# LIFE **SF6-FREE**
# **HV** BREAKER

GE Vernova's **LIFE $SF_6$-FREE HV BREAKER** (LIFE 2020) project aims to develop our new range of GL circuit breakers for the 420 kV voltage level, the backbone of the electrical grid in Europe. Using a $CO_2$-$O_2$ gas mixture instead of $SF_6$ for switching, this new circuit breaker will help power transmission operators decarbonize the high-voltage grids.

LIFE20 CCM/FR/001749

Life
Co-founded by the European Union

GE VERNOVA

**1 - Illustration of our new GL316c 420 kV live tank circuit breaker**

## 1 • PROJECT DATA

**Summary:** The LIFE $SF_6$-FREE HV BREAKER project aims to replace $SF_6$ gas with a $CO_2$-$O_2$ gas mixture in 420 kilovolts (kV) circuit breakers dedicated to air-insulated substations. By doing so, the solution significantly reduces the carbon footprint of the switchgear while maintaining reliability and performance without increasing equipment dimensions, achieving a best-in-class life cycle assessment.

The solution is a major step towards the complete elimination of $SF_6$ in air-insulated electrical substations, not only in Europe but worldwide

**Coordinating beneficiary:** GE Vernova's Grid Solutions Business
**Associated beneficiaries:** INP Greifswald

**Project start date:** 01/07/2021
**Project end date:** 31/03/2026
**Project budget:** 4.533 M€
**EU Life program contribution:** 2.493 M€ (55%)

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## 2 • ABBREVIATIONS AND CHEMICAL FORMULAE

### 2.1. ABBREVIATIONS

| Acronym | Designation |
|---|---|
| CB | Circuit Breaker |
| HV | High Voltage |
| HVCB | High Voltage Circuit Breaker |
| GIS | Gas-Insulated Substation |
| GIL | Gas-Insulated Line |
| AIS | Air-Insulated Substation |
| HVLTCB | High-Voltage Live Tank – Circuit Breaker |
| LTCB | Live Tank Circuit Breaker |
| MV | Medium Voltage |
| T&D | Transmission and Distribution |
| kA | kiloamperes |
| kV | kilovolts |

### 2.2 CHEMICAL FORMULAE

2 - $SF_6$ or sulfur hexafluoride molecule

| Chemical Formulae | Chemical Name |
|---|---|
| $SF_6$ | Sulfur Hexafluoride |
| $CO_2$ | Carbon Dioxide |
| $O_2$ | Oxygen |

## 3 • PROJECT IN BRIEF

### 3.1. INTRODUCTION

The LIFE $SF_6$-FREE HV BREAKER project is co-funded by the European Union's LIFE Program to accelerate decarbonization in high-voltage networks. It replaces $SF_6$ with a $CO_2$-$O_2$ gas mixture in outdoor 420 kV live tank circuit breakers for air-insulated substations, optimized for reliable operation down to –50°C while maintaining a comparable footprint and safety profile. The 420 kV level is prioritized because it concentrates a large installed base of $SF_6$ breakers in Europe, offering strong potential for climate impact. This work builds on field experience already achieved at lower voltages and benefits from public support for $SF_6$-free technologies.

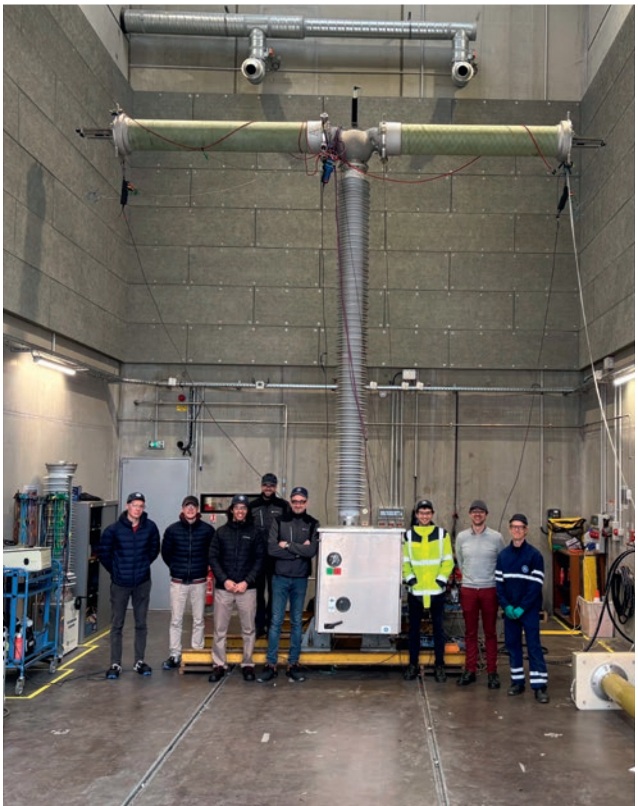

3 - The LIFE SF6-Free HV Breaker Team

**The project in a nutshell:** The team develops and validates the GL316c 420 kV / 50 kA live tank circuit breaker using a $CO_2$-$O_2$ gas mixture, combining extended gas property data, a dedicated dielectric database, and multiphysics modelling with targeted adaptations of the interrupting unit and operating speeds. Comprehensive type testing covers critical duties, including short-line and terminal faults, followed by a performance confirmation pilot at the manufacturer's premises and a demonstration with a transmission system operator. The goal is to confirm reliability, grid compatibility, and a practical path to wider adoption in Europe and beyond.

