התאגדות מהנדסי חשמל, אלקטרוניקה ואנרגיה בישראל

SEEI Electricity & Energy 2024

The 23rd International Annual Convention of SEEEI | 12-16.11.2024 | Eilat, Israel


# Consequences of EU Fgas regulation on MV Panels in Israel

## השלכות שינויי הרגולציה האירופאית על לוחות מתח גבוה בישראל

Dov Zimerman

EATON
Powering Business Worldwide

# Providing power management technologies that are more reliable, efficient and safe.

## 2023 Financials

| ETN | $23.2B | >92K |
|---|---|---|
| NYSE ticker | 2023 sales (USD) | Employees around the world |

### Electrical Sector

| | |
|---|---|
| Electrical Americas: | **$10.1 Billion** |
| Electrical Global: | **$6.1 Billion** |

### Industrial Sector

| | |
|---|---|
| Aerospace: | **$3.4 Billion** |
| Vehicle: | **$2.9 Billion** |
| eMobility: | **$636 Million** |

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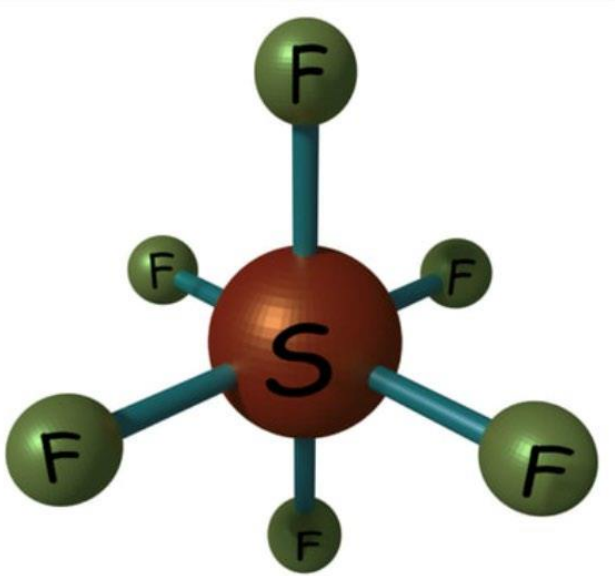
# What is $SF_6$?

- First reported in 1900 by French Chemist Henri Moissan
- **$SF_6$ or sulfur hexafluoride** is a human made, colourless, and odourless **gas.**
- Chemically stable, Non-toxic*, Non-flammable
- F-gases are a range of chemicals involving fluorine which have been used for a variety of things including the manufacture of shoes, tennis balls, and windows, and as a coolant in refrigerators.
- **Good properties as a dielectric insulating medium, prevents voltage electrical breakdown and explosion hazards.**

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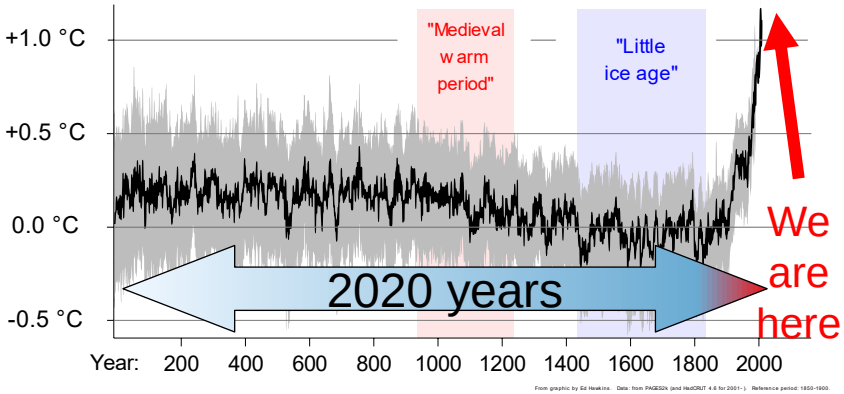
# SF6 (fluorinated gas)

- Dielectric strength:
  - 2.5 times higher than that of air
- Arc quenching:
  - SF6 is 100x more effective at quenching an arc than air
  - Creates resistance across the arcing contacts and eventually extinguishing the arc. Once the arc is extinguished, sulfur hexafluoride begins to regenerate almost immediately.
- Thermal properties:
  - More effective at dissipating heat then air, nitrogen, or other dielectrics.
  - The volumetric specific heat of $SF_6$ is 3.7 times that of air, meaning it is more effective at removing heat from the electric equipment

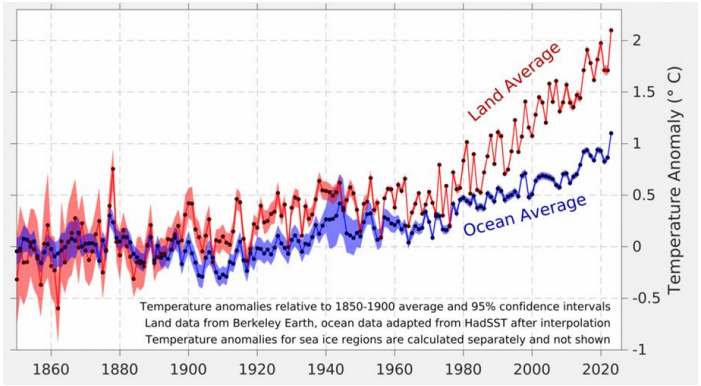
# Global view on climate and energy
# Motivation: global temperature rise

## Global Average Temperature Change




Source:Global temp. Change: By RCraig09 - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=87832845

