Layman's Report

LIFE SF6-FREE HV BREAKER

The LIFE SF_6-Free HV Breaker project supports the transition toward cleaner and more sustainable power networks by developing an innovative 420 kV SF_6-free high-voltage breaker. Designed to meet the needs of future electricity grids, the project focuses on compactness, performance and environmental responsibility, helping pave the way for a new generation of switching technology.

LIFE20 CCM/FR/001749

Co-founded by
The European Union

GE VERNOVA

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

Project in brief

The LIFE SF_6-Free HV Breaker project was created to address one of the most pressing challenges facing the electricity sector: how to reduce the environmental impact of high-voltage equipment without compromising reliability, safety or performance. For decades, sulfur hexafluoride, or SF_6, has been used in high-voltage circuit breakers because of its excellent electrical properties. Yet SF_6 is also a very powerful greenhouse gas, with a long atmospheric lifetime, which makes its continued use increasingly difficult to justify in a decarbonizing energy system.

This project therefore set out to develop and demonstrate a new generation of outdoor high-voltage live tank circuit breakers using a CO_2-O_2 gas mixture instead of SF_6. The target was not a laboratory concept, but a practical solution for transmission networks. The work focused on a 420 kV / 50 kA breaker, with the ambition of opening the way towards wider deployment at other voltage levels, including 362 kV and 170 kV. In other words, the project aimed to prove that SF_6-free technology can be used where the need is greatest: at the highest voltage levels of the European grid.

From the beginning, the project followed a clear logic. First, the technical basis had to be established through gas property data, dielectric studies and simulation work. Then the design of the breaker itself had to be adapted, particularly the spring mechanism, tulip contact, nozzle and permanent arc contacts, so that the equipment could operate reliably in demanding conditions, including very low temperatures. Finally, the solution had to be tested, validated and prepared for real-world demonstration on transmission system operators' networks.

The project is significant because it combines climate action with industrial innovation. It contributes to the reduction of greenhouse gas emissions, supports European climate objectives and helps prepare the electricity sector for a future in which SF_6-free solutions become the norm rather than the exception. More generally, it demonstrates that transitioning to a clean power supply isn't just about generating renewable energy, but also about transmitting those green electrons via a decarbonized high-voltage grid.

Why the project matters

The energy transition is not only changing how electricity is generated; it is also changing the infrastructure that carries electricity from one place to another. Transmission networks are under pressure to expand, modernize and integrate more renewable energy, often in a context of tighter land availability, higher public expectations and stronger environmental regulations. High-voltage substations are a central part of this system, and compact gas-insulated or air-insulated equipment plays a key role in making these networks reliable and efficient.

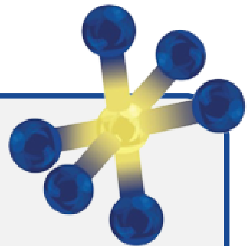
2. GL316 (SF_6) live tank circuit breaker in substation

At the same time, the environmental footprint of these assets must be addressed. SF_6 has long been valued for its technical performance, but its climate impact is extremely high. As a result, replacing SF_6 has become a priority for utilities, manufacturers and regulators alike. The LIFE SF_6-Free HV Breaker project is important because it targets a segment where alternatives have been limited until now: outdoor high-voltage live tank circuit breakers for air-insulated substations.

This is a demanding application. The equipment must withstand very high electrical stresses, operate safely in severe weather conditions and remain compact enough to fit within existing substation layouts. The project therefore did not aim for a theoretical substitute, but for a solution that could realistically be integrated into the grid. That distinction matters. A technology can only contribute to decarbonization if it is technically robust, economically viable and acceptable for operators.

The project also matters because of its demonstration value. Utilities are more likely to adopt new solutions when they see them validated in practice. By moving step by step from modelling to testing and then to pilot deployment, the project creates confidence. It shows that SF_6-free alternatives can be scaled beyond a single prototype and adapted to the operational needs of transmission system operators.

SF_6
A gas with a very high climate impact



SF_6 or sulfur hexafluoride molecule has a global warming potential of 24,300 times CO_2 over 100 years and can remain in the atmosphere for around 1,000 years.

