Electric Transmission & Distribution SF_6 Coalition

New Jersey Clean Air Council Annual Public Hearing

April 10, 2019

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Coalition Member

IEEE Chair for SF_6 Gas handling group & Member of K group (regarding SF_6)

Presentation Topics

1. SF_6 Gas

2. History (GIE)

3. Safety

4. Why SF_6 gas is an excellent solution for GIE

5. Overview of SF_6reporting regulations
   a. EPA
   b. CARB
   c. MASS DEP
   d. Others

6. What's being done to reduce emissions
   a. SF_6 handling practices
   b. Alternative Solutions

NEMA SF_6 Gas Coalition

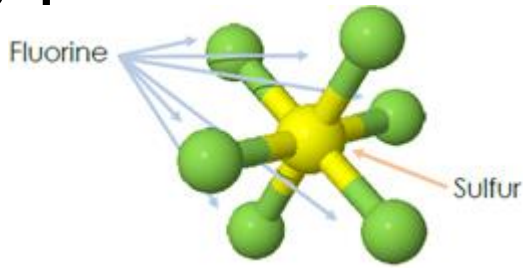
SF_6 Gas

History

- Discovered in 1901 by Henri Moissan and Paul LaBeau
- Characteristics:
  - **Manmade** – not naturally occurring
  - **Undetectable** – colorless, odorless, tasteless
  - **Stable** – Chemically inert
  - **Dielectric** – excellent arc quenching capabilities
  - Thermally Stable / heat trapping
  - Excellent re-association / self-healing after arcing event

Properties

- **Heavy** – 5 times heavier than air
- **Compressible** – liquifies at approx. 250psi at 68°F
- **Asphyxiant** – displaces atmospheric oxygen
  - OSHA maximum exposure limit 1,000 PPM
- **Unmatched dielectric strength** – 2.5x better than air
- **Arc quenching capabilities** – 100x better than air
- **Thermally stable** – high breakdown temperature
- **Self-healing** –molecules will recombine after heat source is removed

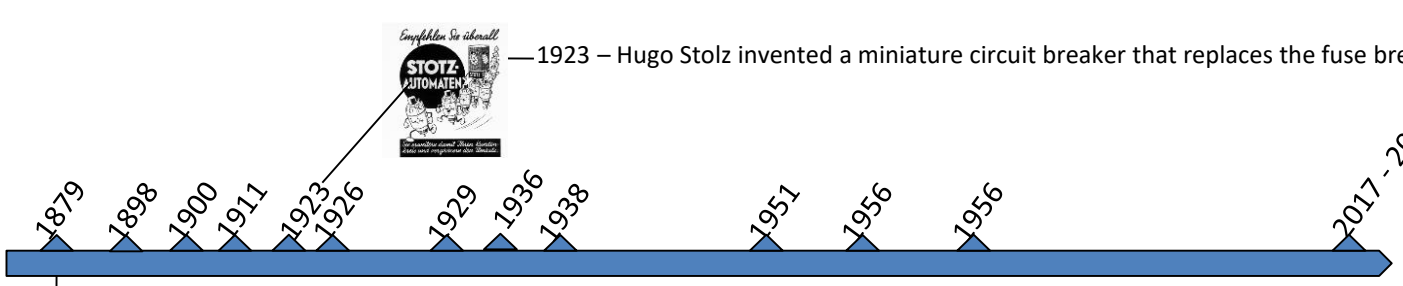


NEMA SF_6 Gas Coalition

GIE History

GIE History

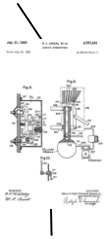
- The time line as described by me!

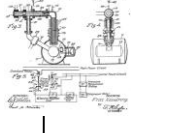


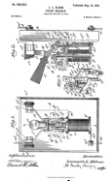
1923 – Hugo Stolz invented a miniature circuit breaker that replaces the fuse break type breaker.

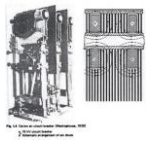
Alternative solutions to SF6

Fluorinated nitrile
(Novec 4710 fluid) + CO2









1956 – Application for patent for a Selenium Hexafluoride circuit breaker

1951 – First US Patent where SF6 Gas was used as an arc quenching medium in a circuit breaker (Westinghouse)

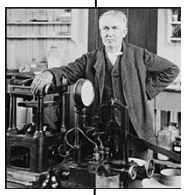
1938 – Patent Vitaly Grosse (AEG) for the first SF6 circuit breaker, where SF6 gas is extinguishing the arc at open operation

1936 – First Freon Gas Solution applied to a GIS

1929 – De-Ion Air Circuit Breaker was introduced (Westinghouse) 15kV Application

1926 Vacuum interrupter technology successfully experimented by 2 engineers from Westinghouse Sorenson & Mendenhall

1911 – 1956 Oil & Air break circuit breakers were being used for circuit interruption, as well as vacuum technology (~40kV range)



1900 – Invention of SF6 gas by Henri Moissan & Paul LeBeau

1898 –Leonard L Elden Boston Edison Co. (Patent for an open tank oil circuit breaker. had actually worked on his design as early as 1897)

1879 – Thomas Edison designed and patented his idea of a circuit breaker.

