ONE VISION.
ZERO EMISSIONS.

The future of SF_6 gas: reconditioning, innovation and alternative gases

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Agenda

DILO Germany

- Brief company presentation

SF_6 reconditioning

- SF_6 Gas Handling
- SF_6 Re-use and Zero Emissions
- Specifications / Regulations
- SF_6 reconditioning technologies
- DILO Certified Gas + case studies
- Conclusion

Alternative Insulating Gases

- Overview about tradenames
- Products for handling of Alternative gases
- Gas life cycle

DILO Germany

- Located in Babenhausen, South Germany
- Founded in 1951
- > 85% global customer

- World market and technology leader in SF6 gas handling
- Full-service supplier in the field of gas handling, gas measurement and gas treatment
- All DILO products are ‘Made in Germany’

SF_6 Gas Handling

Properties

- Colourless and odourless
- Chemically neutral (inert)
- Non toxic (if not decomposed by electric discharges), non-flammable, non-corrosive
- Five times heavier than air – 6.08 g / L
- Excellent arc-quenching and insulation properties (electronegative gas)
- High chemical and thermal stability / thermally constant up to 500°C
- **Molecule life time 3,200 years in the atmosphere**
- **Global Warming Potential (GWP_{100}) of 25,200* CO_2e**

* GWP_{100} based on United Nations Framework Convention on Climate Change

Source: DILO SF_6 Molecule

SF_6 Gas Handling

Why SF_6 gas handling?

- Environmental protection

- Less expenditure for SF_6 gas

- Compliance with regulations
  - IEC 60480
  - IEC 60376
  - IEC 62271-4
  - Misc. CIGRE documents*
  - Misc. IEEE documents

* e.g. TB 914: Guidelines for SF_6 end-of-life treatment of T&D equipment (> 1kV) in substations

SF_6 Gas Handling

Reasons for replacing SF_6

- The technical quality of the gas is no longer given:
  - High level humidity
  - High level of decomposition products
  - Low level of purity
- Maintenance must be carried out on the GIE
- The GIE will be replaced / shut down / dismantled

Source: DILO

SF_6 Re-use and Zero Emissions

On-site re-use SF_6 process

Root cause for SF_6 exchange:

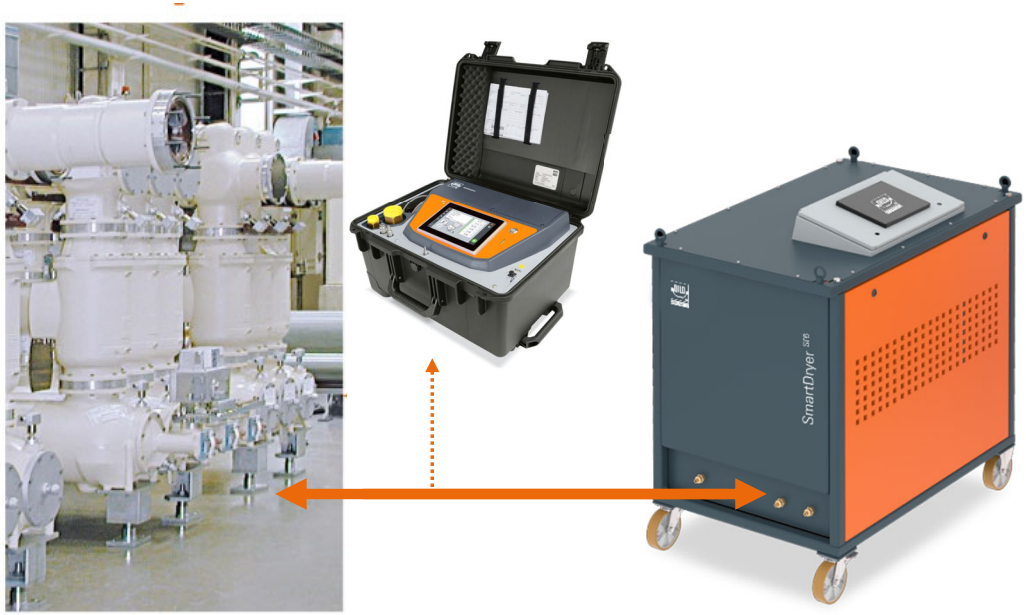
- High level humidity
- High level of decomposition products

Solutions:

- Usage of a DILO SmartDryer^{SF6} (energized solution)
- Optional usage of a DILO Service cart but system must be de-energized

Advantage:

- No down time of the GIE
- No costs for new SF_6
- No disposal costs for the “old” SF_6
- No emissions of SF_6



Source: DILO

SF_6 Re-use and Zero Emissions

On-site re-use SF_6 process

Removal of decomposition products

Solid decomposition products:

- With a particle filter in the pre-filter unit and on the service cart during the recovery process

Gaseous decomposition products

- With filters in the gas compartment
- With filters in the pre-filter unit and on the service cart during the recovery process