## Land and Ocean Temperatures 1850-2023

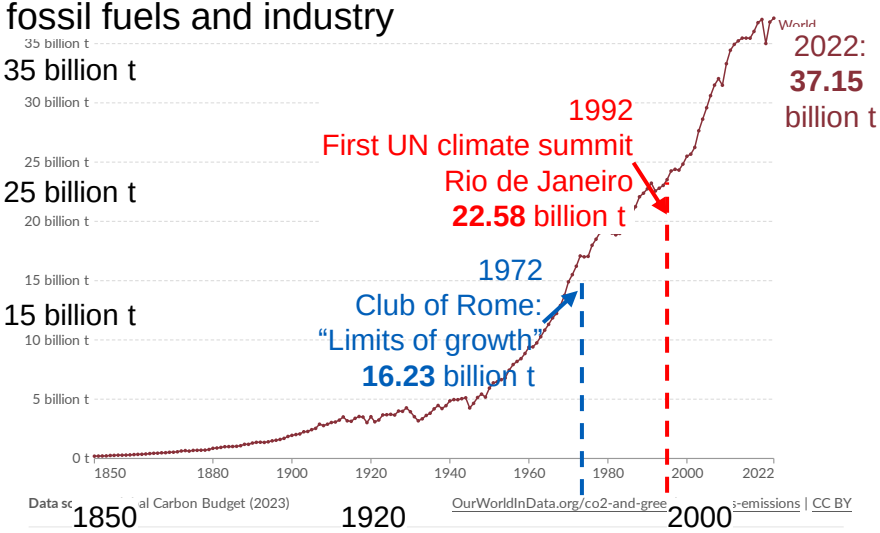



Source: https://berkeleyearth.org/global-temperature-report-for-2023/

# Global view on climate and energy

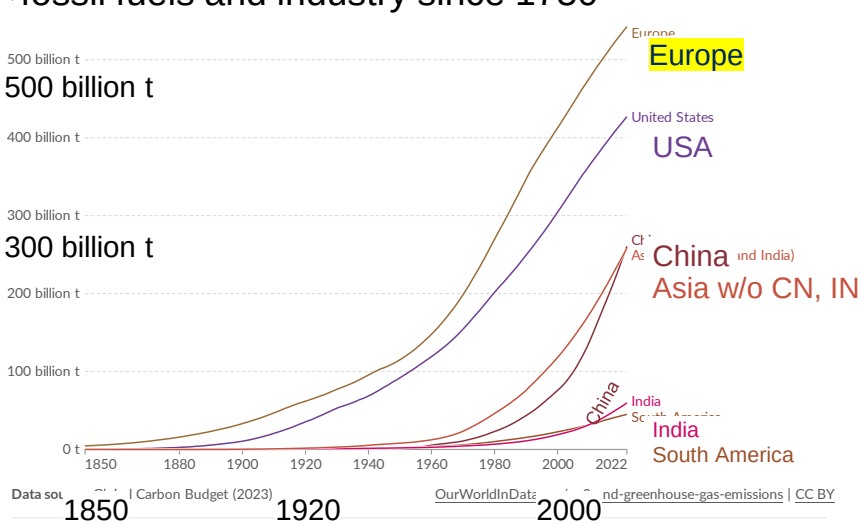
## Motivation: $CO_2$ emissions

Worldwide annual $CO_2$ emissions from fossil fuels and industry




1. **Fossil emissions**: Fossil emissions measure the quantity of carbon dioxide ($CO_2$) emitted from the burning of fossil fuels, and directly from industrial processes such as cement and steel production. Fossil $CO_2$ includes emissions from coal, oil, gas, flaring, cement, steel, and other industrial processes. Fossil emissions do not include land use change, deforestation, soils, or vegetation.

Cumulative $CO_2$ emissions from fossil fuels and industry since 1750

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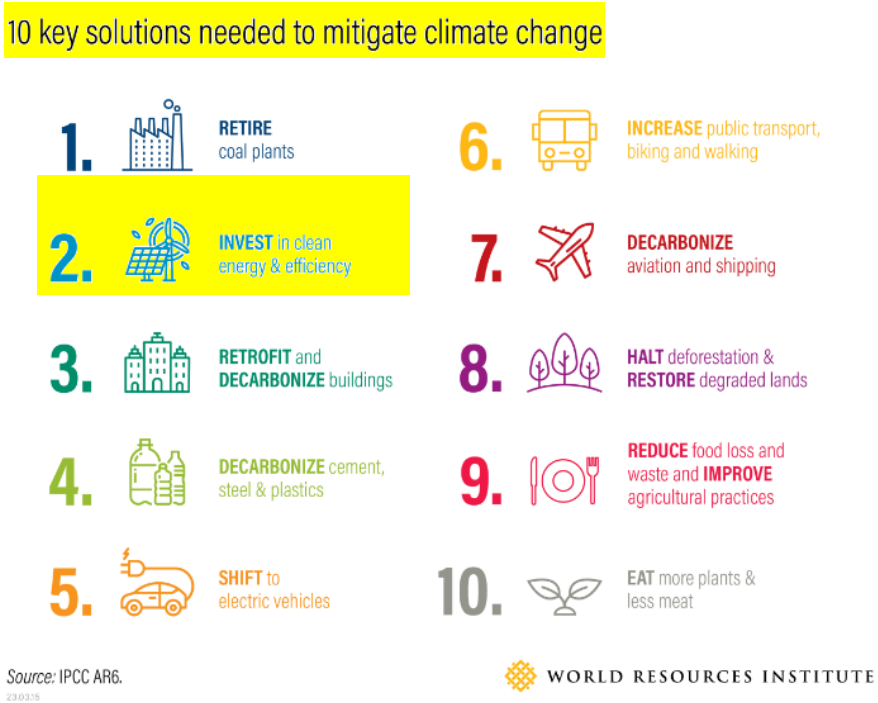
https://ourworldindata.org/grapher/annual-co2-emissions-per-country

https://ourworldindata.org/grapher/cumulative-co-emissions

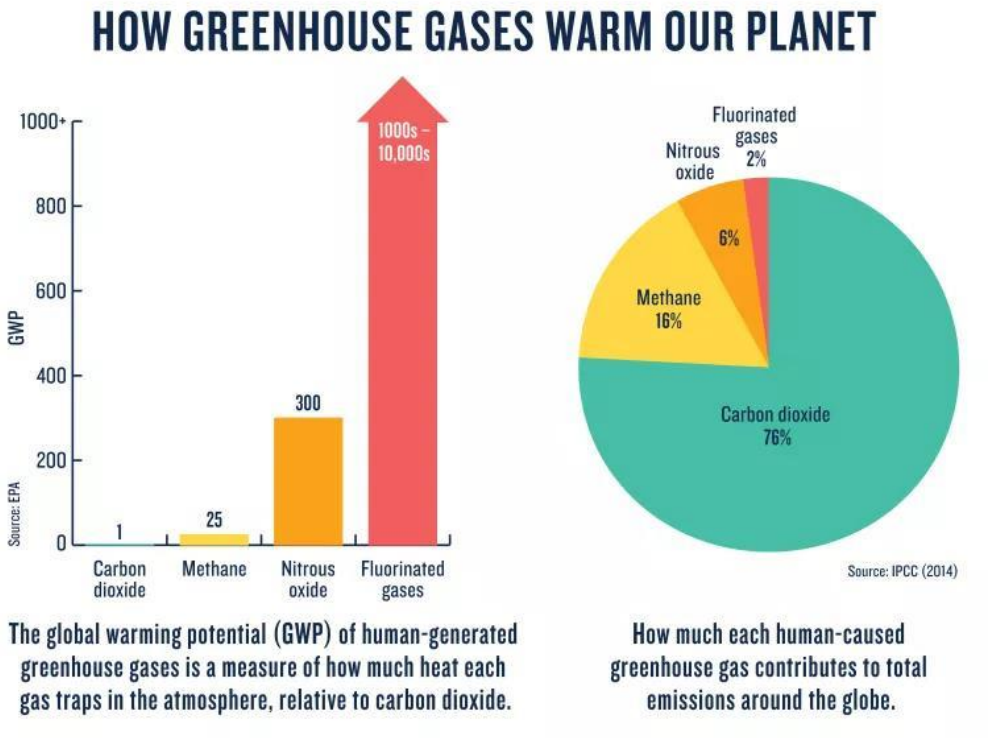
# Motivation: Energy efficiency
# Invest in clean energy and efficiency

- IPCC report 2023
  - Power generation, buildings, industry, and transport are responsible for close to 80% of global emissions
  - One necessary measure is **investment in clean energy & efficiency (2.)**




Source: https://www.wri.org/insights/2023-ipcc-ar6-synthesis-report-climate-change-findings and https://www.ipcc.ch/report/ar6/syr/

