SF6 Free HV GIS and Breakers

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Manager of Substation
and T-Line Standards Engineering

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Purpose

- **Share status on replacement of SF6 with environmentally friendly insulating gas for high voltage GIS and breakers.**

- **SDG&E, SCE, SMUD, LADWP & PG&E**
- **EPRI**
- **ABB, GE, Hitachi & Siemens**
  3M

- **Discussion on the Eco Gas replacement for SF6**

- **November 29, 30 2016**
  What we learned

Why SF6 Free GIS and Breakers?

Environmental Stewardship

"Environmental stewardship is core to PG&E's culture and, in the supply chain context, that means finding ways to deliver energy with cleaner technology.

Procuring SF6 free technology is an imperative in this regard. Because the electric utility industry is responsible for 90% of the SF6 global market, we see eliminating this potent greenhouse gas from our value chain as a duty of care. Additionally, the move away from SF6 help us comply with SF6 leak rate legal requirements, as well as help eliminate the hazardous waste costs associated with the gas."

Gun Shim PG&E Vice President Supply Chain

Why SF6 Free GIS and Breakers?

Customer Requested

"Timely Announcements by WalMart & Microsoft"

Jess Brown PG&E Director, Large Enterprise Accounts

Why SF6 Free GIS and Breakers?
Reporting Obligations

USEPA

- Report annually by March 31
- Resubmit report within 45 days (plus an additional 30 days if requested) of substantive errors being discovered [40 CFR Part 98.3(h)]
- Report calculated annual SF6 emissions (lbs) – to include both hermitically and non-hermetically sealed gas insulated switchgear (GIS)

CARB

- Report annually by June 1
- Resubmit report within 45 days (plus an additional 30 days if requested) of substantive errors being discovered [adopted 40 CFR Part 98.3(h) by reference]
- Report calculated annual SF6 emissions (lbs) and calculated SF6 emission rate for only non-hermetically sealed GIS (which uses average nameplate capacity of the GIS)

Maximum Allowable SF6 Emission Rate by Calendar Year

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020 & beyond
CARB allowable values	10%	9.0%	8.0%	7.0%	6.0%	5.0%	4.0%	3.0%	2.0%	1.0%

Why SF6 Free GIS and breakers?

Because alternatives are available

ABB, GE, Hitachi and Siemens have alternatives to SF6

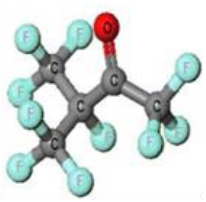
	Year non-SF6 Live Tank Breakers will be available	Year non-SF6 Dead Tank Breakers will be available	Year non-SF6 GIS Will be available
70kV	Available 2015	Available 2016	Available 2016
115kV	Available 2017	Available 2017	Available 2016
230kV	Available 2020	Available 2019	Available 2020
500kV	Available 2020	Available 2019	Available 2022

Please Note: For PG&E Asset Strategy planning purposes, I have included target availability dates above for our QSL suppliers for GIS and Breakers. These dates may change and will likely evolve as PG&E, SDG&E, SCE, SMUD and LADWP continue to work with our suppliers.

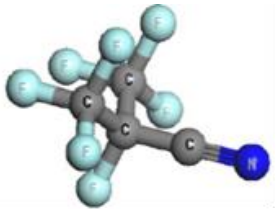
Four Alternatives to SF6

world class vendors

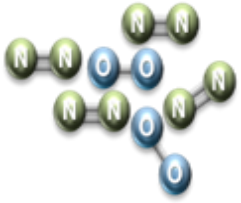
- 3M™ Novec™ Dielectric Fluids
  - GE
  - ABB
- Vacuum/clean air
  - Siemens
  - Hitachi



