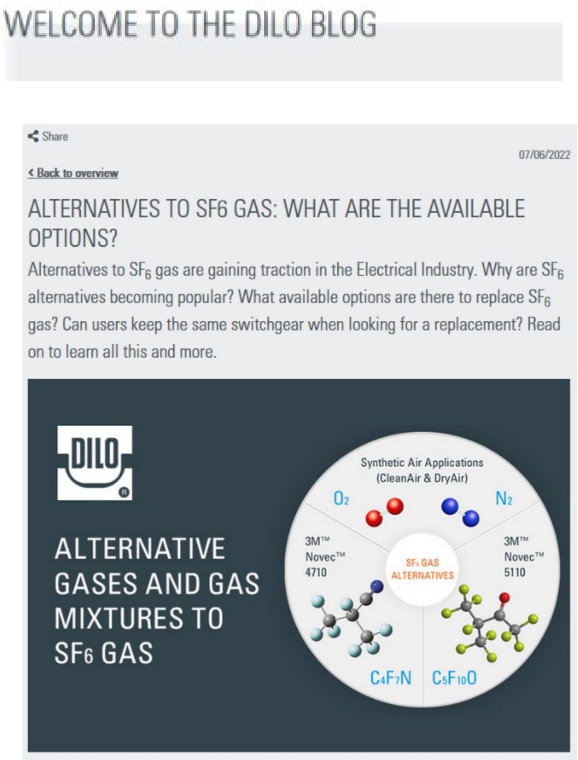

Questions?

SF_6 GAS

ALTERNATIVE GASES

INDUSTRIAL GAS EQUIPMENT

HIGH PRESSURE PRODUCTS