**Why this matters:** $SF_6$ is a potent greenhouse gas with a very high global warming potential and long atmospheric lifetime. Reducing its use is a priority for climate policy and the industry. In live tank architectures, where external insulation is provided by ambient air, a $CO_2$-$O_2$ mixture can be used—through mixture ratio and filling pressure—to deliver the required performance in outdoor conditions, including very low temperatures. Transitioning to proven $SF_6$-free solutions at the highest voltage level supports EU objectives and the revised F-gas framework.

### 3.2. PROJECT OBJECTIVES

The project will demonstrate the GL316c, an $SF_6$-free 420 kV / 50 kA outdoor live tank circuit breaker using a $CO_2$-$O_2$ gas mixture, reliable down to –50°C with the same footprint. It builds the technical basis (gas properties to –50°C and a dielectric database), optimizes the interrupting unit, and validates performance through comprehensive laboratory type tests. A pilot at our premises will precede an installation at a Transmission System Operator (TSO) substation to demonstrate and validate grid integration. The results will help further develop the 362 kV and 170 kV circuit breakers and are backed by life cycle and socio-economic assessments with targeted dissemination.

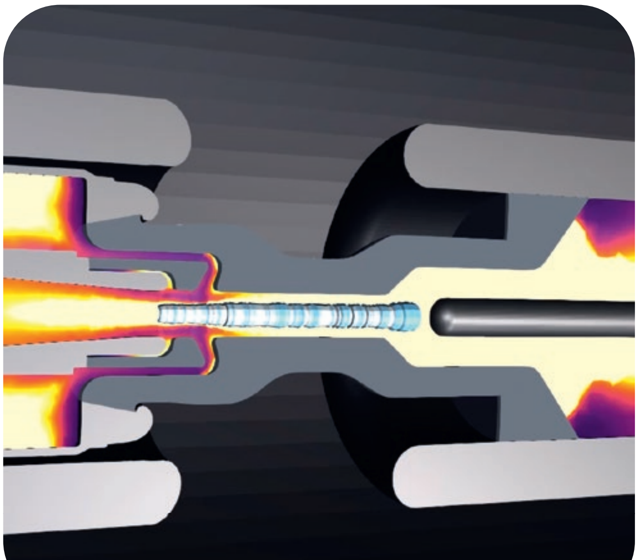


4 - Fully assembled T-shape circuit breaker

# 4 • PROJECT PHASES

## 4.1. PHASE ONE
### Prepare and model

This first phase extends the existing gas properties database for the $CO_2$-$O_2$ mixture to cover −50°C and to account for potential condensed-phase behavior during arcing.
Using this extended dataset, a dielectric withstand database is created to describe insulation recovery during arc extinction considering pressure, temperature, and plasma composition.
Multiphysics numerical models guide design choices, saving time, cost, and test iterations while lowering the project's carbon footprint. Key results are cross-checked with targeted laboratory measurements to confirm the model validity.


5 - Electric arc extinction simulation

## 4.2. PHASE TWO Design, prototype, and type-test


6 - Candle mock-up in high-voltage lab

We engineer the GL316c 420 kV / 50 kA live tank circuit breaker for $CO_2$-$O_2$ operation down to −50°C while keeping a comparable footprint. The interrupting unit is redesigned as a compact double-break self-blast assembly, with grading capacitors to balance voltage across the two chambers and avoid oversizing. The spring-operated drive has been retuned (energy set-points, kinematics, damping) to deliver the higher opening/closing speeds required by the gas mixture. On the interrupter side, we re-profile the tulip and arcing contacts and select low-resistance contact materials to reduce Joule losses. We optimize the blast nozzle and internal flow path for stable pressure build-up and arc cooling. We reshape dielectric shields to control fields under severe duties. We also calibrate filling pressure and density monitoring strategies for cold climates, and qualified tightness, seals, and interfaces under repeated thermal cycles and handling.

Design iterations have been driven by multiphysics models and fast prototypes, then verified through lab programs covering dielectric withstand (including internal lightning impulse on "candle" mock-ups), temperature rise, mechanical endurance, and critical interruption duties on representative chambers. Measurements confirmed target contact speeds inside the interrupters, stable post-arc behavior, and close agreement between simulations and tests.