GIE History

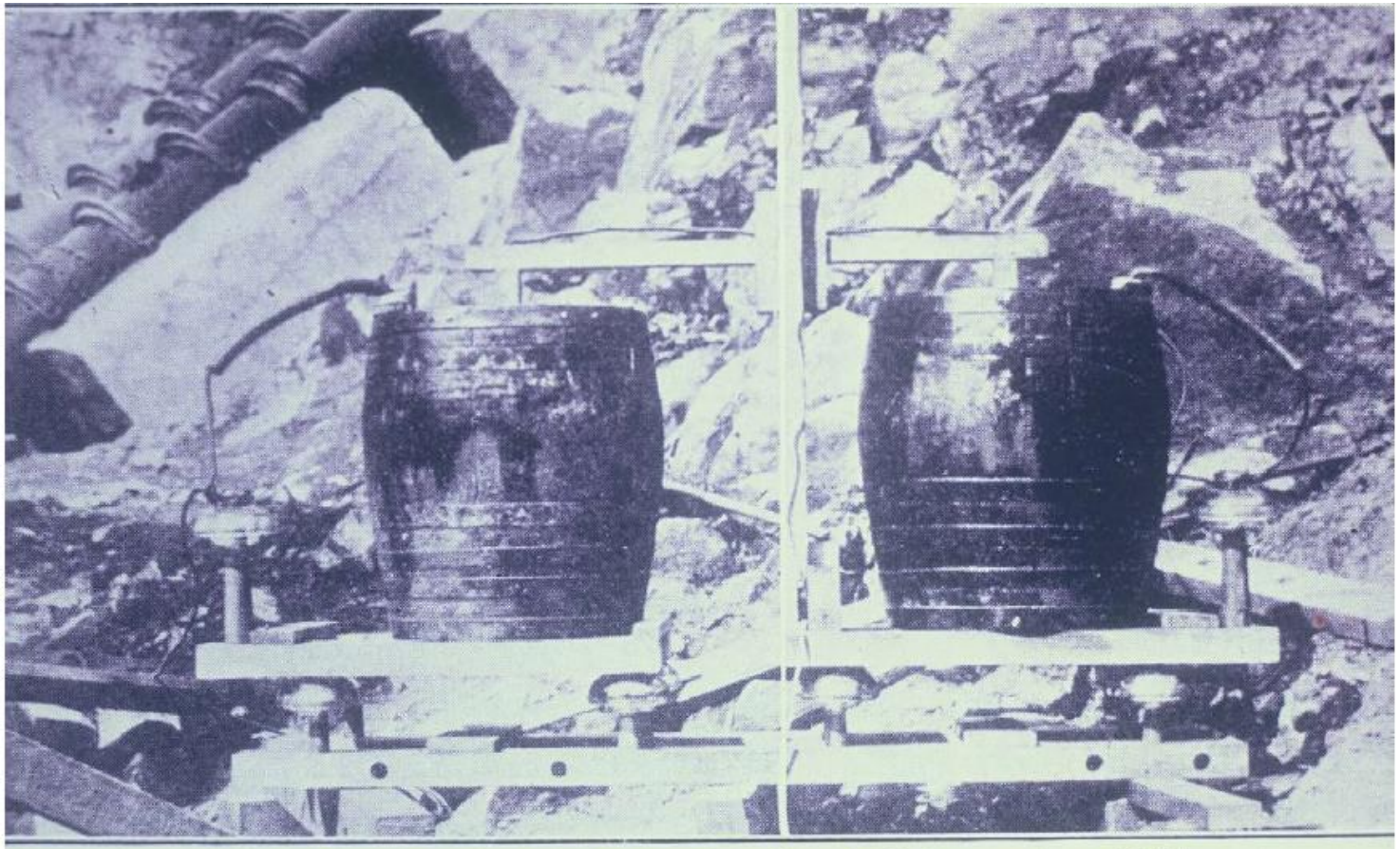
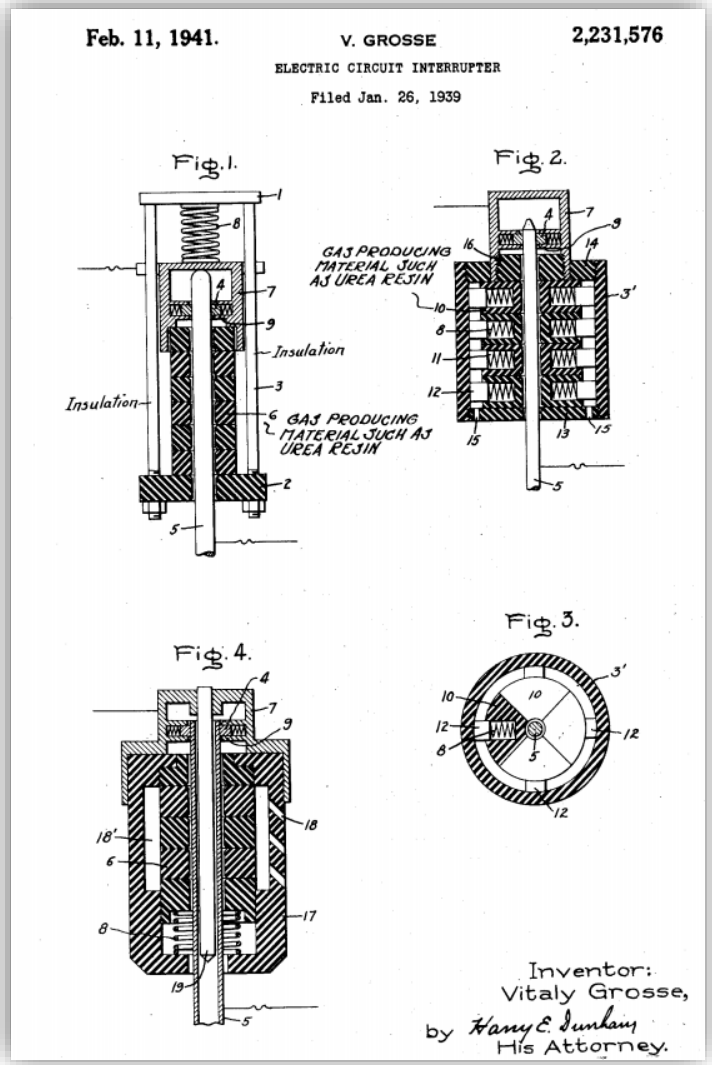


FIG. 11.—The first 40,000-volt oil switch in service, 1901.

I have heard it called a pickle barrel breaker!

