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Question: Much development has taken place to reduce SF_6 impact on the environment from utility application for electrical insulating and interrupting equipment. What are likely to be the enduring initiatives to prevent SF6 gas leaks and find a possible alternative to SF6 for GIS applications?

Carbon Footprint of SF_6 Alternatives for HV GIS

LCA to assess the carbon footprint

SF_6 has enabled reliable, compact and performant HV gas-insulated switchgear (GIS). With improved sealing systems, handling procedures, and adequate service, SF_6 emissions are significantly reduced, but they stay dominant in overall carbon footprint of SF6 HV GIS. Regulators are pushing to reduce carbon footprint of the equipment. The 2022 F-gas regulation proposal by the European Commission can pave the way to a phase-out of SF_6 by the end of the decade. The proposal in its current form is focused on the GWP (global warming potential) of the gas only, giving preference to solutions with GWP < 10. Today, eco-efficient SF_6 alternatives have been developed and first equipment is commissioned and operated by the users. For high-voltage GIS two SF_6 alternative technologies are dominant:

- C4-FN/CO_2/O_2 gas mixture for insulation and interruption, gas GWP = 300…600
- Synthetic air in combination with vacuum circuit breakers, gas GWP = 0

To reduce the overall carbon footprint of the equipment, GWP of the gas is not the only criteria, it does not consider the overall environmental footprint of the entire switchgear and the substation. In this regard, product Life Cycle Assessments (LCA) can help chose the solution with minimal environmental impact. Additionally, equipment size is an important factor for application of GIS. In this contribution we present results of LCA for 145 kV GIS in different technology options.