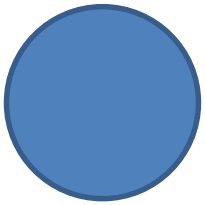
C5-Flourketone 5110



Flournitrile 4710



Clean-Air

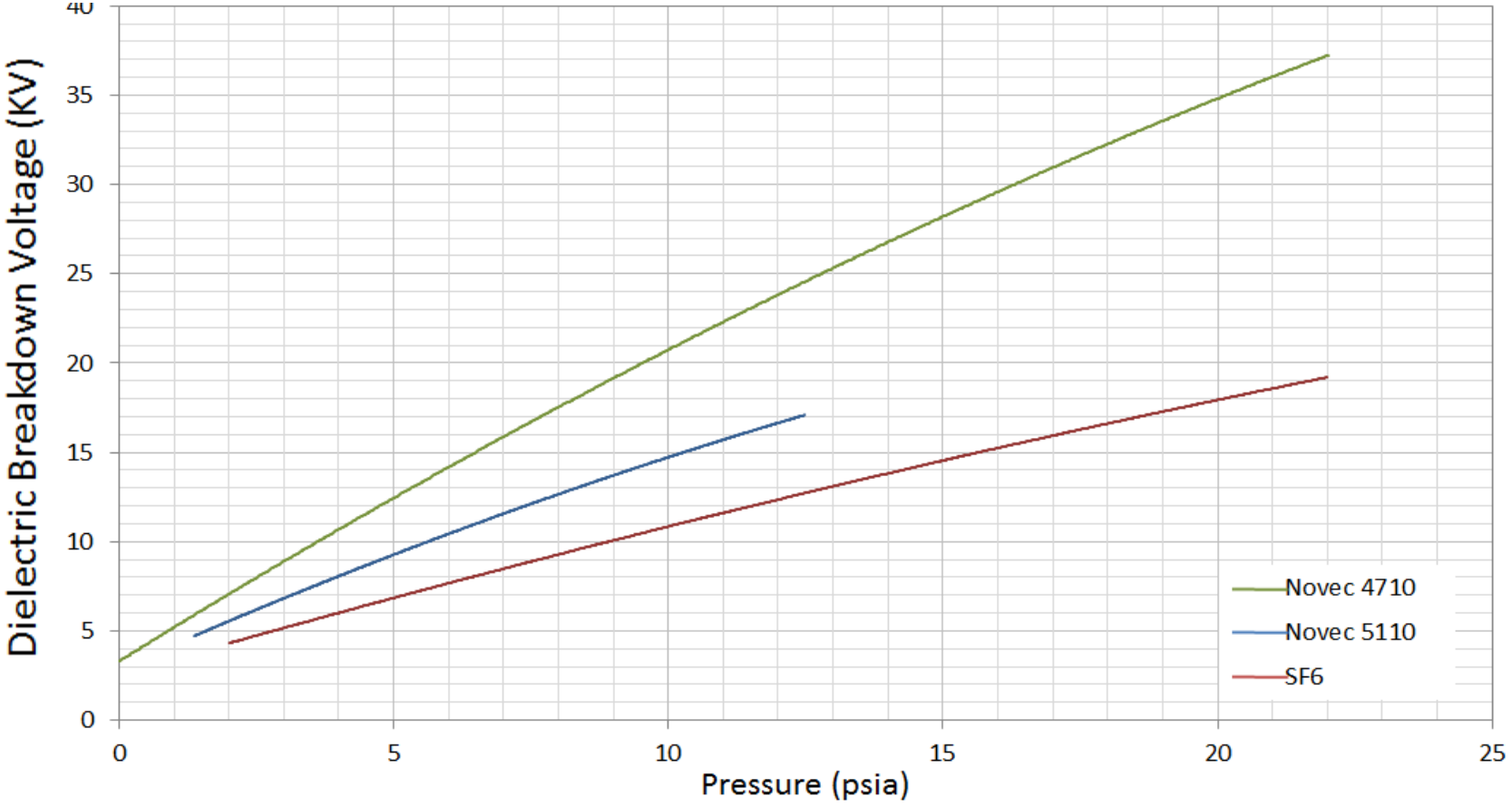


Vacuum

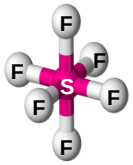
Novec™ 4710 vs. Novec™ 5110

Dielectric Breakdown Voltage

Dielectric strength of pure Novec™ Dielectric Fluids exceeds SF6

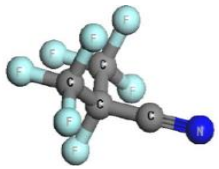


Properties of different gases for GIS and breakers



Sulfurhexaflouride

Clean-Air



Flournitrile 4710

C5-Flourketone 5110

Pure Gases	Chemical formula	SF_6	$N_2 + O_2$ (80% / 20%)	$(CF_3)_2CFCN$	$(CF_3)_2CFC(O)CF_3$
	CO_2-equivalent (GWP)	22.800	0	2.210	1
	Boiling point (Celsius)	-64°	< -183°	-5°	+27°
	Dielectric strength	1*	0,43	2,2	1,7
Gas Mixture	Carrier gas	None, N_2 or CF_4	/	~ 95% CO_2	~ 90% CO_2 w. N2 or O_2
	CO_2-equivalent (GWP)	< 22.800		~ 380	<1
	Boiling point (Celsius)	<-64°(variable)		~ -25°	+5°
	Dielectric strength at same pressure	1*	0,43	0,87…0,92 [2]	0,7 [3]
Arc Impact	Decomposition products	hydrofluoric acid, sulfur dioxide, sulfur compounds	Only if failure: ozone and nitrogen oxides	Incl. Carbon monoxide, carbon dioxide, hydrofluoric acid	