In this sense, the project is part of a larger transformation. It supports the EU's climate goals, responds to the evolving F-gas regulatory framework and helps set a direction for the wider high-voltage industry. Its value lies not only in one product, but it also sets for future developments.

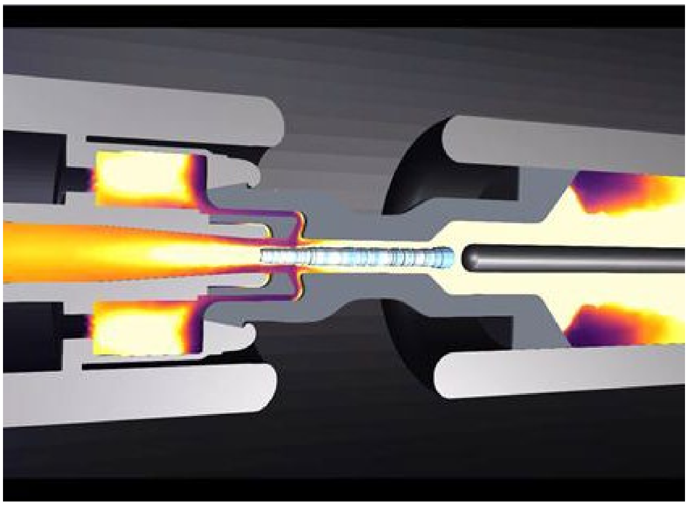
CO_2-O_2 technology at a glance

At the heart of the project is a new outdoor high-voltage live tank circuit breaker designed to operate with a CO_2-O_2 gas mixture instead of SF_6. The technology combines a new insulating and switching medium with a redesigned interrupting unit, so that the breaker can meet demanding electrical and mechanical requirements while preserving a comparable footprint to conventional equipment.

The development work began with the gas itself. The project team extended the existing gas property database to include low-temperature behavior and to capture possible condensed-phase effects. This step was essential, because the performance of the breaker depends not only on the gas mixture, but also on how that mixture behaves under pressure, temperature and arc-extinction conditions. A dielectric withstand database was also created to better understand how the gas performs during switching events.

Interrupter design and development

The next step was the design of the interrupter. Several components were optimized, including the spring mechanism, the tulip contact, the nozzle and the permanent arc contacts. The objective was to improve performance while avoiding unnecessary growth in equipment size. This is important because substation layouts are often constrained, and any replacement technology must fit within the practical limits of existing infrastructure.



3. Electric arc extinction simulation

The project also relied heavily on simulation and testing. Multiphysics modelling helped guide the design choices, while laboratory tests were used to validate performance under realistic conditions. These tests were not limited to routine checks; they addressed the critical duties that matter most for utility operation, including severe short-circuit events. This combination of modelling, redesign and validation makes the technology credible as an industrial solution, not simply as a research result.