# SF6 aka Fluorinated gas

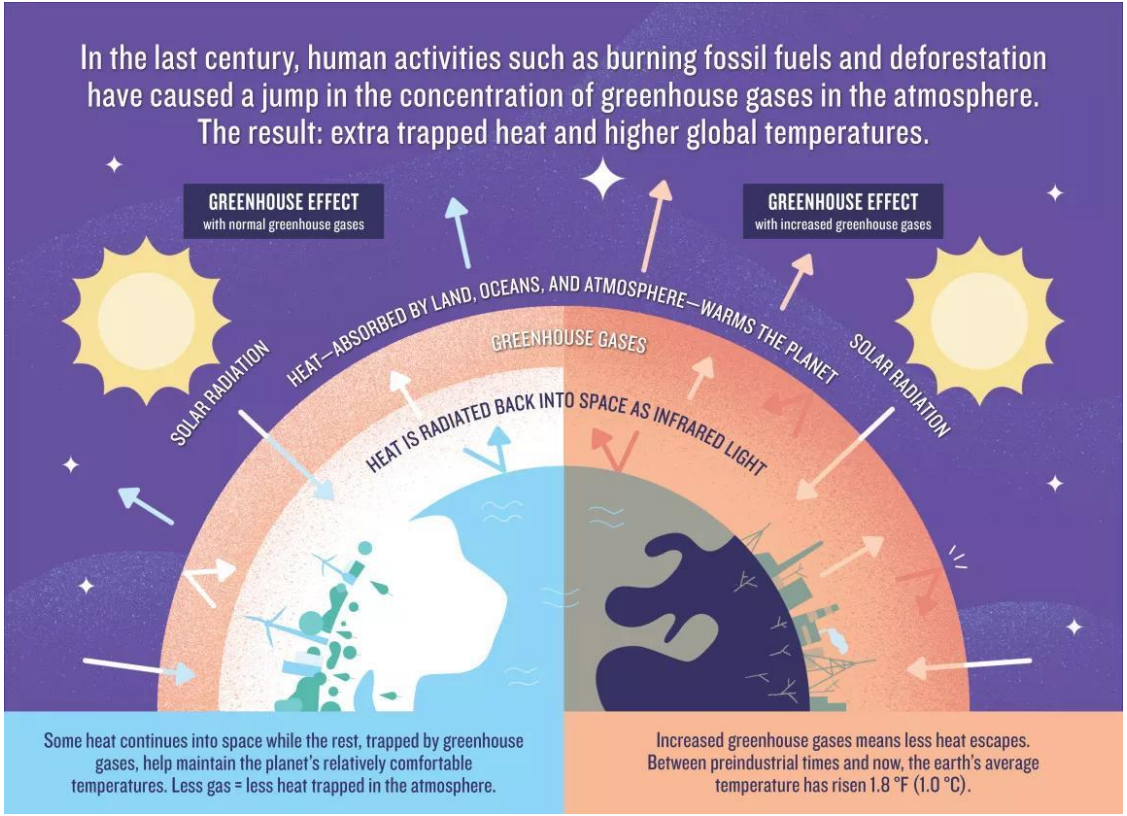



Over a 100-year period, $SF_6$ is **23,500 times** more effective at trapping infrared radiation than an equivalent amount of carbon dioxide ($CO_2$). $SF_6$ is also a very stable chemical, with an **atmospheric lifetime of 3,200 years.**

# What is a greenhouse gas?

During the day, the sun shines through the atmosphere, warming the earth's surface. At night, the earth's surface cools, releasing heat back into the air. But some of the heat is trapped by the greenhouse gases in the atmosphere.

The gases act like the glass walls of a greenhouse – hence the name, greenhouse gases



# Greenhouse Gases Global Warming Potential (GWP)

| Gas | Common Source or Application | Global Warming Potential (GWP) |
|---|---|---|
| Carbon Dioxide (CO2) | Fire suppression, carbonated beverages, by-product of fossil fuel consumption | 1 |
| Methane (CH4) | Consumed as fuel (also known as Natural Gas) | 21 |
| HFC6-152a | Refrigerant, aerosol spray propellant | 140 |
| Nitrous Oxide (N2O) | Known as 'Laughing Gases, pain relief in dental procedures, car performance, and preservative. | 310 |
| HFC-32 | Refrigerant | 650 |
| HFC-4310mee | Solvent for cleaning process | 1,300 |
| HFC-125 | Used as a fire suppression agent | 2,800 |
| HFC-143a | Refrigerant, aerosol spray propellant | 3,800 |
| HFC-236fa | Used as a fire suppression agent, refrigerant | 6,300 |
| CF4 | Refrigerant, electronics fabrication | 6,500 |
| C2F6 | Semiconductor fabrication | 9,200 |
| Fluoroform (HFC-23) | Semiconductor fabrication, fire suppressant | 11,700 |
| **$SF_6$** | **Electrical Switchgear** | **25,200** |

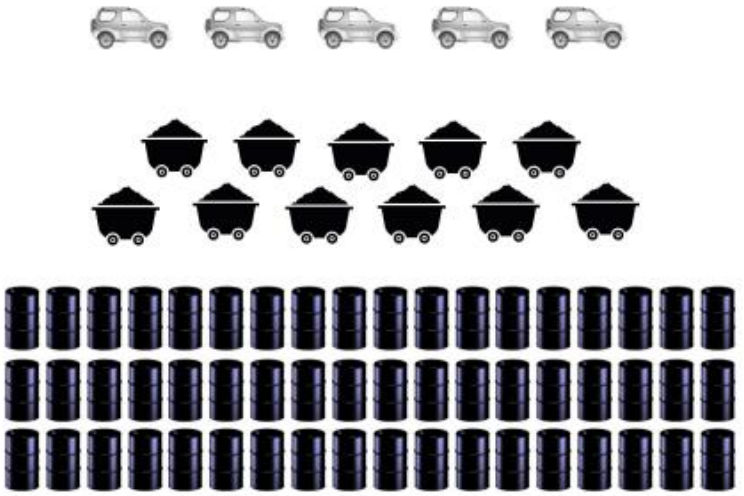
Source: WPD, A Literature Review on SF6 Gas Alternatives for use on the Distribution Network, 2018 [2]

# Greenhouse gas equivalents

- Preventing emission of **1kg of SF6**

  has the equivalent environmental impact as:

  - Removing **5 vehicles** from the road for an entire year
  - Preventing the burning of **11 metric tons of coal**
  - Eliminating the combustion of **54 barrels of oil**



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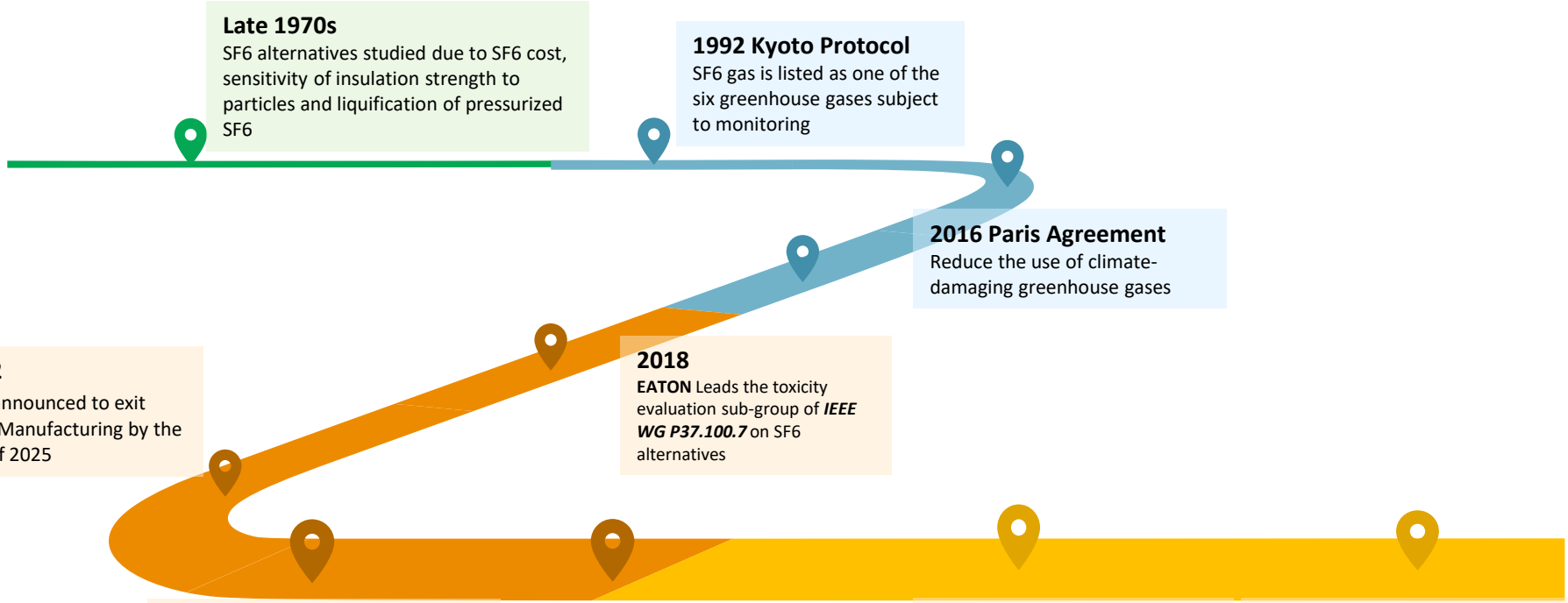
# $SF_6$ Toxic By-products