GIE History



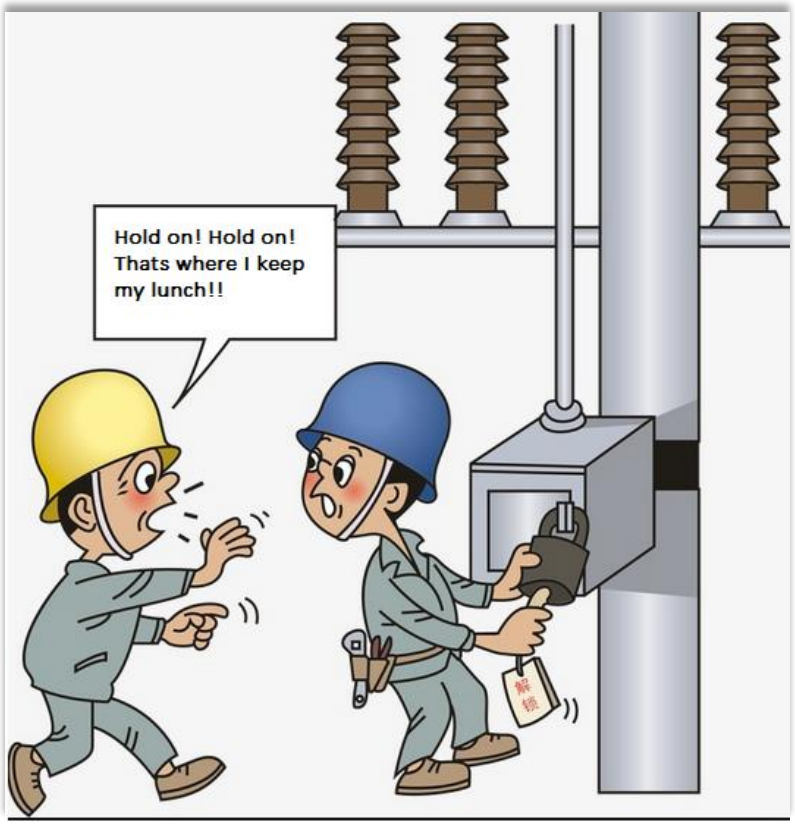
- The first patents on the use of SF_6 as an interrupting medium were filed in Germany in 1938 by Vitaly Grosse (AEG) and independently later in the United States in July 1951 by H. J. Lingal, T. E. Browne and A. P. Storm (Westinghouse).

- The first industrial application of SF_6 for current interruption dates to 1953. High-voltage 15 kV to 161 kV load switches were developed with a breaking capacity of 600 A. The first high-voltage SF_6 circuit breaker built in 1956 by Westinghouse, could interrupt 5 kA under 115 kV, but it had six interrupting chambers in series per pole.

SF_6 Gas in GIE – How it works

The world's first 800 kV GIS - Joshua Falls, VA – 1980 - DELL ALSTHOM

Safety



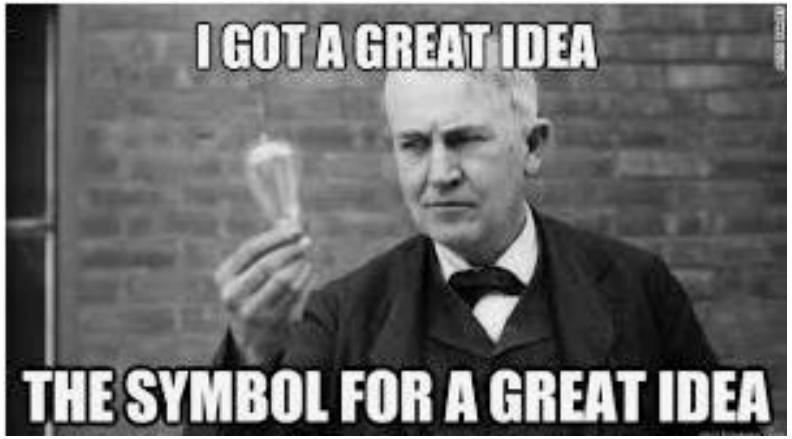
Safety

- Harmless in the presence of air (5x heavier than air)
  - Will displace air / asphyxiation
- Will decompose at temperatures > 350 F
  - Breaker operations
  - Welding
  - Running engines / heaters / open flames
  - Smoking
    - Temperature during drawing up to 700 C (1292 F)
      - Source: http://www.physlink.com/education/askexperts/ae1.cfm

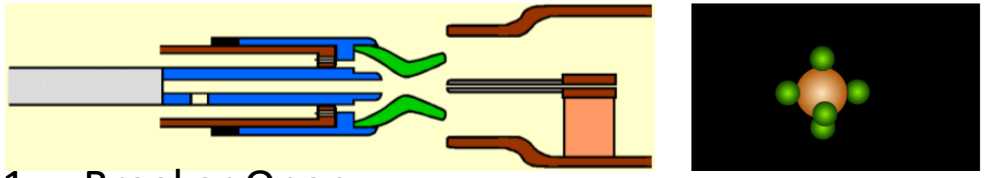
At very high temperatures, or in the presence of an electric arc which can reach 15,000°C (27000°F), SF_6 can be slowly decomposed. Decomposition by-products include lower fluorides of sulfur, which are hydrolysable (change), yielding SO_2 and HF.

Electric Transmission & Distribution SF_6 Coalition

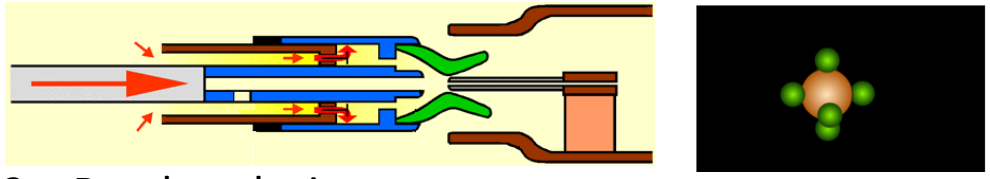
Why SF_6 gas is an excellent solution for GIE