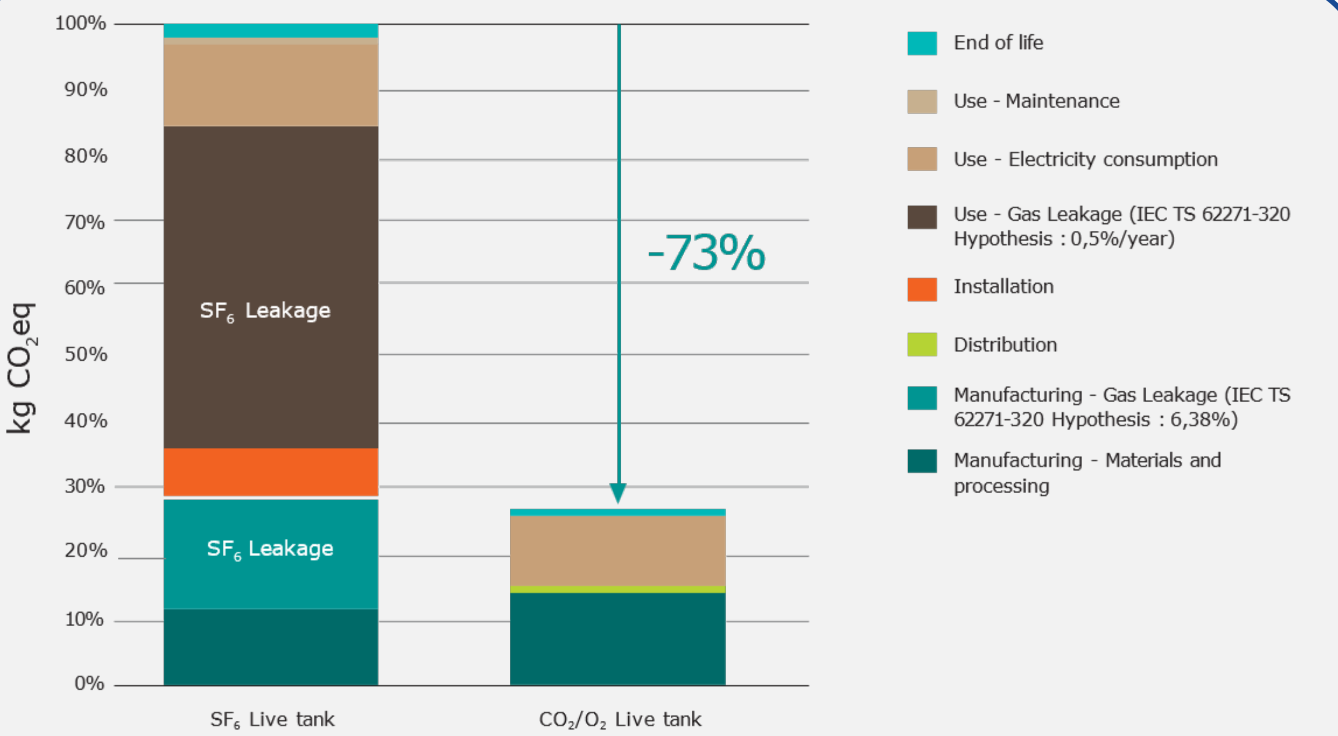
Another important aspect of the innovation is that the project is not isolated. It builds on previous GE Vernova experience in SF_6-free development and contributes to a broader portfolio strategy. The knowledge generated here is intended to support future work at other voltage levels and to help establish a family of SF_6-free products for the wider market.

Environmental benefits and climate impact

The project delivers a clear environmental benefit by reducing the use of SF_6. This means that even small emissions can have a significant climate impact over the lifetime of electrical equipment. By replacing SF_6 with a lower-impact alternative, the project contributes to measurable emission savings and supports the transition toward cleaner high-voltage infrastructure.

What makes this especially relevant is the scale of the market. High-voltage circuit breakers are long-life assets (40+ years), and they are widely deployed across large transmission networks. Every successful replacement has a long-term effect, because it avoids SF_6 emissions not just for one piece of equipment, but over years of operation and maintenance. The benefit is therefore cumulative.

The project also contributes to better environmental governance. By demonstrating an alternative technology at high voltage, it supports the practical implementation of European climate policies and F-gas regulation. It helps move the industry from discussion to action. In that sense, the project is more than a technical exercise: it is part of the transition towards a lower-emission grid infrastructure and a decarbonized Europe.



4. Climate change comparison between SF6 and CO2/O2 420 kV live tank circuit breakers

Economic and operational benefits

A new technology is only useful if it can be adopted by utilities without creating unreasonable cost or operational burden. For this reason, the project paid close attention to the economic and operational dimensions of the solution. One of the main design objectives was to preserve the footprint of conventional equipment, because compatibility with existing substations reduces civil works, limits installation constraints and simplifies integration.

5. The LIFE SF_6-Free HV Breaker Team

The project also sought to offer a realistic cost path. Early-stage technologies can be more expensive at first, but costs typically improve as volumes increase, design is optimized, and supply chain matures. CO_2-O_2 solution was identified by GE Vernova as the preferred alternative for Live Tank circuit breaker compared with other technical options, particularly because it combines high-voltage capability, low-temperature performance, a more manageable long-term cost outlook and better Life Cycle Assessment results.

Operationally, the solution aims to remain dependable in harsh conditions. This is essential for transmission system operators, especially in regions where equipment may face very low temperatures. The project's technical work focused on ensuring robust performance down to severe winter conditions (down to -50°C), while maintaining safe switching behavior and long-term reliability.