- Reactive decomposition by-products form when $SF_6$ is exposed to:
  - **spark discharges**
  - **partial discharges**
  - **switching arcs**
  - **failure arcing**
- Decomposition **by-products** can take the **form of gas** or **powders**
- If by-products are ingested or inhaled this can cause: eye, nose and throat irritation, **pulmonary oedema**, and other **lung damage**, skin and eye burns, nasal congestion, Bronchitis, rashes

**Caution $SF_6$**

# Timeline to SF6 free



**Late 1970s**
SF6 alternatives studied due to SF6 cost, sensitivity of insulation strength to particles and liquification of pressurized SF6

**1992 Kyoto Protocol**
SF6 gas is listed as one of the six greenhouse gases subject to monitoring

**2016 Paris Agreement**
Reduce the use of climate-damaging greenhouse gases

**2018**
**EATON** Leads the toxicity evaluation sub-group of ***IEEE WG P37.100.7*** on SF6 alternatives

**2022**
**3M** announced to exit PFAS Manufacturing by the end of 2025

**2023**
**DE, NL, DK, SE, NO** have submitted a proposal for a complete ban or "restriction" of PFAS, except for essential uses.

**2024 EU F-Gas Regulation**
New F-gas regulation and its legal framework was adopted and started to apply on **11 Mar. 2024**

**2028 CARB regulation**
Full ban of F-gas in new above ground switchgear (38kV)

**2030 EU F-gas regulation**
Full ban of F-gas in new switchgear (24~52kV)

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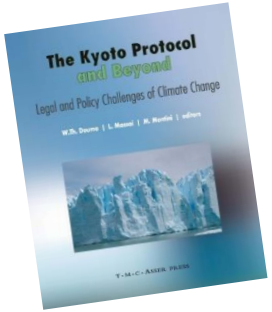
# Kyoto protocol sets path for F-Gas regulation




The Kyoto protocol stimulated the European Union to enforce the 2007 F-gas regulation.

Today $SF_6$ is banned for most industries. Exception is the switchgear industry because in 2014 $SF_6$ was deemed to have no reliable alternative.

**The switchgear industry and its users are responsible for 80% of total annual SF6 gas emissions.**

**European Union:**

*"No later than 1 July 2023, the Commission shall publish a report assessing whether* ***cost-effective, technically feasible, energy-efficient and reliable alternatives*** *exist, which make the replacement of fluorinated greenhouse gases possible in new medium-voltage secondary switchgear and new small single split air-conditioning systems and shall submit, if appropriate, a legislative proposal to the European Parliament and to the Council to amend the list set out in Annex III."*
– **Current F-gas regulation**

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# How damaging is $SF_6$ to the environment?

## The Power and Energy Industry is the Largest Emitter of $SF_6$ Gas.

**1** kg $SF_6$ **25200** kg $CO_2$
= **10.000** liters of burned gasoline

On average **2,5 kg $SF_6$** are used in one switchgear

**$SF_6$** lasts in the atmosphere for **3,200 years** after it is released

The power and energy industry is responsible for **80% of total annual $SF_6$ gas emissions**

*Last remaining loophole for $SF_6$ Gas emissions

- **Switchgear systems** ($SF_6$ switching & insulation)
- **Sport shoes** ($SF_6$ filled bags for shock absorption)
- **Tennis balls** (Less pressure loss with $SF_6$)
- **Car tires** (Less pressure loss with $SF_6$)
- **Double glazing** (Temperature insulation with $SF_6$)

## It is Time to End the Use of $SF_6$ in Switchgear!

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* IPCC AR6 Report

# Applications

- Utilities
- Industry
- Infrastructure
- Datacenter
- Commercial & Institutional
- Power generation

# עדכון 3-2024

Official Journal
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20.2.2024

**REGULATION (EU) 2024/573 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL**

**of 7 February 2024**

**on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014**

**(Text with EEA relevance)**

# עדכון 3-2024

## מתי יחלו ההגבלות?

תקנות הגז נכנסו לתוקף **באירופה** 20 יום מהפרסום הרשמי – כלומר הם נכנסו כבר לתוקף **ב-11/3/2024.**

| | מתח | החל מ- |
|---|---|---|
| **איסור על התקנת ציוד או לוחות מתח גבוה המכילים גז SF6 / F-gases** | **≥ 24kV** | **1/1/2026** |
| **איסור על התקנת ציוד או לוחות מתח גבוה המכילים SF6 / F-gases** | מ- 24kV עד 52kV | 1/1/2030 |
| **איסור על התקנת ציוד או לוחות מתח עליון עם F-gases בהם GWP ≥ 1*** | מ 52kV ועד 145kV | 1/1/2028 |
| **איסור על התקנת ציוד או לוחות מתח עליון עם F-gases בהם GWP ≥ 1*** | מ 145kV | 1/1/2032 |

*GWP - global warming potential

## REGULATION (EU) 2024/573 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

**Leak checks** (*Article 5)*

Electrical switchgear shall not be checked for leaks provided that it complies with one of the following conditions:

(a) it has a tested leakage rate of less than 0,1 % per year as set out in the technical specification of the manufacturer and is labelled accordingly;

(b) it is equipped with a pressure or density monitoring device with an automatic alert system while in operation;

(c) it contains less than 6 kilograms of fluorinated greenhouse gases listed in Annex I.

# עדכון 3-2024 ?

## High-voltage switchgear and controlgear - Part 4: Handling procedures for gases for insulation and/or switching (IEC 62271-4:2022)

**3.1.21**
**sealed pressure system**
volume for which no further liquid, gas or vacuum processing is required during its expected operating duration

Note 1 to entry: Examples of sealed pressure systems are vacuum circuit-breakers or some MV circuit-breakers or MV switchgear with leakage rates < 0,1 %/a.

Note 2 to entry: Sealed pressure systems are typically assembled and tested in the factory.

Note 3 to entry: Expected operating duration starts when the device is sealed.

[SOURCE: IEC 62271-1:2017, 3.6.6.3, modified – Note 1 to entry and Note 2 to entry modified.]

**IEC 62271-4:2022**

## 5 Gas handling during normal service life

### 5.1 Topping-up of gas to the filling pressure/density for insulation and/or switching

This subclause applies to gas compartments of closed pressure systems to assure continuity of service. Usually, the pressure/density monitor generates an alarm/indication due to too low pressure/density. The alarm value shall be proposed by the electric power equipment manufacturer.

#### A.6.14 Gas concentration alarm systems

Gas concentration alarm systems might be installed to monitor the $SF_6$ concentration in a room. Such alarm systems require detectors with very high long-term stability. The infrared absorption characteristic of $SF_6$ is used as the basis for most detectors of this type. An infrared source is used to heat a gas sample in a differential pressure-measuring device using a sensitive capacitance transducer. The pressure rise is measured.