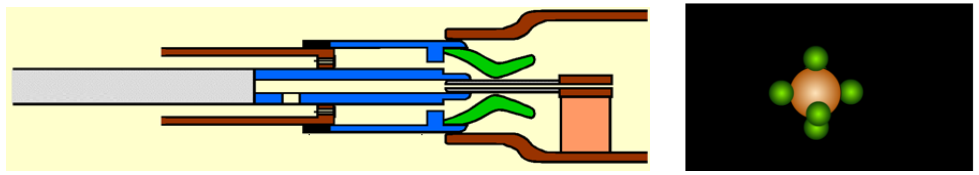
SF_6 Gas in GIE – How it works



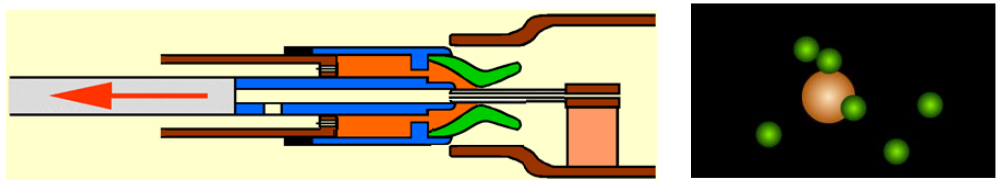
1 – Breaker Open



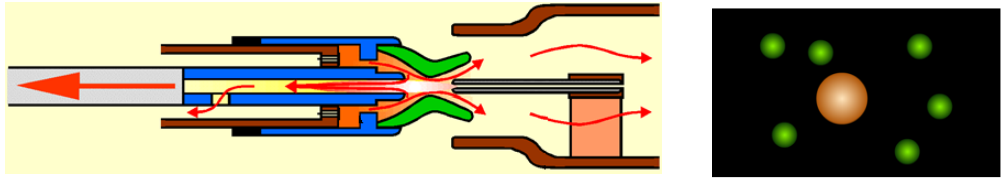
2 – Breaker closing



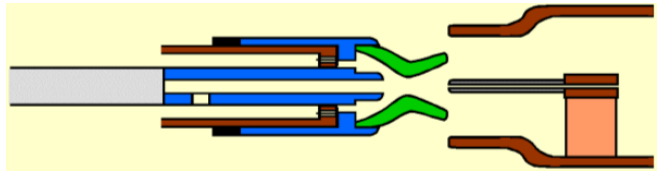
3 – Breaker closed



4 – Breaker Opening / Commutation



5 – Breaker Opening / Arc Quenching



6 – Breaker Open

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Overview of SF_6 reporting regulations

Overview of SF_6 reporting regulations

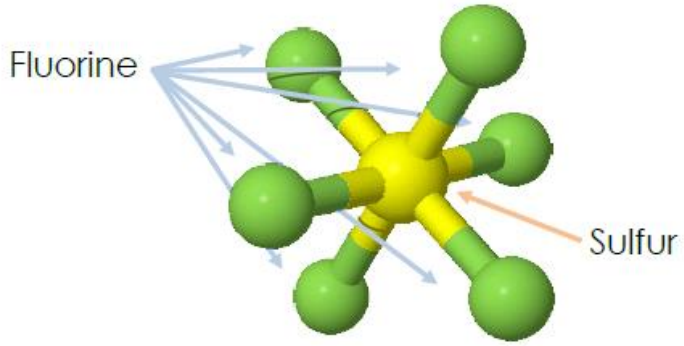
SF6 = Global Warming gas

- Not an ozone-depleting gas

- SF6 – Global wamring potential (GWP) = 24,000
- CO2 – Global warming potential (GWP) = 1

- SF6 - estimated lifespan = 3,200 years
- CO2 - estimated lifespan = 90 years

- 1 Pound SF6 = 11 Tons CO2



Overview of SF_6 reporting regulations

EPA considerations

- **Began investigating SF6 - 1997**
- **2012 - Mandatory reporting**
  - **for name plate capacity of 17,820 lbs**

- EPA's online reporting tool
  - https://ghgreporting.epa.gov

- **Additional information**
  - www.epa.gov/electricpower-SF6

Overview of SF_6 reporting regulations

SF_6 Emissions Reduction Partnership for Electric Power Systems

Annual Reporting Form

Name:	EH&S Manager Name	Company Name:	Customer Name
Title:	EH&S Manager	Report Year:	2015
Phone:	(555)555-5555	Date Completed:	Mar-16

Change in Inventory (SF_6 contained in cylinders, not electrical equipment)

Inventory (in cylinders, not equipment)	AMOUNT (lbs.)	Comments
1. Beginning of Year	5,844.08	
2. End of Year	6,040.10	
A. Change in Inventory (1 - 2)	(196.02)	

Purchases/Acquisitions of SF_6

	AMOUNT (lbs.)	Comments
3. SF_6 purchased from producers or distributors in cylinders	2,070.00	
4. SF_6 provided by equipment manufacturers with/inside equipment	8,357.00	
5. SF_6 returned to the site after off-site recycling	-	
B. Total Purchases/Acquisitions (3+4+5)	10,427.00	

Sales/Disbursements of SF_6

	AMOUNT (lbs.)	Comments
6. Sales of SF_6 to other entities, including gas left in equipment that is sold	-	
7. Returns of SF_6 to supplier	343.20	
8. SF_6 sent to destruction facilities	-	
9. SF_6 sent off-site for recycling	3,551.80	
C. Total Sales/Disbursements (6+7+8+9)	3,895.00	

Change in Nameplate Capacity

	AMOUNT (lbs.)	Comments
10. Total nameplate capacity (proper full charge) of new equipment	910.00	
11. Total nameplate capacity (proper full charge) of retired or sold equipment	1,170.00	
D. Change in Capacity (10 - 11)	(260.00)	

Total Annual Emissions

	lbs. SF_6	Tonnes CO_2 equiv. (lbs.SF_6x22,800/2205)
E. Total Emissions (A+B-C-D)	6,595.98	68,203.33

Emission Rate (optional)

	AMOUNT (lbs.)	Comments
Total Nameplate Capacity at End of Year	48,872.00	
	PERCENT (%)	
F. Emission Rate (Emissions/Capacity)	13.5%	

EPA Reporting is required every calendar year (due March/April of the following year).

What is required reporting

- Nameplate capacity of:
  1) equipment containing SF6 at the beginning of the year
  2) new equipment purchased during the year; and
  3) equipment retired during the year.