Source: DILO

SF_6 Re-use and Zero Emissions

Off-site Reconditioning with a DILO separation plant

Root cause for SF_6 exchange:

- The technical quality of the gas is no longer given:
  - Low level of purity
- Maintenance must be carried out on the GIE
- The GIE will be replaced / shut down / dismantled

Solution:

- Usage of a DILO Separation plant

Process steps on-site:

1. Measure the SF_6 quality
2. Recovery of the complete SF_6
3. Store the gas in transportation vessels

SF_6 Re-use and Zero Emissions

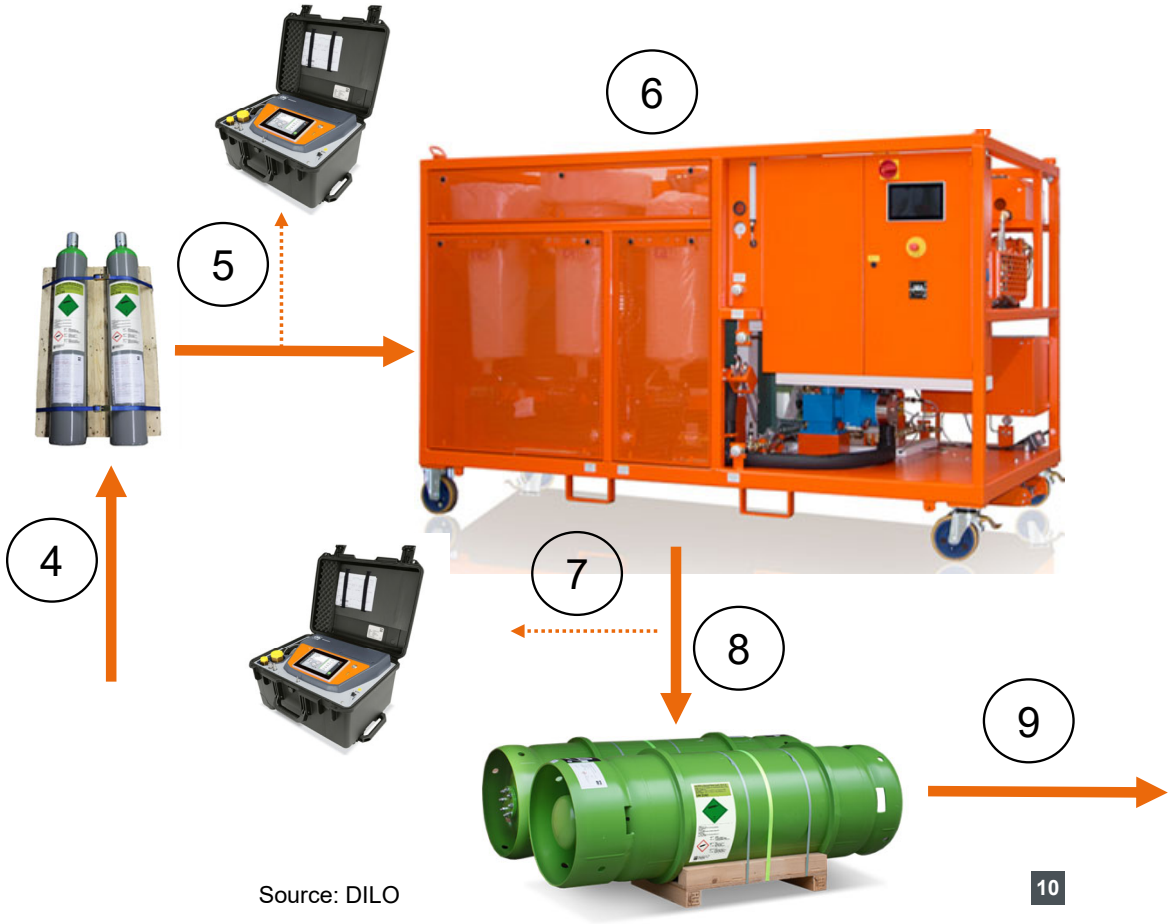
Off-site Reconditioning with a DILO separation plant

Process steps off-site:

4. Transport the gas to the separation plant
5. Measure the gas quality before separation
6. Carry out the SF_6 treatment
7. Measure the gas quality after separation
8. Fill the processed gas into transport vessels
9. Transport back to the GIE

Advantage:

- No disposal costs for the old SF_6
- No costs for new SF_6
- Minimisation of total emissions (SF_6 and CO_2)