Sensitivities down to 10 µl/l (ppmv) can be achieved. Automatic functional check facilities can

# IEC 62271-4:2022

## Table A.1 – Measures when working with $SF_6$ electric power equipment

A notice stating that open fire, naked flames (for example matches), smoking, use of heat engines, heating to more than 180 °C and welding without special precautions are prohibited because $SF_6$ decomposes in the presence of certain metals above the temperature of 200 °C, and will decompose on its own at temperatures above 500 °C, should be displayed. Electric arcing (through normal operations or interruption of fault currents) causes decomposition. Naked flames can also cause decomposition. Instructions for giving first-aid (see A.2.8) should be displayed while $SF_6$ is being handled in any location.

When a gas compartment is opened after the electric power equipment has been in service, personnel should wear suitable protective clothing in order to avoid contact with the fine solid by-products, which can be present. Particular attention should be given to protecting the eyes and the respiratory tract. Personnel working in or near to opened gas compartments, which have contained normally arced or heavily arced $SF_6$ should:

- use suitable tools and handling equipment;
- wear suitable protective clothing (see A.2.5);
- observe high standards of personal hygiene;
- clean themselves and their handling equipment using disposable materials, before leaving the work area;
- remove protective clothing and wash them thoroughly as soon as possible after having left the work area;
- ensure that clothing, tools and components which have been in contact with by-products are securely packed in sealed bags or other sealed containers and are subsequently treated to neutralise any residues.

# עדכון 3-2024 ?

IEC 61936-1

Edition 2.1 2014-02

## Power installations exceeding 1 kV a.c.
## Part 1: Common rules

# IEC 61936-1 2014

## 8.8.2 $SF_6$ leakage

Recommendations for use and handling of $SF_6$ gas are given in IEC/TR 62271-303.

To cover the unlikely event of an abnormal leakage, ventilation shall be provided in the switchgear room and in other accessible locations where the accumulation of gas may present a hazard. In case of outdoor installation, no special precautions are needed.

In rooms with $SF_6$ installations, which are above ground, natural venting is sufficient, if the gas volume of the largest compartment at atmospheric pressure does not exceed 10 % of the volume of the accessible switchgear room. If this demand cannot be fulfilled, mechanical ventilation shall be installed.

In rooms with $SF_6$ installations which are below ground on all sides, mechanical ventilation shall be provided if gas quantities which pose an intolerable risk to the health and safety of personnel (see note below) are capable of collecting in terms of gas quantity versus size of the room.

Chambers, ducts, pits, shafts, etc., situated below $SF_6$ installation rooms and connected to them, shall have the possibility of being ventilated.

To guarantee that no thermal decomposition of $SF_6$ present in the atmosphere can occur the

# Why $SF_6$ is used in switchgear?

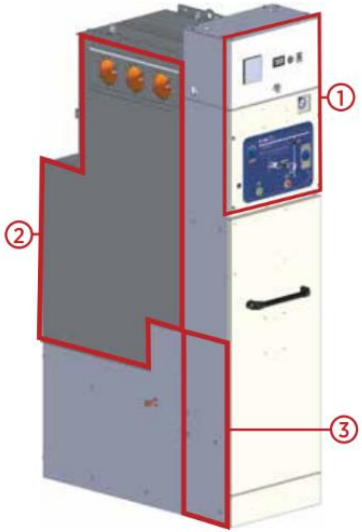
- $SF_6$ has been widely used in the electrical industry to prevent short circuits and accidents
- When used as an interrupting medium, $SF_6$ is able to quench the arc
- It is non-flammable, non-explosive, colourless, odourless, and non-toxic*
- It is effective as an insulating material for medium and high-voltage electrical installations
- $SF_6$ switchgear falls under three categories:
  - Closed pressure systems
  - Controlled pressure systems
  - Hermetically sealed systems

*Whilst $SF_6$ is non-toxic, it does not support life and can cause suffocation. Heavy duty switching operations can generate harmful by-products from decomposition.

# $SF_6$ switchgears & GIS/AIS Switchgears

HMH Series
**Air insulated** Switchgear

URING Series
**SF gas insulated switchgear**

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# The Energy Transition is on full speed

- Rise of electrification due to economic growth and ongoing sector coupling
- Move from coal-powered generators to mixed green sources of power including wind, solar and gas
- Increased grid connections and rise in switchgear and circuit breakers
- Global installed base of $SF_6$ was expected to grow by 75% by 2030

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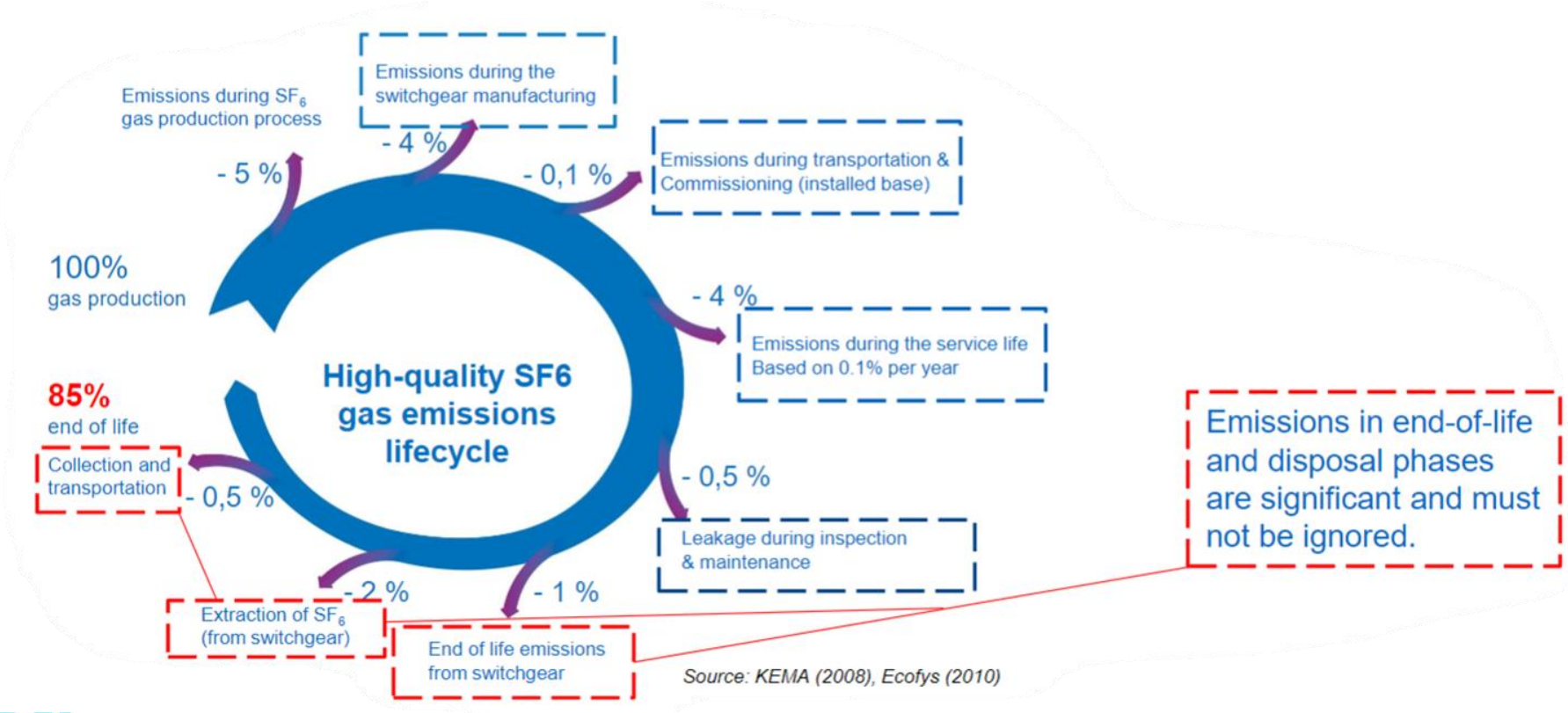
# Leakage during Life Cycle