- Transmission miles (length of lines carrying voltages at or above 34.5 kV).

- SF6 sales and purchases.

- SF6 sent off site for destruction

  .

- SF6 sent off site for recycling.

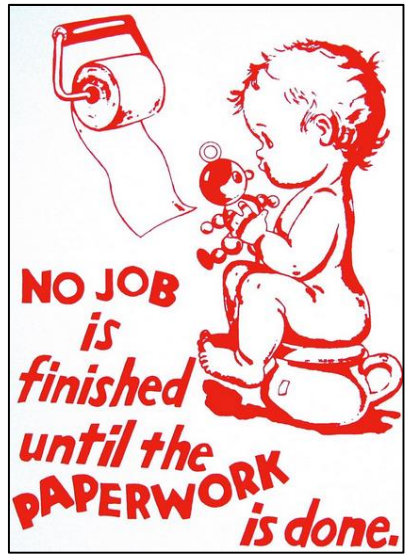
- SF6 returned to site after recycling.

- SF6 stored in containers at the beginning and end of the year.

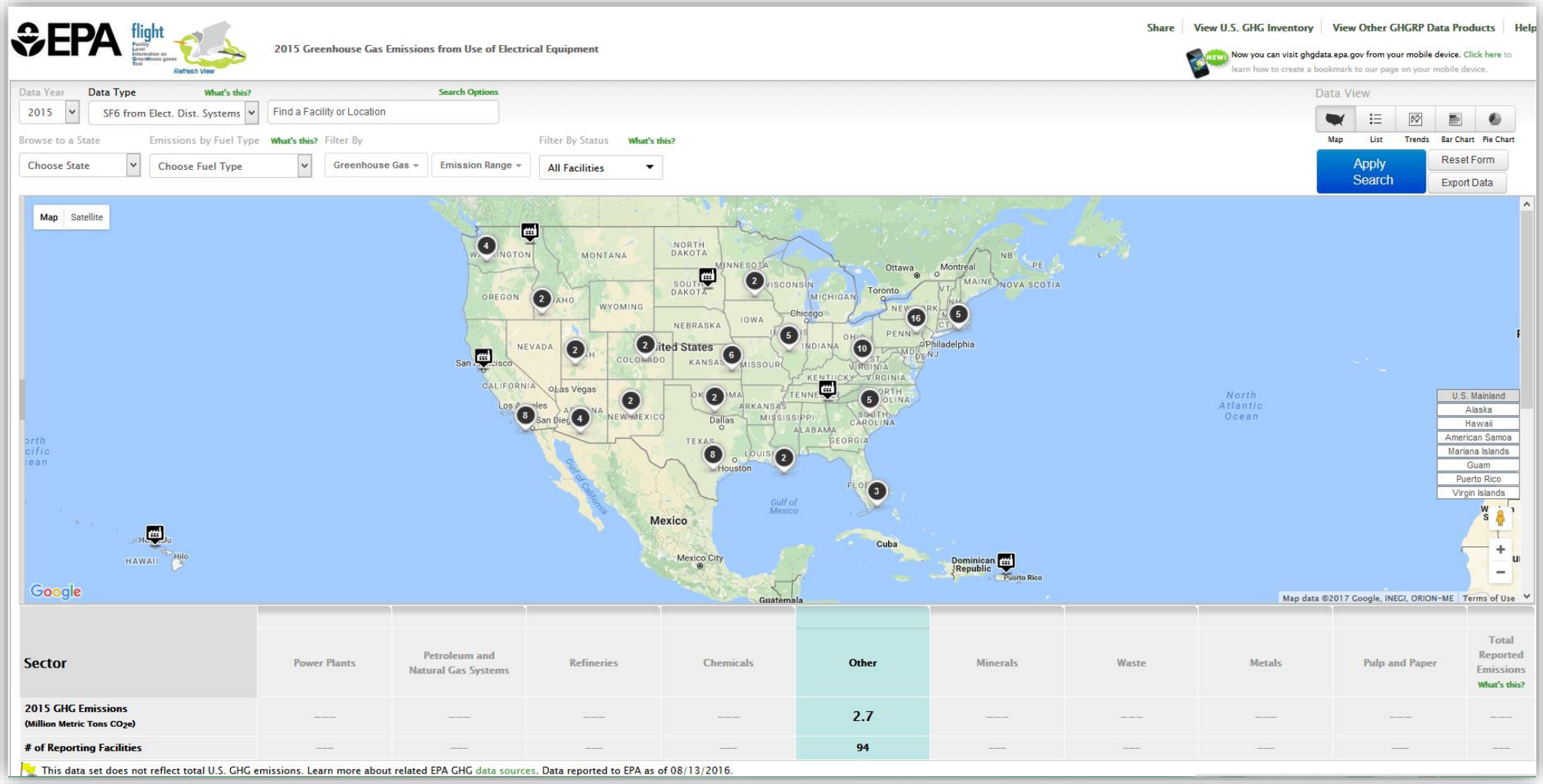
- SF6 with or inside new equipment purchased during the year.

- SF6 with or inside equipment sold to other entities.

- SF6 returned to suppliers.



Overview of SF_6 reporting regulations



Overview of SF_6 reporting regulations

Not many reporters to the EPA in NJ.
However the trend illustrates a drastic drop in emissions through the history of the GHGR Tool.

http://www.njcleanenergy.com

https://ghgdata.epa.gov/ghgp/main.do#/listFacility/?q=Find a Facility or Location&st=&bs=&fid

EPA flight Refresh View

2017 Greenhouse Gas Emissions from Use of Electrical Equipment

Share | View U.S. GHG Inventory | View Other GHGRP Data Products | Help

NEW! Now you can visit ghgdata.epa.gov from your mobile device. Click here to learn how to create a bookmark to our page on your mobile device.

Data Year: 2017 | Data Type: SF6 from Elect. Dist. Systems | What's this? | Search Options: Find a Facility or Location

Browse to a State: Choose State | Filter By: Greenhouse Gas, Emission Range | Filter By Status: All Facilities | What's this?