Source: DILO

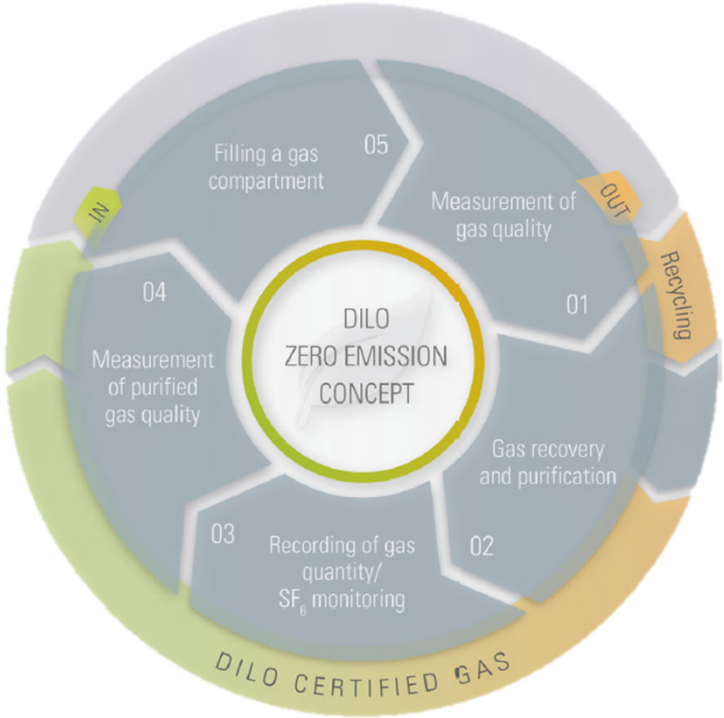
SF_6 Re-use and Zero Emissions

A closed loop

Advantages:

- Environmental:
  - During the production of new SF_6, approx. 3% to 8%* is emitted due to the process.
  - The disposal of bad SF_6 requires at least 1200°C – 1500°C and is also very energy-intensive and causes severe CO_2 emissions.
  - Low energy consumption for reconditioning (approx. 0.6 kW/kg**)
- Financial aspects:
  - Reduced stock of SF_6 required
  - Reduced costs as disposal costs and new gas costs are eliminated.

➢ DILO ZERO EMMISSION CONCEPT



* Source: 2019 IPCC Refinement of the 2006 Guidelines for National Greenhouse Gas Inventories

** Dependent on the initial quality of the SF_6 gas

SF_6 Re-use and Zero Emissions

Comparison of Specification:

Substance:	DILO Certified Gas	IEC 60376:2018* (New gas)	IEC 60480:2019 Re-use	ASTM D2472-15
SF_6	> 99.9 vol.-% (> 99.99 wt%)	> 98.5 vol.-%	> 97 vol.-%	≥ 99.8 weight.-%
Frost point (100 kPa)	-62 °C	-36 °C (< 200 µl/l)	-36 °C (< 200 µl/l)	-62 °C
H_2S	8 µl/l	< 200 µl/l	--	≤ 8 ppm_w
Total acidity (HF equivalent)	< 0.1 µl/l	< 7 µl/l	< 50 µl/l (50 ppm_V)	≤ 0.3 ppm_w
Air	< 500 µl/l	< 10.000 µl/l	< 30.000 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 –	< 1 mg/kg	
SO_2 (SO_2 + SOF_2)	< 0.1 µl/l	--	< 12 µl/l (12 ppm_V)	--

F-gas regulation

Chapter 3: Article 13: Control of use

9. The putting into operation of the following electrical switchgear using, or whose functioning relies upon, fluorinated greenhouse gases in insulating or breaking medium shall be prohibited as follows:

(a) from 1 January 2026, medium voltage electrical switchgear for primary and secondary distribution up to and including 24 kV;

(b) from 1 January 2030, medium voltage electrical switchgear for primary and secondary distribution from more than 24 kV up to and including 52 kV;

(c) from 1 January 2028, high voltage electrical switchgear from 52 kV up to and including 145 kV and up to and including 50 kA short circuit current, with a global warming potential of 1 or more;

(d) from 1 January 2032, high voltage electrical switchgear of more than 145 kV or more than 50 kA short circuit current, with a global warming potential of 1 or more.

→ *(22) In order to limit the need for the production of virgin sulphur hexafluoride (SF_6), the capacity for reclamation of SF_6 from existing equipment should be increased. Without endangering the safe functioning of the electrical grids and power plants, the use of virgin SF_6 in electrical switchgear should be avoided where it is technically feasible to use reclaimed or recycled SF_6 and it is available.*

SF_6 reconditioning technologies

Technology overview

- Combined temperature & pressure-controlled process:
  - Complex process control system
  - High recovery rate (dependent on gas quality) but residual gas still contains up to 15%* SF_6
  - High flow rate, up to 40kg/h
  - Requested SF_6 gas concentration: > 40%
  - Semi mobile equipment

DILO Separation plant w/o Membrane Segment

SF_6 reconditioning technologies

Technology overview

- Membrane separation:
  - Complex process control system
  - Sensitive membrane technology
  - Requested SF_6 gas concentration: 10 – 30%
  - Low flow rate, 1.5m^3/h
  - High performance in recovery of SF_6 (less 0.5% of SF_6 in the residual gas)

* regeneration level of 98.5% at incoming purity of 90%

SF_6 reconditioning technologies

Why has DILO selected this combination?