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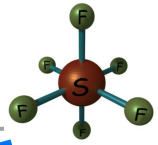
20.2.2024

- תאריך החלת האיסור -ינואר 2026, נוגע לתאריך **<u>הפעלת הציוד</u>** (ולא לתאריך הזמנת הציוד או להעמדת הציוד באתר) – ראו Article 13 - סעיף 9 ע"מ 29 בפרסום הרשמי המצורף, ולכן האיסור יחול גם על שימוש בלוחות שהוזמנו או אף הועמדו באתר (ולא הופעלו) לפני ה 1/1/2026.
- האיסור אינו נוגע לציוד מותקן ומופעל.
- תתאפשר מכירה של ציוד לצורך הרחבת לוחות קיימים או לצורכי תחזוקה, עם זאת סביר שמאחר והרגולציה תשפיע באופן ניכר על יצרני הציוד בחו"ל - זמינות הציוד והמחיר יהיו בהתאם.
- התקנות החדשות מכילות הגבלות ופיקוח הדוק גם על ייצור גזי ה "F", לרבות אופן השימוש בגזים, ההובלה, האחסון, ועד להנחיות ורגולציה בנושא הגריטה בשלב ה"end of live", כך שסביר שיהיו לכך השלכות משמעותיות על זמינותו ומחירו של גז ה- $SF_6$.



(44) The import from and export to a State that is not party to the Protocol of HFCs as well as of products and equipment containing HFCs or whose functioning relies upon those gases should be prohibited as from 2028. The Protocol envisages that prohibition from 2033, and the purpose of its earlier application under this Regulation is to ensure that the global HFC reduction measures of the Kigali Amendment provide the envisaged benefit to the climate as soon as possible.

$SF_6$



# הפחתת פליטות גזי חממה בישראל

כדי לצמצם את ההשלכות של שינויי האקלים ולהתייעל בשימוש במשאבים, נוקטים בעולם פעולות ותוכניות להפחתת פליטות גזי חממה, בעיקר על ידי צמצום שרֵפת דלקים פוסיליים, סוגי דלק שמקורם במחצבים (נפט ותזקיקיו, גז) והטמעת תהליכי התייעלות בכל מגזרי הפעילות האנושית. ממשלת ישראל התחייבה ב-2021 להפחית פליטות גזי חממה עד 2030 בשיעור 27% בהשוואה ל-2015 ולעמוד באפס פליטות עד 2050 בהשוואה ל-2015. המאמצים הבין-לאומיים להפחתת גזי החממה מתקיימים במסגרת אמנת המסגרת של האו"ם להתמודדות עם שינויי האקלים

**נושא:** אקלים, יחסים בין-לאומיים • **נושא משני:** הפחתת פליטות (מיטיגציה) • **תאריך פרסום:** 27.10.2019 • **תאריך עדכון:** 09.05.2024

## דין וחשבון סביבתי לשנת 2022

חברת החשמל

טבלה 17: פירוט מקדמי ההתחממות הגלובלית של גזי החממה השונים כפי שנקבעו במסגרת מתודולוגיית החישוב של המנגנון הוולונטרי:

| | מקדם ההתחממות הגלובלית GWP | | |
|---|---|---|---|
| | עד שנת 2013 | החל משנת 2014 | החל משנת 2020 |
| $CO_2$ פחמן דו חמצני | 1 | 1 | 1 |
| $N_2O$ חנקן תת חמצני | 310 | 298 | 265 |
| $CH_4$ מתאן | 21 | 25 | 28 |
| $SF_6$ גופרית שש פלואורית | 23900 | 22800 | 23500 |

טבלה 15: סיכום דיווחי חברת החשמל למנגנון המקומי הוולונטרי של המשרד להגנת הסביבה הישראלי לשנים 2010 - 2014: פילוח הפליטות הישירות לפי סוג גזי חממה

| | פליטות גזי חממה (טון שווה ערך פחמן דו-חמצני) | | | | |
|---|---|---|---|---|---|
| | $CO_2$ | $N_2O$ | $CH_4$ | $SF_6$ | סה"כ פליטות |
| 2014 | 34,123,738 | 128,097 | 10,684 | 49,998 | 34,312,517 |
| 2013 | 38,554,817 | 145,145 | 10,904 | 51,922 | 38,762,789 |
| 2012 | 46,108,389 | 188,309 | 16,770 | 50,519 | 46,363,988 |
| 2011 | 40,440,866 | 158,381 | 12,178 | 50,283 | 40,661,709 |
| 2010 | 39,272,597 | 150,993 | 10,930 | 33,149 | 39,467,669 |

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# What between now and 1-1-2026?

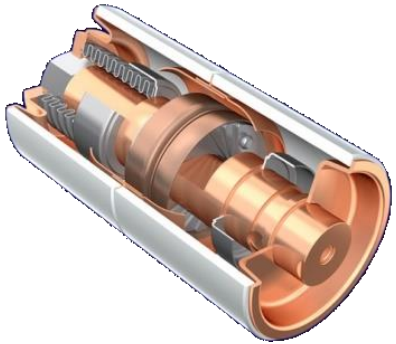
## To consider

- $SF_6$ insulation is seen as environmental unfriendly. The banked amount adds to $CO_2$ footprint
- The dismantling cost for $SF_6$ insulated gear will raise and negatively influence TCO
- Green public procurement in public tenders

# Alternatives to SF6 GIS

- Conventional AIS (primary switchgear)
- Fluorketones / Fluornitrilles (GIS) Prohibited PFAS, GWP
- Air (or natural air components) under high pressure (GIS)
- Solid Insulation (SIS)
- Air under Atmospheric pressure (AIR GIS) > Xiria

  - Switching in Vacuum



# Ahead of our time

## Eaton – Ahead of Its Time Developing $SF_6$-free Switchgear

**1920**
First insulation in switchgears (e.g. oil)

**1960**
Eaton introduces a compact solid insulated Ring Main Unit Magnefix

**1965**
First medium voltage switchgear with sulfur hexafluoride ($SF_6$) gas

**1967**
Eaton ships first commercially produced vacuum interrupters for medium voltage applications

**1989**
Eaton introduces SVS Ring Main Units based on air with solid insulation and vacuum interrupter technology.

**1997**
Kyoto Protocol adopted, which stimulated the EU to regulate $SF_6$

**2002**
Eaton introduces Xiria. Air-GIS technology, up to 24 kV-630 A-21 kA, using natural air without overpressure

**2006**
EU F-gas directive bans $SF_6$ in all applications except switchgear.

**2019**
Eaton has shipped over 350,000 $SF_6$-free switchgears and 15 million vacuum interrupters

$SF_6$'s use in the power and energy industry is forecast to grow by around 50%, from 2005 levels, by 2030

**2023**
EU decided to ban F-gas in MV switchgear
- 2026: ≤ 24 kV
- 2030: between 24 kV and ≤ 52 kV

**2024**
Eaton introduces Xiria NGX. Proven Air-GIS technology, up to 24 kV-1250 A-25 kA, using natural air without overpressure