Data View: Map, List, Trends, Bar Chart, Pie Chart

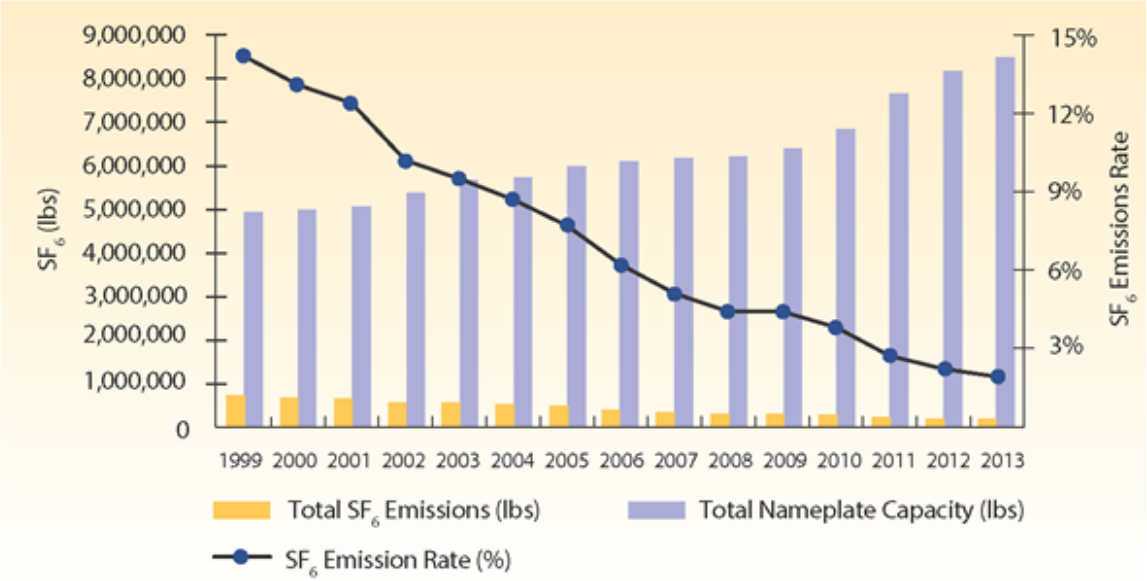
Apply Search | Reset Form | Export Data

View by: Selected Year | Changes

U.S. – Total Reported Emissions by Facility, by Year in Metric Tons of CO_2e

Facility	City	State	Total Reported Emissions, 2011	Total Reported Emissions, 2012	Total Reported Emissions, 2013	Total Reported Emissions, 2014	Total Reported Emissions, 2015	Total Reported Emissions, 2016	Total Reported Emissions, 2017	Change in Emissions (2016 to 2017)	Change in Emissions (2011 to 2017)	S...
Atlantic City Electric	Carneys Point	NJ	5,039	5,584	1,781	1,126	0	0	0	0	-5,039	O...
Cogen Technologies Linden...	Linden	NJ	880	4,257	19,857	0	7	0	0	0	-880	O...
PSE&G	Newark	NJ	117,586	---	---	---	---	---	---	---	---	O...
PSE&G Subpart DD	Newark	NJ	---	74,608	62,018	12,670	64,068	100,555	1,972	-98,583	---	O...

Overview of SF_6 reporting regulations

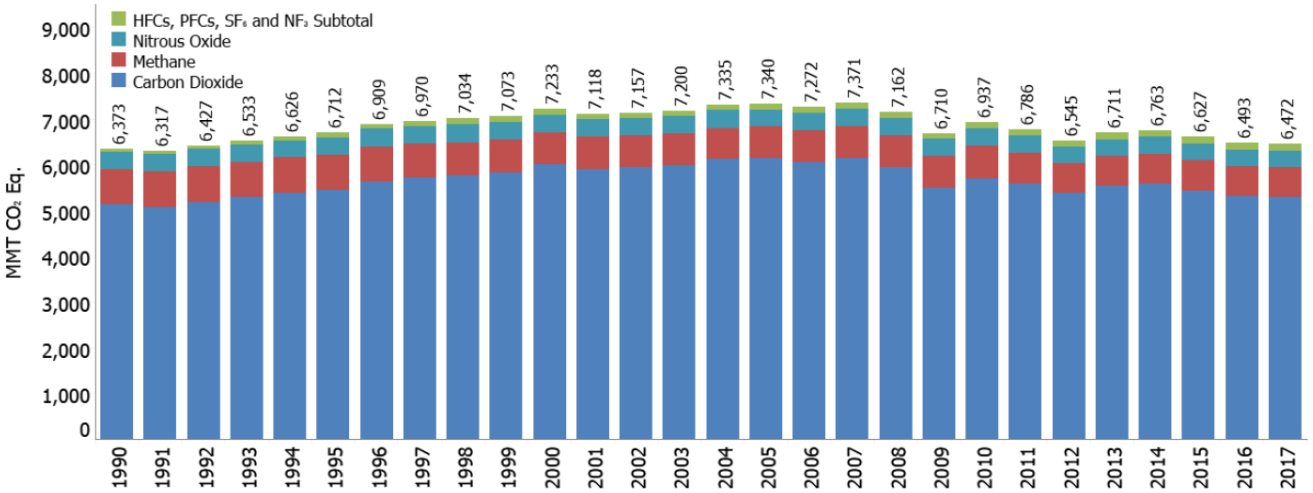


The annual average SF_6 emission rate of Partners has decreased drastically since 1999. In the past five years, the emission rate has halved, from over 4 percent to just below 2 percent. Overall, the annual average SF_6 emission rate for the Partnership is down approximately 87 percent from the 1999 baseline emission rate of 14.2 percent to 1.9 percent in 2013.

https://www.epa.gov/f-gas-partnership-programs/electric-power-systems-partnership

Responsible practices and processes, improvement in reporting accuracy and technological improvements with GIE & recovery systems and measuring equipment have contributed to great improvements.