Combined temperature & pressure-controlled process + Membrane separation:

- Using the high flow capability of the temperature & pressure-controlled unit to separate the majority of SF_6
- Adding the membrane unit to process the residual gases and recover 99.9*% of the complete SF_6
- As both segments are controlled by one system highest efficiency is given
- Highest quality of the reconditioned SF_6 can be granted

* Dependent on the purity level at the beginning, based on 90% purity at process start

DILO Certified Gas

Quality assurance of DCG at DILO Laboratory

Analytical methods:

- Gas chromatography - Mass Spectrometry (GC-MS): separation of analytes via chromatography and detection by mass spectrometry – quantitative and qualitative analysis (limit of detection: 7 ppm)
- Infrared – Spectroscopy (IR): Identification of analytes through their unique absorption band of infrared light waves - quantitative and semi-quantitative analysis of known compounds

Quality assurance of DILO Certified Gas (DCG):

- Analytical screening for side products in recovered gas by GC-MS
- Determination of purity of DCG by GC-MS
- Assurance of mixing ratio of gas mixtures by IR

DILO Certified Gas

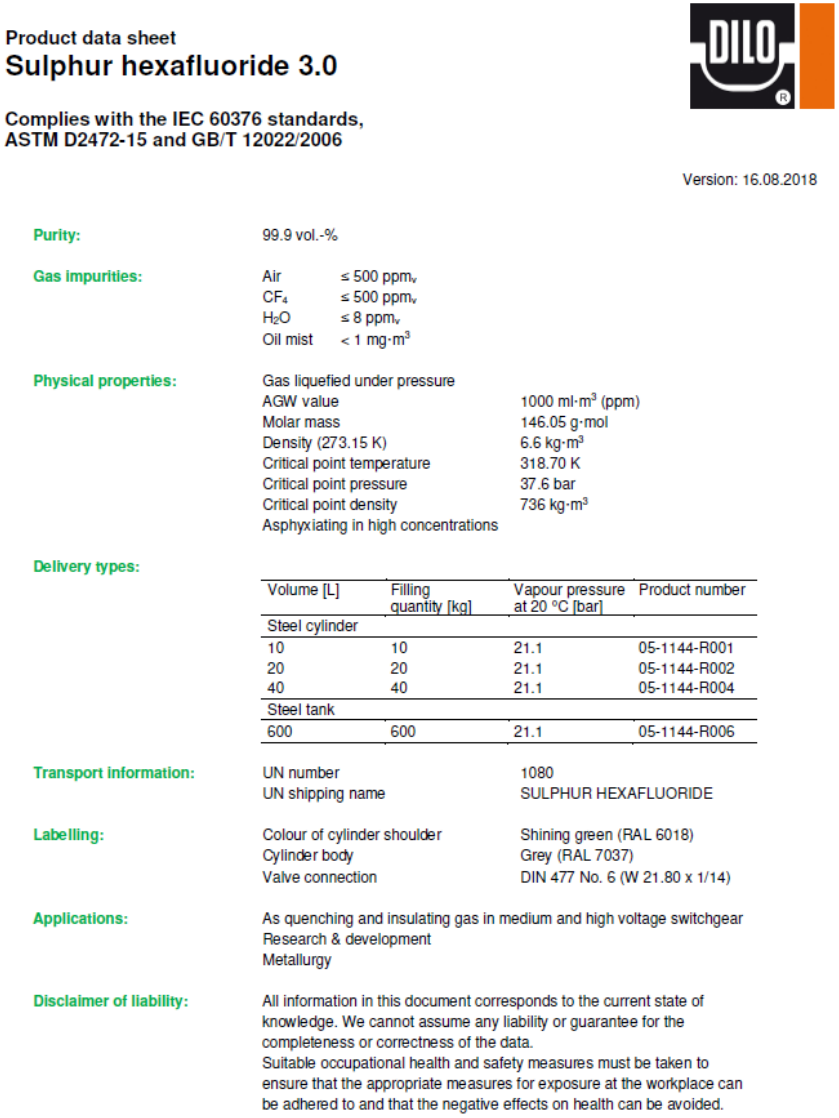
What is behind this name?