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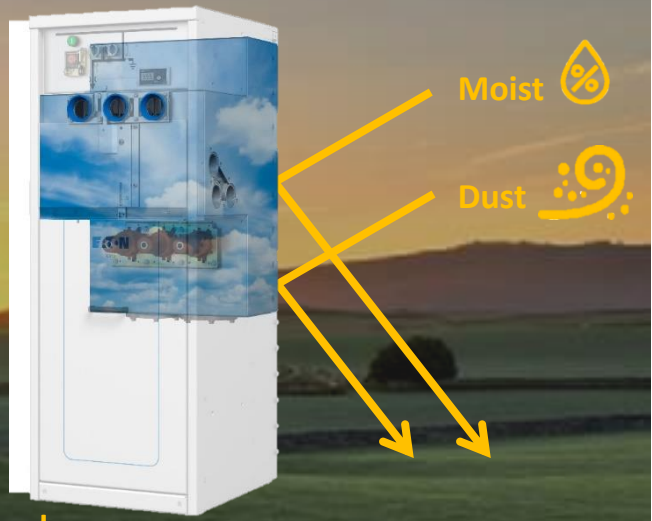
# F-gas free Solution Natural Air GIS

## We make what matters work




Xiria's sealed for life compartment contains air under atmospheric pressure

GIS concept prevents primary components from ingress of moisture and dust

Switching in vacuum will not detoriate the dielectrical strenghth of the switchboard

Proven design, Xiria's are in all kind off applications since 2002 (12kV) and 2003 (24kV)

No pressure vessel, No additional trainings, no pressure meter

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# Sealed-for-Life Enclosure -GIS-

- The sealed compartment is filled with **dry air** and by sealing this compartment the primary parts and tripping mechanism are protected from environmental influences such as moist, dust and any kind of animals or insects
- By means of the sealed compartment the primary parts, switches and circuit breakers are maintenance free
- Where $SF_6$ insulated switchgear relies on a man-made gas to prevent from an internal arc, this solution is 100% F-gas free. With the benefit of maximised safety for people and the planet, personnel and our environment
- See also our Cired paper 0088 from the conference in 2021

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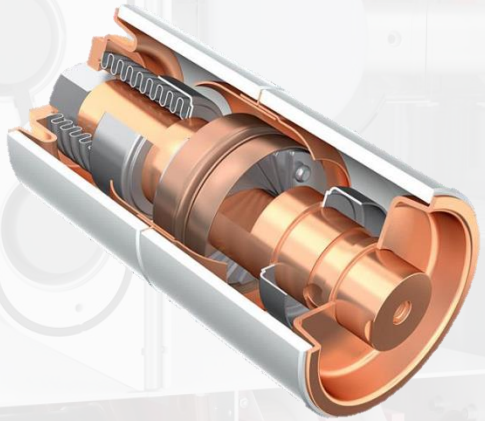
# Core competences

**Safety, Sustainability and Availability**

- Arc free design
- Arc proof design
- $SF_6$ free
- System integration

**Vacuum Interrupters**

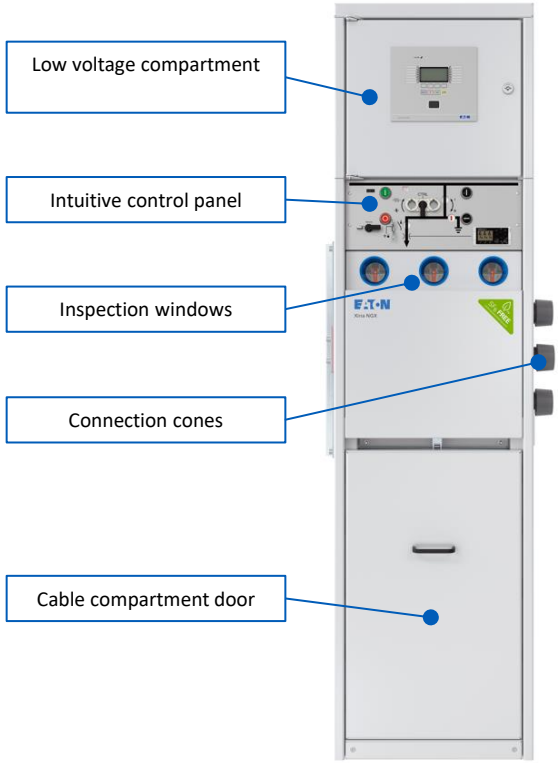


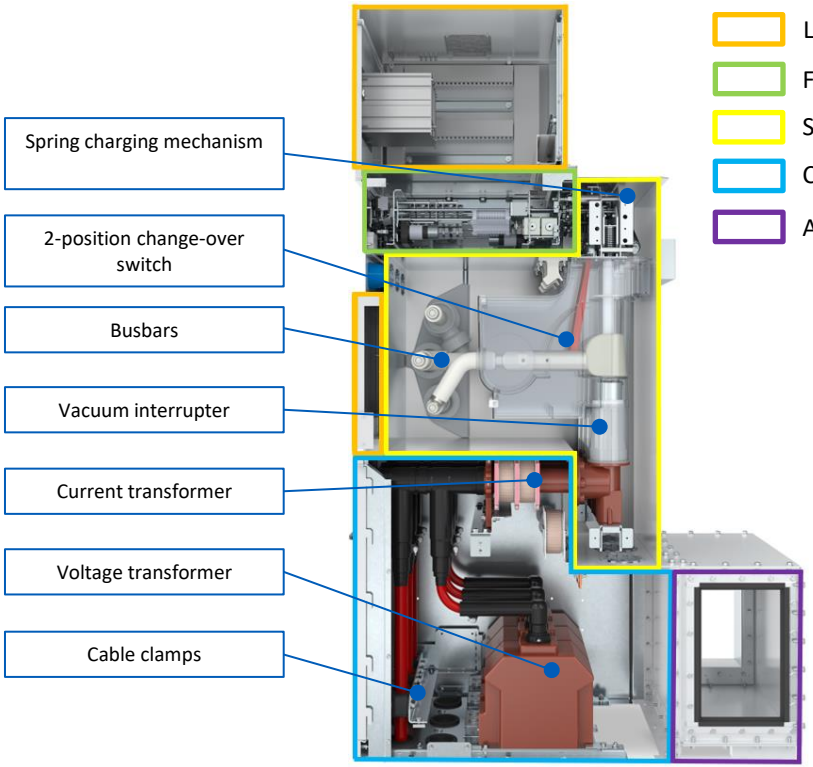
**Solid Insulation & Electrical Field Control**

# Xiria NGX

- Single compact **500 mm** wide **extendable** panels
- Rated voltage 24 kV
- Busbar current 1250 A
- Circuit-breaker rating 630 or **1250 A**
- Short circuit rating up to 25 kA - 3s
- Internal arc classification **AFL(R) 25 kA - 1s**
- Loss of Service Continuity LSC2
- Partition class PM
- Robust **auto-reclose** switching mechanism (OCO)
- IEC type tested by STL laboratory **KEMA**, Netherlands