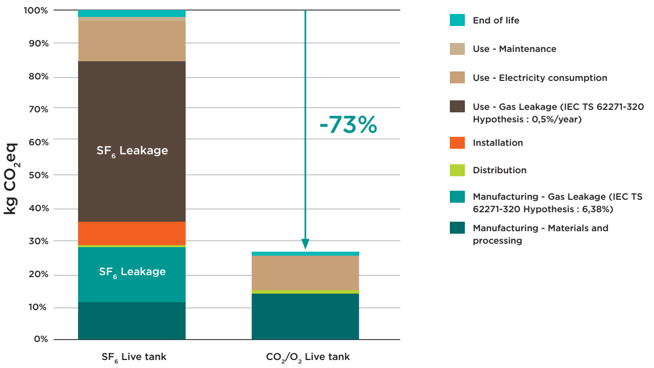
A performance confirmation pilot at our premises consolidates these optimizations under operationally representative scenarios and qualifies gas handling and monitoring procedures. A subsequent demonstration with a TSO will validate grid integration and deployment documentation. This achievement will prepare replication to other standard high-voltage levels.

## 4.3. PHASE THREE Demonstration and impact assessment

7 - GL316 ($SF_6$) live tank circuit breaker in substation

This phase combines on-grid demonstration with a full life cycle and socio-economic assessment to verify real-world performance and benefits. Field operation data from the GL316c 420 kV $CO_2$-$O_2$ live tank circuit breaker are used to confirm grid integration and to refine the environmental model with actual measurements (energy use, gas quality, maintenance, and monitoring), ensuring that findings reflect operational conditions.

Life cycle assessment (LCA) is carried out as per international standards for high-voltage switchgear. It covers the entire life of the breaker: raw materials and manufacturing, transportation, installation, operation, maintenance, and end-of-life. The functional unit reflects typical utility use (420 kV, 4000 A, 50 kA, 40-year service). Beyond climate change, the LCA screens multiple environmental indicators to avoid burden shifting. Early results confirm a major reduction in the climate change indicator from eliminating $SF_6$, while highlighting the next drivers of impact: operational energy losses and materials. This is why Phase Two focused on reducing contact resistance (to lower Joule losses) and on optimizing the interrupter architecture and component mass. Where added components are necessary (for example, to control voltage distribution and meet performance at –50°C), the LCA quantifies small increases in resource indicators and guides mitigation via eco-design choices, supplier specifications, and end-of-life recovery plans.




8 - Cimate change comparison between $SF_6$ and $CO_2$/$O_2$ 420 kV live tank circuit breakers

Monitoring performance indicators is essential to keep the project on track. By tracking metrics such as environmental benefits, technical performance, quality and reliability, and stakeholder engagement, we can make timely adjustments and ensure the solution delivers measurable, real-world value.

The socio-economic assessment looks at people and operations: worker safety and training for $CO_2$-$O_2$ handling and monitoring, supply-chain readiness, acceptance by grid operators, and potential local community effects during installation and maintenance. Demonstration feedback informs practical guidance (procedures, checklists, recommended tools) to support safe and efficient deployment at scale.

Key performance indicators are tracked throughout: environmental benefits (including life cycle $CO_2$e), technical performance and reliability, quality of gas handling and monitoring, and stakeholder engagement. Continuous monitoring allows timely corrections and ensures the solution delivers measurable, real-world value during the project and beyond.

## 4.4. PHASE FOUR Communication and stakeholder engagement

This phase spotlights our partners, especially TSOs, who have been involved from the beginning. Through structured workshops and technical reviews, TSO experts helped define requirements, validate design choices (operation at –50°C, interface and maintenance practices, gas handling and monitoring), and witness key type tests. The pilot project is prepared collaboratively: site selection, protection and control interfaces, operational procedures, and outage planning—ensuring grid compatibility and safe deployment. In parallel, we share outcomes through concise materials (website, brochures, layman's report) so partners can reuse best practices across their networks.

9 - Our partners

## 4.5. PHASE FIVE After-LIFE replicability

The after-LIFE plan prioritizes replication at lower voltages. It supports deployment through clear procedures for gas handling and monitoring, training and guidance for operators, and maintained communication channels and materials during three years after the end of the project. It also prepares adaptation to 362 kV and 170 kV air-insulated substations by consolidating lessons learned, design rules and validation evidence (operating speeds, filling pressures, dielectric margins), enabling a responsible, scalable path to $SF_6$-free implementation.

10 - Illustration of the coming range of 420 / 362 / 170 kV live tank circuit breakers

# 5 • GL 316c Benefits

**22+ tons of $CO_2$eq saved per breaker per year (life cycle assessment)**

**329 + tons of $CO_2$eq saved during project (prototypes + simulation)**

**420 kV / 50 kA - 50°C ready Same footprint**

**Standards-based type tests TSO-ready demonstration**

**Aligned with EU F-gas regulation**
**Contributes to power sector decarbonization**

# LIFE SF6-FREE HV BREAKER

**To learn more, please visit**
www.lifesf6freehvbreaker.eu

**To join our teams, please visit**
https://careers.gevernova.com/global/en/search-results



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