Process verification on-site:

- Each batch of reconditioned SF_6 will be verified by the DILO Lab.
- DILO supplies a material data sheet for each delivery
- All transport vessels will be sealed by a DILO Certified Gas – sticker

Process verification on-site:

- Verification of gas quality by using a multi measuring equipment (MultiAnalyser or MirrorAnalyser)
- If possible, cooperation with a local lab (can be supported by DILO-Lab)
- If requested, gas samples will be sent to DILO Babenhausen and be tested by DILO-Lab



Product data sheet
Sulphur hexafluoride 3.0

Complies with the IEC 60376 standards, ASTM D2472-15 and GB/T 12022/2006

Version: 16.08.2018

Purity: 99.9 vol.-%

Gas impurities:

Air	≤ 500 ppm_v
CF_4	≤ 500 ppm_v
H_2O	≤ 8 ppm_v
Oil mist	< 1 $mg \cdot m^3$

Physical properties: Gas liquefied under pressure

AGW value	1000 $ml \cdot m^3$ (ppm)
Molar mass	146.05 g·mol
Density (273.15 K)	6.6 $kg \cdot m^3$
Critical point temperature	318.70 K
Critical point pressure	37.6 bar
Critical point density	736 $kg \cdot m^3$

Asphyxiating in high concentrations

Delivery types:

Volume [L]	Filling quantity [kg]	Vapour pressure at 20 °C [bar]	Product number
Steel cylinder			
10	10	21.1	05-1144-R001
20	20	21.1	05-1144-R002
40	40	21.1	05-1144-R004
Steel tank			
600	600	21.1	05-1144-R006

Transport information:

UN number	1080
UN shipping name	SULPHUR HEXAFLUORIDE

Labelling:

Colour of cylinder shoulder	Shining green (RAL 6018)
Cylinder body	Grey (RAL 7037)
Valve connection	DIN 477 No. 6 (W 21.80 x 1/14)

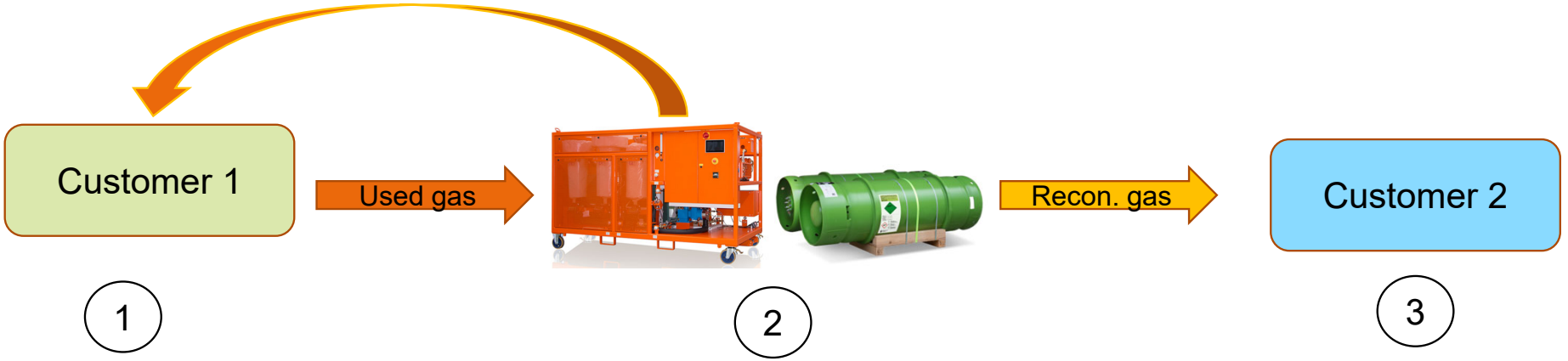
Applications: As quenching and insulating gas in medium and high voltage switchgear
Research & development
Metallurgy

Disclaimer of liability: All information in this document corresponds to the current state of knowledge. We cannot assume any liability or guarantee for the completeness or correctness of the data.
Suitable occupational health and safety measures must be taken to ensure that the appropriate measures for exposure at the workplace can be adhered to and that the negative effects on health can be avoided.

DILO Certified Gas

Ways of reconditioned SF_6 reuse

- No change in ownership of the gas:
  The customer takes back the reconditioned gas and continues to use it in his inventory
- Change of ownership of the gas:
  1. The customer 1 sells the used gas to DILO
  2. DILO recondition the gas and store it at DILO
  3. Customer 2 has a demand for gas and is buying the reconditioned SF_6 from DILO



DILO Certified Gas

Reasons to recondition SF_6

- Ecological and economical advantage
  - CO_2 neutral production of DILO CERTIFIED GAS instead of:
    - » Environmentally damaging disposal/burning of SF_6 gases.
    - » New production of SF_6 gas
  - No increase in Green House Gas concentration /
  - Reconditioning is the ecologically best process for the reuse of SF_6 gas
  - Conservation of resources, as no additional SF_6 new gas has to be produced

DILO Certified Gas

Case study: Norway - a permanent process

Due to a new tax on SF_6 gas in Norway, gas reconditioning at DILO in Babenhausen is too expensive and therefore gas separation will be carried out on site in Norway.