* Relative dielectric strength, normalized to SF_6 (=1)

[2] pressure 0,67MPa…0,77MPa, Source: Y. Kieffel, et al. „SF6 Alternative Development for High Voltage Switchgears," in Cigré Session, 2014.

[3] pressure 0,45 MPa Source: J. Mantilla, et al „Investigation of the Insulation Performance of a New Gas Mixture with Extremely Low GWP," in Electrical Insulation Conference, USA, 2014.

SF6: High Impact to Environment
Dry Air: no Impact to Environment

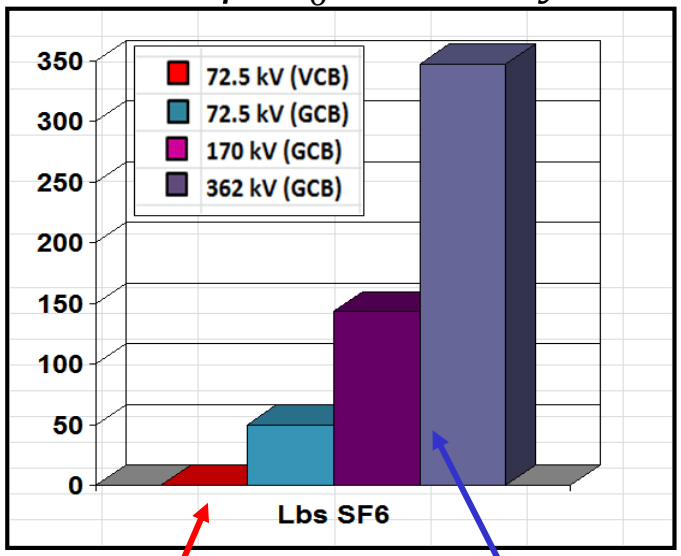
HITACHI
Inspire the Next

***G**lobal **W**arming **P**otential: A measure of how much a given mass of greenhouse gas contributes to global warming.*

Relative scale compared to CO_2

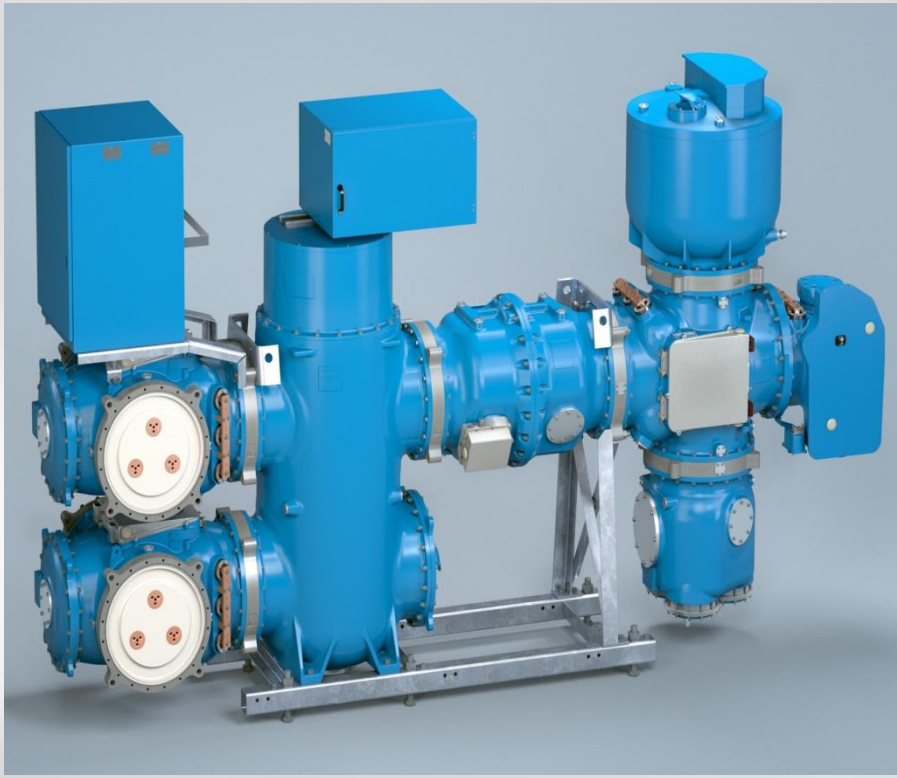
Gas	GWP
Dry Air (VCB)	NONE
CO_2 (Carbon dioxide)	1
SF_6 (GCB)	23,900