Figure 2-1: Gross U.S. Greenhouse Gas Emissions by Gas (MMT CO_2 Eq.)



REF: Draft Greenhouse Gas Emissions Inventory Report – Released for 2019

Overview of SF_6 reporting regulations

State Regulations - Subarticle 3.1, Regulation for Reducing Sulfur Hexafluoride Emissions from Gas Insulated Switchgear sections 95350 to 95359, title 17, California Code of Regulations.

- CARB – California Air Resources Board
- Goal – lower annual emissions to no more than 1% by 2020

- Entity Name (Company, Corporation, Entity or agency)
  - CARB ID as assigned
  - Record location (site or plant name of reporting origination) - Street Address, City, Zip Code, State
  - Name of the individual preparing the report - Telephone, email
- Emission Reporting
  - Reporting Year
  - Annual SF_6 Gas emissions in pounds
    - User Emissions LBS = (Decrease in SF_6 inventory)+ (Acquisitions of SF_6) – (Disbursements of SF_6) – (Net Increase of Nameplate SF_6 Capacity of Active & Owned GIS Equipment)
  - Annual SF6 emissions in %
    - User Emissions % = Emissions (LBS) ÷ Cavg
      - Cavg = The average number of days a GIS is installed the reporting year.
  - GIS Serial Number, Type (bus, breaker, switch), Seal type (Hermetically Sealed or Not), MFG, MFG Date.
  - Cylinder ID (Serial Number)
  - Container size (capacity in lbs.)
  - Location of storage of each cylinder - Street address, City, Zip Code and State
  - SF_6 Gas in each container.

Overview of SF_6 reporting regulations

Maximum Annual SF_6 Emission Rate Calendar Year Maximum Allowable SF_6 Emission Rate	
2011	10%
2012	9%
2013	8%
2014	7%
2015	6%
2016	5%
2017	4%
2018	3%
2019	2%
2020 and each calendar year thereafter	1%

Overview of SF_6 reporting regulations

MassDEP

- **Massachusetts Department of Environmental Protection**
- **(GHG) –reporting rule**
  - **40CFR part 98 and 310 CMR 7.71, et seq., respectively**

- **Control of Emissions from (GIS)**

- **NEW equipment purchased by MA after Jan. 1 2015, may not exceed a 1% emission rate.**
- **Must comply with declining all emissions to 1% or less by 2020**

Maximum Annual SF_6 Emission Rate	
Calendar Year	Maximum Allowable SF_6 Emission Rate
2013	3.5%
2014	3.5%
2015	3.5%
2016	3.0%
2017	2.5%
2018	2.0%
2019	1.5%
2020, and each calendar year thereafter	1.0%

Overview of SF_6 reporting regulations

Oregon Department of Environmental Quality

- Chapter 340, Division 215 GREENHOUSE GAS REPORTING REQUIREMENTS
- Investor Owned & Consumer Owned Utilities, electricity service suppliers and other electricity suppliers (with some specific exceptions for each type (consumer or investor owned) consumer-owned utilities) required to register and report under OAR 340-215-0030(6)

- Investor owned utilities and electricity service suppliers must determine SF6 emissions from transmission and distribution equipment, they own or operate pursuant to methodologies included in 40 CFR Part 98, Subpart DD with a modification to delineate emissions for Oregon. While EPA's protocols require reporting of the total emissions for all equipment owned or operated by the company, each company must estimate the emissions associated with their provision of electricity to Oregonians in their report to DEQ. Each company must do this by calculating the SF6 emissions based upon the portion of electricity they supply to Oregon end users. Companies must do this by first calculating the total SF6 emissions from all their transmission and distribution equipment pursuant to 40 CFR Part 98, Subpart DD, and then multiplying these emissions by the ratio of the amount of electricity the utility supplied to Oregon end users compared to the total electricity the utility supplied within its jurisdiction.

Overview of SF_6 reporting regulations

Washington State

- Washington State Department of Ecology & Wash Environmental Council
- City of Seattle
- Puget Sound Clean Air Agency

All have adopted and/or reference policies and regulations as set by the EPA.

In some cases Carbon Taxes are issued to SF_6 gas emissions based on calculations set by these policies and regulations. Each agency or local Environmental Agency enforces the policies and regulations as applicable to each region.

The state and the regional agencies are reviewing their policies. However, they have been reporting a significant reduction in emissions and improved management.

Overview of SF_6 reporting regulations

EMERGENT GAS LOSS Rule & Regulation:

- EPA
- CARB
- MassDEP
- Others

a) A GIS owner may request emissions from an emergency event to be exempted from the calculation of the maximum allowable emission rate if it is demonstrated to the Executive Officer's satisfaction that the release of SF_6 :

(1) Could not have been prevented by the exercise of prudence, diligence, and care; and

(2) Was beyond the control of the GIS owner.

Each agency may have additional requirements:

- Location
- Event desription
- Equipment model, Type, Serial Number and MFG
- Amount of SF_6 gas emission

Electric Transmission & Distribution SF_6 Coalition

What's being done to reduce emissions

- SF_6 handling practices
- Alternative Solutions

Processes & Actions for SF_6 emission Reduction

- What has been done:
  - Improved Accountability and Documentation
  - Training of field personnel to ensure zero loss during any gas handling event
  - Traceability of events including Emergent Loss events, leaking GIE, Repair/Replacement of leaking GIE.
  - Technological advancement of recovery equipment which allows for zero emission practices.
  - Scale calibration and Mass Flow Meter implementation
  - Self Sealing fittings that are zero emission
  - Improved leak detection processes
  - Cylinder accountability
  - MFG improvements of GIE with <1% annual leakage rates

Processes & Actions for SF_6 emission Reduction

Recovery Preparations

Prior to starting the recovery process, the following steps and tests should be performed:

- **Adequate sized recovery system**: guarantees the most amount of gas can be recovered in a reasonable amount of time

- **Testing the SF_6 for arc by-products**: to determine the need for filtration and personnel protective equipment (PPE)

- **Testing the SF_6 for moisture**: to determine the need for additional filtration
- **Testing the SF_6 for purity (Volume Percentage)**: to determine the need for makeup SF_6 and possibly additional storage