Solution:

Dispatch of separation plant for the reconditioning of 2 tones SF_6 gas at the customers premises

Source: DILO

Further information:

- Recovered SF_6 gas had a purity level of 80% - 90%
- After training, DILO Agent has operated the separation plant by his own
- It´s scheduled to redo this approx. 2 times a year

DILO Certified Gas

Case study: DEWA – UAE – a single big approach

DEWA (state-owned energy and water supply company of the Emirate of Dubai) has had cylinders with used SF_6 gas.

Solution:

Dispatch of separation plant for the reconditioning of 14,5 tones SF_6 gas at the customers premises

Further information:

- Recovered SF_6 gas had a purity level of 80% - 90%
- After training, DILO Agent has operated the separation plant

Source: DILO

DILO Certified Gas

Case study: 50Hertz-Germany & Siemens – extension/renewal of a 380kV substation

The extension/ renewal of an existing 380 kV substation to 10 fields voltage level required 12 tones of SF_6 gas. Customer allowed just reconditioned gas for the new substation.

Solution:

The used gas was field by field recovered by DILO partner and shipped to Babenhausen for reconditioning and afterwards was sent back to the Substation to be filled into the new GIS.

Further information:

- Recovered SF_6 gas had a purity level of 95%
- Complete reuse of the SF_6 w/o any need of additional new gas procurement.

Source: DILO

Conclusion

- Reconditioning of SF_6 is in the meantime a standard method
- Full mature equipment is available
- The quality standards of reconditioned gas are higher than the standards for new gas.
- Reconditioning is a cost-efficient solution compared to the previous way of handling SF_6
- It allows a significant reduction of CO_2 emissions
- Latest international regulations (CIGRE, IEEE, IEC, …) are focusing on reconditioning instead of new production
- Legislation supports processing through legal regulations / taxes on new SF_6 gas based on its CO_2e

➔ SF_6 has to be seen in the future as an asset and not as an consumable product due to its economical and ecological impact and outstanding – partially unused – behaviors.

Alternative Insulating Gases

 05.04.2025

Alternative Insulating Gases

Well known tradenames in use

System brand name of GE Vernova

C4-FN (C_4F_7N) **+ CO_2 + O_2 + N_2 + O_2 (Retrofit)**

System brand name HITACHI Energy

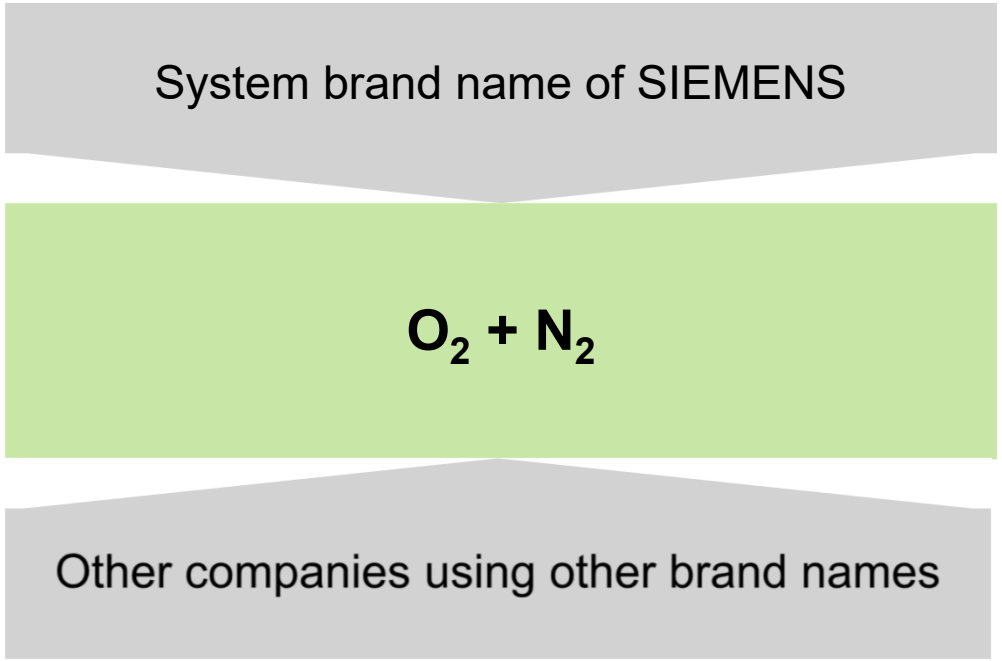
C4-FN (C_4F_7N) **+ CO_2 + O_2 + N_2 + O_2 (Retrofit)**