Pounds of SF_6 in GCB by



145kV SF6 Free GIS

Switchgear type	8VN1
Rated voltage	145 kV
Rated power-frequency	275 kV
Rated lightning impulse (1.2 / 50 µs)	650 kV
Rated normal current	3150 A
Rated short-circuit breaking current	40 kA
Rated short-time current (up to 3 s)	40 kA
Leakage rate per year	< 0.1 %
Driving mechanism of circuit-breaker	Spring
Rated operating sequence	O-CO-15s-CO
Interrupter technology	Vacuum
Insulation medium	Clean air
Bay width common pole drive	3'4"
Bay height, depth (typical)	10'6" x 18'
Bay weight (typical)	5 t
Ambient temperature range	-58 ºF up to +122 ºF
Installation	indoor / outdoor
First major inspection	> 25 years
Expected lifetime	> 50 years



Technology Pilot for 145 kV

SF6 Free LTB & DCB

- Technology Pilot in 2010
  - Tested according to IEC 62271-100
  - Installed in March 2010
  - Daily switched capacitor bank application
  - Test installation works flawlessly

World‘s first Non-SF6 GIS installation with AirPlus™

UW Oerlikon, ewz, Switzerland

Energized in summer 2015

- 8 high-voltage GIS bays (top)
- 50 medium-voltage GIS bays (bottom)

	GLK-14	ZX2
Rated Voltage	170 kV	24 kV
Rated current	1250 A	2500 A
Rated frequency	50 Hz	50 Hz
Rated short-circuit current	40 kA	25 kA
Minimal functional pressure	700 kPa abs	120 kPa abs
Minimal operating temperature	+5°C	-15°C
Background gas	CO_2 and O_2	Tech. Air

Products & First Available Applications

GE AIS Current Transformers 245 kV (-30°C)

First Application:
Frankfurt North & Sottrum S/S for TenneT (Germany)

6 units produced
FAT performed with TenneT.
E&C @ site 2017

GE Gas-Insulated Lines 420 kV (-25°C)

First Application:
Sellindge S/S for NG (UK)

Second Application:
Kilmarnoch S/S for SPEN (Scotland)

Sellindge ready for energization

GE GIS 145 kV incl. CB (-25°C)

First Application:
AXPO (CH)

Grimaud – RTE (France) End 2017?

F35-145kV g³ GIS

Same footprint with g³ as SF_6 solution

Item		Value			Unit
Rated Voltage		145			kV
Nominal Frequency		50 / 60			Hz
Rated Nominal current		up to 2500			A
Short duration pow frequency voltage		275	315		kV
BIL		650	750		kV
Short circuit	Ith	40			kA
	duration	3			s
Short circuit current peak		108			kA
Mechanical class for CB and		10,000 (M2)			Ops
Cap. Switching performance		C2 (LC/CC/BC)			
Pressure Design (lockout/Warning/Filling)		6	6.5	7	bar
		87	94	102	psi
Medium for insulation / interruption		6%vol g³			

SF_6 = 60 kg Equiv 1'400 t CO_2

g³ Equiv 27 t CO_2

Synergy

- PG&E
  - Purchased/Installed 6 72 kV SF6 free HV breakers from Hitachi (Pilot)
  - Writing specification for 115kV single bay SF6 free GIS (Pilot)
  - Livermore Training center Non SF6 GIS installation 2017 (Pilot)
  - PG&E will pilot Non SF6 technology for 2018 acceptance.
  - Planning 115kV multi bay SF6 free HV GIS for bid in 2018
  - Team with other CA utilities

- PG&E will work with other CA Utilities
  - To avoid duplication
  - Reduce cost
  - Standardize on replacement gas
  - Multi SME
  - IEEE standard
  - Utility specification

Thank you

Pacific Gas and Electric Company

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

SDGE

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