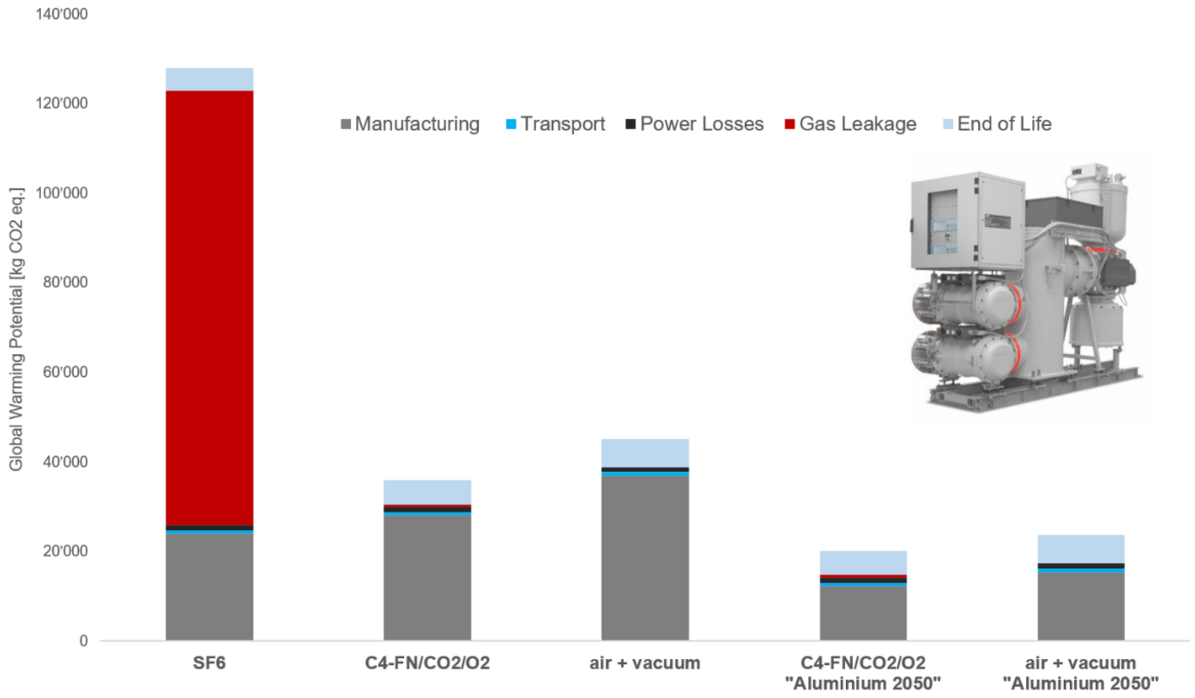

Figure 1: Comparison of global warming potential of a 145 kV GIS (exemplary picture of SF_6 equipment) considering manufacturing, transport, power losses, gas leakage and end of life. Boundary conditions are listed in Table 1

Table 1: Boundary conditions for LCA shown in Figure 1

equipment scope	One double-busbar-bay including CB, CT, DES, MPES, VT, cable connection, LCC and steel support
assumption SF_6 equipment	design current equipment, 0.1 %/year leakage
assumption SF_6 alternative equipment	detailed design study,
leakage	0.2 %/year for C4-FN/CO_2/O_2, irrelevant for air
size	air + VCB: one size up (equivalent to 170 kV SF_6), smaller drive for VCB
production location (incl. aluminum)	Europe (global carbon footprint of aluminum would be higher)
power losses	800 A current permanently (chosen based on typical CT ratings), operation in grid with renewable energy
Aluminum assumption today	0 % recycled aluminum is used for production, 95 % is recycled at end of life
“Aluminum 2050” scenario	100 % recycled aluminum is used for production, 100 % is recycled at end of life – circular economy

The LCA clearly shows that both technology options for 145 kV essentially eliminate carbon footprint of insulation gas losses over the lifetime of the GIS (Figure 1):

Option 1: C4-FN/CO_2/O_2 for insulation and interruption
This option generates lowest overall CO_2 eq. emissions because the equipment has similar size as today’s SF_6 equipment, leading to low material and space consumption. For material consumption, aluminum use is most significant. In option 1, proven gas circuit breaker

technology is utilized and the scalability to higher voltages like 245 kV, 420 kV, 550 kV and beyond is given [1].

Option 2: Technical air and vacuum CB

In this option, no CO_2 eq. emissions result from leakage of insulating gas (GWP = 0). However, the equipment is significantly larger, compared to today's equipment based on SF_6 technology. Carbon footprint for material production is higher than in option 1, because aluminum production and recycling generate significant CO_2 eq. emissions. These aluminum related emissions will remain a relevant factor for the foreseeable future, even in a fully circular economy with 100 % recycling, as can be seen in scenario "Aluminum 2050" in Figure 1

Influence of regulation and technology choice

A preference of GWP < 10 for the gas, as in current F-gas regulation proposal, would limit technology choice and disadvantage C4-FN/CO_2/O_2 technology with lowest overall carbon footprint and more compact spatial footprint (smaller switchgear buildings and associated emissions). The SF_6 phase out could actually be delayed by limiting technology choice.

Insulating gas with C4-FN admixture is very versatile and additionally enables Retrofill of existing passive SF_6 equipment, preventing future SF_6 gas leaks in the large installed fleet without exchanging primary equipment: [1], [2]

[1] CIGRE 2022 session Paris, report 10656 "Moving Towards Carbon-Neutral High-Voltage Switchgear by Combining Eco-Efficient Technologies" SC A3 PS2, Michael GATZSCHE, Ueli STRAUMANN, Patrick STOLLER, Moritz BÖHM, Saskia BUFFONI-SCHEEL, Henrik LOHRBERG, Manuel NAEF, Freddy VON ARX, Adrian SKEA
[2] CIGRE 2022 session Paris, report 10103 "Application of SF6 Alternatives for Retro-filling Existing Equipment" SC A3 PS2, Loizos LOIZOU, Lujia CHEN, Qiang LIU, Mark WALDRON, Gordon WILSON, and John OWENS