Other companies using other brand names

Alternative Insulating Gases

Well know tradenames in use

Clean Air



Alternative Insulating Gases

Well know tradenames in use

Natural Origin Gases

Different brand names

CO_2 + O_2

Handling – differences compared to SF_6

SF_6

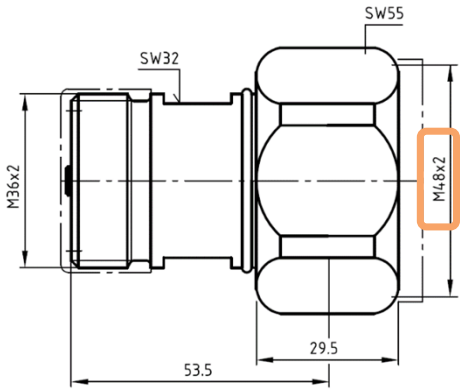
Alternative Gases

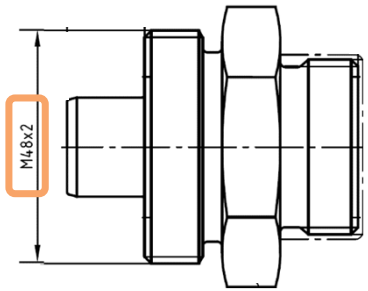
SF_6 equipment <u>cannot</u> be used for handling of Alternative Gases!

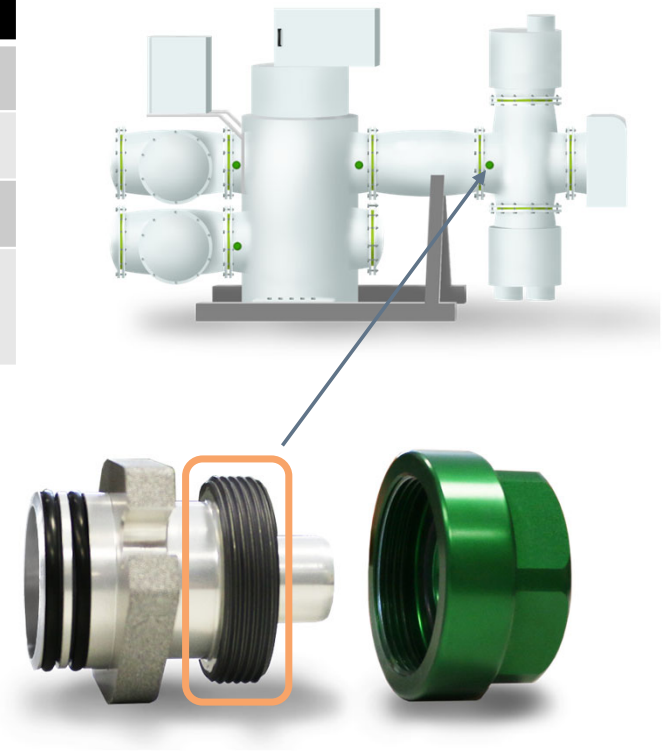
Couplings

Alternative Insulation Gases – Proposal thread sizes

Thread sizes	DN20	DN8	Others
SF_6	M45x2	M26x1.5	
C4-FN gas mixtures	M48x2	M28x1.5	
CO_2 gas mixtures	M43x2	M24x1.5	ASEA M32x2
Compressed Air gas mixtures (CA)	M50x2	M24x1.5 M30x1.5	







C4-FN handling products

MiniSeries C4	EconomySeries C4 MegaSeries C4	EconomyReclaimer C4 MegaReclaimer C4
		
C4-B095R12 / C4-B093R30	**C4-G057R01 / C4-G170R01**	**C4-G057R51 / C4-G170R51**
C4-FN mixtures	**C4-FN mixtures**	**C4-FN mixtures**
→ **Recovery and filling** → Gaseous storage (25 bar) → Filling from cylinder with gaseous storage → Final vacuum recovery < 5 mbar → For small gas volumes (MV) → Coupling DN8 (C4 = M28x1.5)	→ **Recovery, filling and evacuation** → Gaseous and liquid storage (up to 100 bar) → Temperature controlled filling from bottles for liquefied gas mixture → Final vacuum recovery < 1 mbar → For HV gas volumes → Coupling DN20 (C4 = M48x2 / DN40 M78x2 (Mega-Series only) → 600 or 1,000 Litre integrated buffer tank → Material brass or stainless steel	→ **Recovery only** → Gaseous and liquid storage (up to 100 bar) → Final vacuum recovery < 1 mbar → Coupling DN20 (C4 = M48x2) → Coupling DN40 (C4 = M78x2 MegaReclaimer only) → Material stainless steel