# Xiria NGX basic design

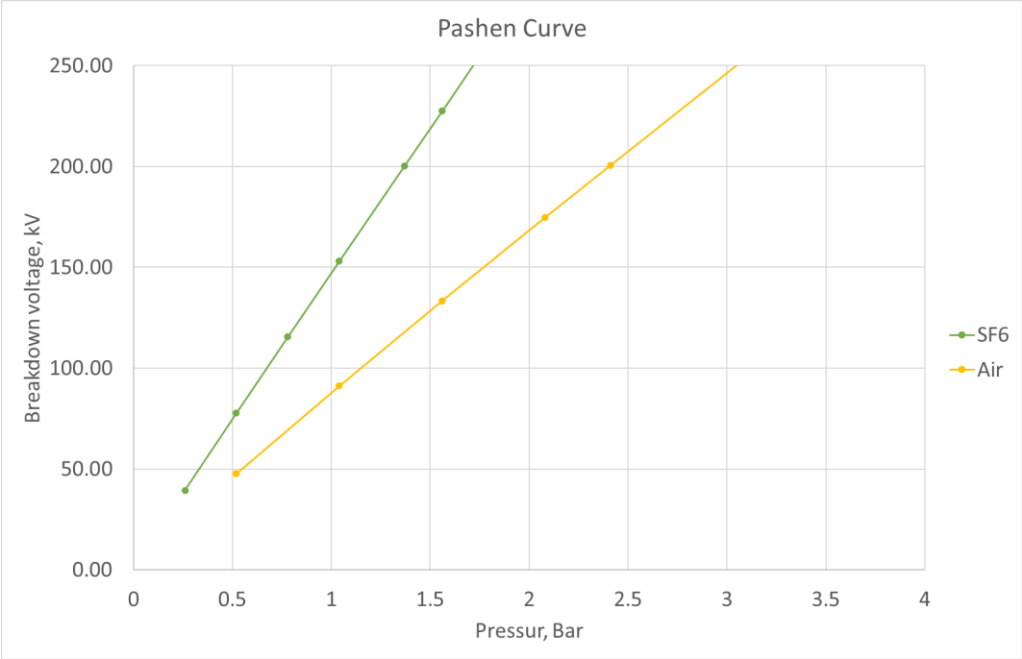


# Insulating mediums comparison

| | SF6 (fluorinated gas) | | Dry Air | |
|---|---|---|---|---|
| | PROS | CONS | PROS | CONS |
| ***Technology*** | Strong dielectric and thermal properties | GWP of 23,500 | Natural origin gases | High pressure or increase tank size required to achieve similar ratings to SF6 |
| | Can be integrated with SSIS system to avoid gas insulating of main bus | Liquifies at lower temperature | | High pressure required for strong thermal or dielectric characteristics |
| | If arc occurs across phases, inherently extinguish quicker | Toxic byproducts as result of arc event (Value of Vacuum Interrupter) | Can be integrated with SSIS system to avoid gas insulating of main bus | oxygen content reacts with materials and can corrode |
| | Better transient response (TRV) | | | |
| ***Supply Chain*** | Readily available in the market | | Readily available in the market | |

# Paschen’s curve

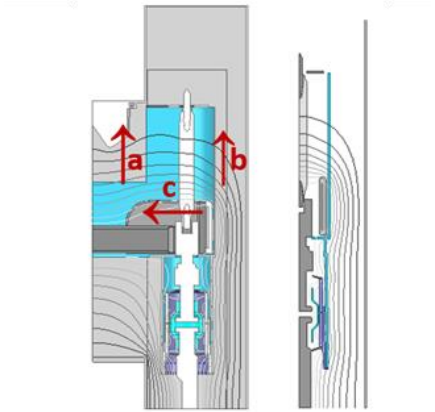


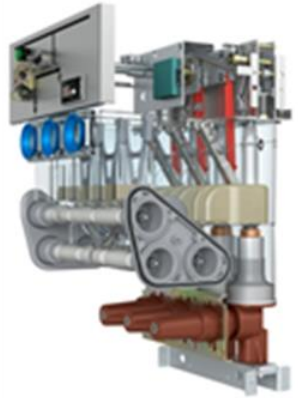

Paschen's curve describes the breakdown voltage as a function of the electrode spacing or gap (d), operating pressure (p), and gas composition.

<u>Pressure above 2 bar:</u>
ASME VIII, Pressure vessel
Higher design costs
DOT shipping impacts
Gas filling on-site
Gas under pressure labeling

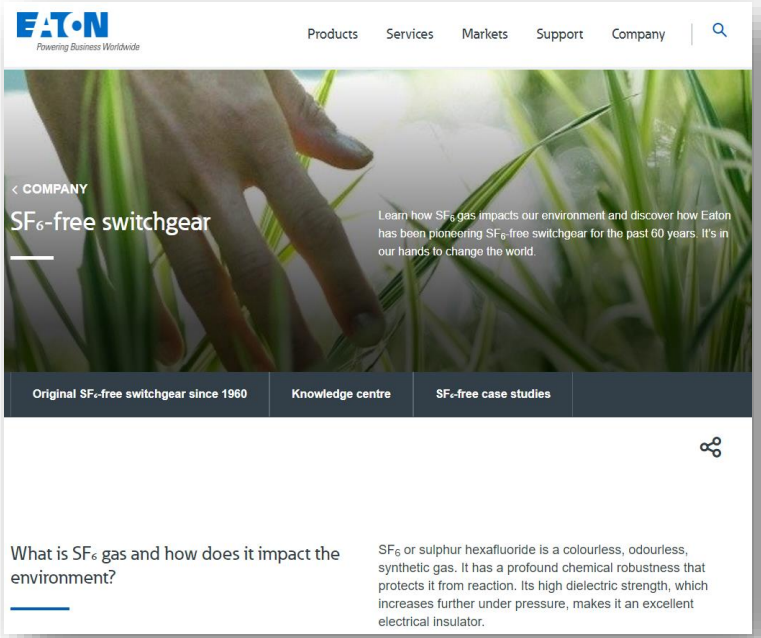
# The Product Development moves on

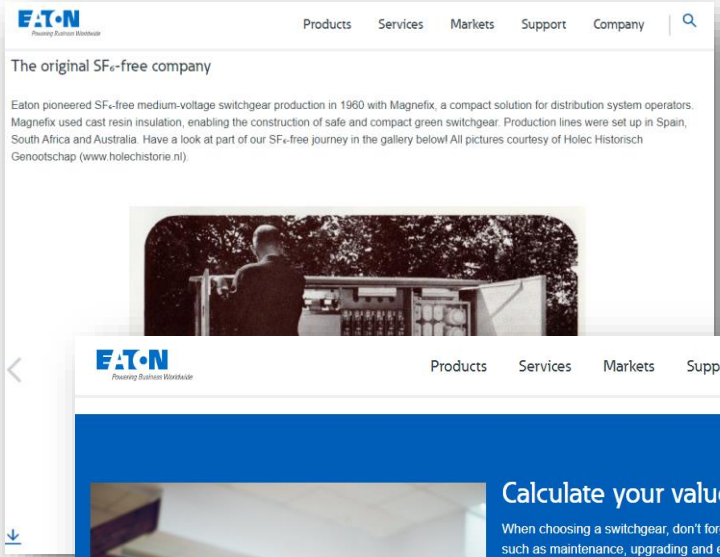
- Technologies for higher voltages (38kV)
- Digitalization – Protection – Control
- 24kV -1250A compact SF6 free introduced
- …..

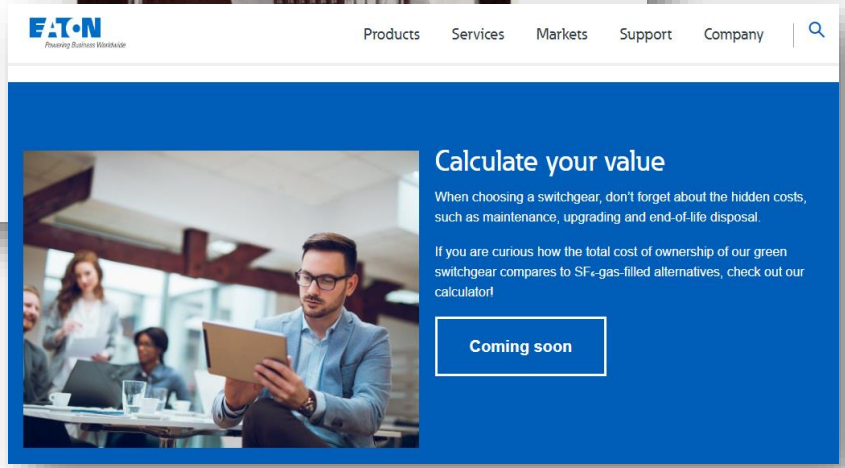


# Further Reading




www.eaton.com/sf6-free

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# תודה!

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