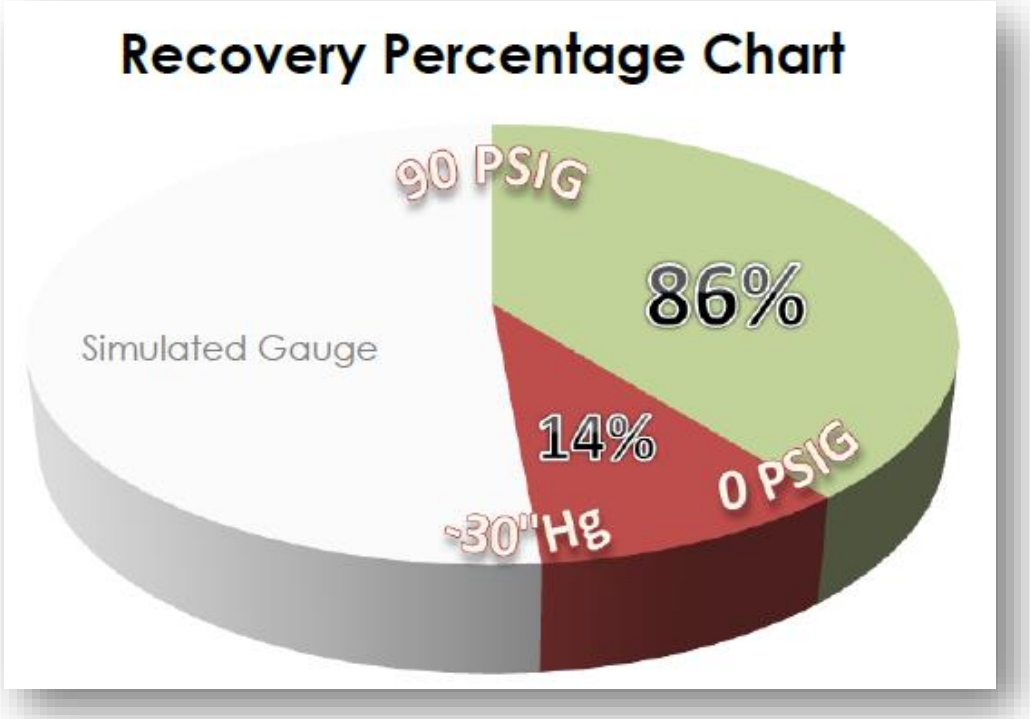
- **Connecting procedures**: properly testing all hoses and fittings to eliminate potential emissions or contamination

- **Proper Storage**: ensure that a large enough storage vessel or an adequate number of in-test DOT cylinders are available

- **Weighing device**: ensure that a properly calibrated weighing device is used to prevent overfilling storage and that all the gas has been removed from GIE

Processes & Actions for SF_6 emission Reduction

- **Understanding residual pressure**
  - Stopping the recovery process at 0 PSIG on a vessel with an operating pressure of 90 PSIG will leave 14% of the SF6 behind
  - If the equipment was opened, the remaining gas would be permanently lost to the atmosphere.



Processes & Actions for SF_6 emission Reduction

All breakers are filled based on the required density per the application.

The use of a Mass Flow Meter during filling and/or calibrated cylinder weigh scales allow the operator to account for all the gas moved from a cylinder to a GIE or from GIE to a cylinder.

Alternative solutions

	SF_6	Fluorinated nitrile (Novec 4710 fluid) + CO_2	Fluoroketone (Novec 5110) + CO_2 or N_2	Synthetic Air (80% N_2 + 20% O_2)
CO_2 equivalent	~ 22,800	~ 380	< 1	0
Carrier gas	Pure or variable with N_2, CF_4	~ 90% CO_2	~ 90% CO_2 with N_2 or O_2	Not applicable
Boiling point	-64° C	~ -25° C	+5° C	< -183° C
Mean residence time in the atmosphere	3,200 years	30 years	16 days	-

Source: CIGRE Paper B3-108 CIGRE Conference 2016; Data sheet 3M™ Novec™ 4710 / Novec™ 5110 *)

Note:

These are only examples of current alternatives being considered & tested. The market is evolving & continuing to add options for different voltages & fault duty.

- Fault duty & continous current must be considered.

	CO_2 equivalent	Carrier Gas	Boiling Point	Mean residence time in the atmosphere
Reconditioned SF_6 Gas	~22,800	Pure or with N_2, CF_4	-64° C	3,200 years

A positive alternative that currently meets all the requirements & lowers overall foot print & contribution of emissions worldwide.

Alternative solutions

Conclusion to Technical Paper from Nov 2002 at the **International Conference on SF_6 and the Environment: Emission and Reduction Strategies EPA workshop,** Technical Paper & Case Study by Solvay Flour, AGA Gas and AEP.

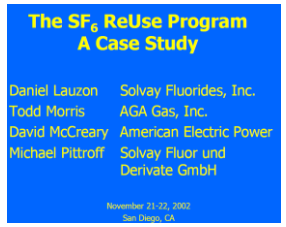
Inventory Management

- Inventory control a must for ReUse Program
  - Control and track every pound of used SF_6
  - Retain ownership until confirmation that gas was introduced in production stream, and
  - Empty cylinders returned to point of origin and final weight recorded

Summary

- Viable program for reclaiming used SF_6 gas
- Logistics of the program tailored for US
  - Working with partners like AGA Gas
  - Currently working on other cases with AEP for reclaiming used gas

"The beneficial impact of the SF_6 Re-Use program on global warming is evident"



Conclusion

Every pound of SF_6 taken back for reclaiming and therefore not released in the atmosphere is equivalent to an emissions savings of 22,500 pounds of CO_2

"Another less evident, but equally beneficial impact to the environment as a result of the program is that the toxic decomposition products found in used SF_6 gas are also not released."

Electric Transmission & Distribution SF_6 Coalition

- THANK YOU for the opportunity to present!

New Jersey Clean Air Council Annual Public Hearing

Q&A