Compressed Air (CA) gas handling

Alternative Gases

Gas refilling device (portable)	Gas refilling device (trolley)	MiniSeries CA	EconomySeries CA MegaSeries CA
			Available Q4 2025 
CA-3-393-R001/R002	**CA-3-001-R001**	**CA-B095R12 / CA-B093R30**	**CA-G057R01** **CA-G170R01**
Compressed Air	**Compressed Air**	**Compressed Air**	**Compressed Air**
→ Pressure reducer for **filling** of gaseous Compressed Air → Adjustable filling pressure 0 – 20 bar → DILO coupling DN8 and DN20 (M24x1.5 and M50x2)	→ Pressure reducer for **filling** of gaseous Compressed Air → Adjustable filling pressure 0 – 20 bar → DILO coupling DN8 and DN20 (M24x1.5 and M50x2)	→ **Recovery and filling** → Gaseous storage → Filling from cylinder with gaseous storage → Final vacuum recovery < 5 mbar → Coupling DN8 (M24x1.5)	→ **Recovery, filling and evacuation** → Gaseous storage (up to 200 bar) → Final vacuum recovery < 1 mbar → Coupling DN20 (M50x2) → Automatic function → Optional with pressure tank (50 bar) → Material brass

Devices for Measuring the gas quality

Overview

Measuring devices			
MultiAnalyser C4	**MirrorAnalyser CA**	**MultiAnalyser CA**	**MultiAnalyser CO2**
			
C4-3-039R-R	**CA-3-035R-R**	**CA-3-039R-R**	**CO2-3-039R-R**
C4-FN mixtures	**Compressed Air**	**Compressed Air**	**CO_2 mixtures**
- Mol-% C4-FN (in CO_2 / O_2 or N_2 / O_2) - Moisture - Mol-% Oxygen (O_2) - Mol-% carbon dioxide (CO_2) - Concentration carbon monoxide (CO)	- Moisture (Frost- / Dewpoint) - Mol-% Oxygen (O_2) - Concentration nitrogen oxides (NO_x)	- Moisture - Mol-% Oxygen (O_2) - Concentration nitrogen oxides (NO_x)	- Mol-% carbon dioxide (CO_2) - Moisture - Mol-% Oxygen (O_2) - Concentration carbon monoxide (CO)

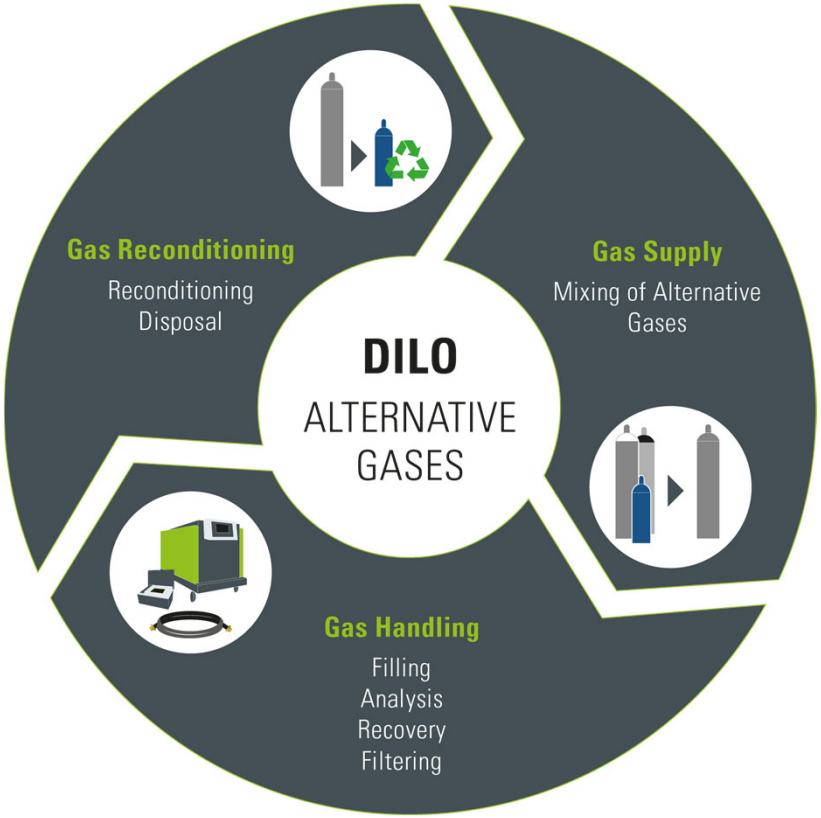
Devices for Measuring the gas quality

Overview

Measuring devices			
MultiAnalyser HE	**EcoAnalyser**	**LeakSpy C4**	**GasSafetySensor / Monitor**
	New 		
HE-3-039R-R	**MGE010**	**C4-3-033-R400**	**3-026-R200 3-026-R…**
Helium	**SF_6, SO_2, CO, H_2O, O_2, CO_2, NO, NO_2**	**C4-FN**	**CO_2, O_2, C4-FN, CO**
- Vol-% HE (in N_2) - Moisture	- Percentage - Moisture	- C4-FN detection	- Sensors: CO_2, O_2, C4-FN, CO

Gas life cycle

- Mixing of gas mixtures
- Reclamation of C4-FN
- Certificates and analysis in the laboratory
- DILO is REACH-registered for the import and distribution of C4-FN in the EU.



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ZERO EMISSIONS.

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