There is also an important maintenance dimension. Because the technology is being developed specifically for grid use, it is designed to integrate into standard utility operating practices. The pilot and demonstration phases are intended to show that the equipment can be commissioned, operated and monitored in a way that is compatible with normal utility procedures. That increases the likelihood of adoption and reduces uncertainty for future users.

6. Full "T-shape" breaker ready for test at CERDA

This project has significantly enhanced the R&D capabilities within the European electrical equipment industry. By fostering a multidisciplinary team, we have strengthened our core competencies in:

<u>Arc Physics Research</u>: Advanced fundamental understanding through PhD-level expertise.
<u>Simulation & Design</u>: Development of robust design criteria utilizing sophisticated simulation tools.
<u>Computational Analysis</u>: Enhanced modeling accuracy through specialized calculation engineering.
<u>Measurement & Validation</u>: Rigorous methodology to define and expand the operational limits of this technology.
<u>Prototyping:</u> Technical excellence in the practical execution and assembly of prototypes.

Applications, pilots and stakeholder engagement

The project was designed with real deployment in mind. Its application is in air-insulated substations, where high-voltage live tank circuit breakers are widely used. These are critical assets in transmission networks, and the market potential is significant because the number of installations at 420 kV remains substantial across Europe.

The project team worked with transmission system operators throughout development to ensure the solution matched real needs. Stakeholder engagement was therefore not an afterthought; it was part of the project method. 11 TSOs from Belgium, Denmark, France, Germany, Norway, Poland, Spain, Sweden, United Kingdom were involved in discussions, workshops and technical exchanges, allowing the team to refine specifications and assess how the technology would fit into operational environments.

7. Our partners

Pilot and demonstration activities were a central part of the approach. The project moved from laboratory validation to a pilot in our premises in Villeurbanne, then towards demonstration with TSOs after the end of the LIFE project. This sequence is important because it reduces risk step by step. It allows the team to validate the equipment before it is introduced into a live network, while also giving utilities the opportunity to build confidence in the solution.

8. Polish PSE participating in type-tests in Cerda in December 2025

The broader relevance of the project is already becoming clear. As European regulations increasingly require the deployment of SF_6-free solutions, the project helps prepare the market for this transition by developing technologies that can meet these new expectations. Through dialogue with major utilities and participation in industry events, the team is supporting the wider understanding and acceptance of SF_6-free high-voltage equipment. This is an important step, because successful innovation in this field must not only be technically sound, but also ready to be adopted by operators facing a changing regulatory environment.

Challenges and considerations

The development of SF_6-free high-voltage equipment is technically challenging. Replacing SF_6 means rethinking both the switching and the insulating technology, and the breaker design, while maintaining dimensions and stringent performance requirements. The solution must operate reliably at very high voltage, under fault conditions, and in harsh environments.

Another challenge is industrial adoption. Utilities are understandably cautious when it comes to equipment that forms part of critical infrastructure. They need evidence, testing, references and confidence in long-term support. For that reason, the project had to progress through multiple stages of validation and stakeholder engagement.

There are also external factors. The regulatory context is evolving, and market expectations are changing. This creates both urgency and complexity. On the one hand, the direction of travel is clear: SF_6 must be reduced. On the other hand, utilities need solutions that are ready for real-life deployment. The project responds to these challenges by focusing on performance, robustness and transferability.

Future outlook

The long-term outlook is encouraging because the project addresses a real market need with a solution that is technically and commercially credible and environmentally relevant. As more utilities look for SF_6-free alternatives, and as regulation continues to evolve, technologies developed under the project will become increasingly important. By demonstrating a viable pathway for scaling live tank solutions, the project helps prepare the ground for future applications at higher voltage levels.

9. Illustration of the coming range of 420 / 362 / 170 kV live tank circuit breaker

In a matter of fact, the LIFE SF_6-Free HV Breaker project is a first step, not an endpoint. Its results provide a solid foundation for further development and industrial replication, including the adaptation of live tank technology to other voltage levels such as 170 kV in 2028 and 362 kV in 2028. As the technology matures, it can support a broader transition to SF_6-free high-voltage networks across Europe, North America and beyond.

The value of the project therefore extends beyond its immediate outputs. It helps define what the next generation of high-voltage equipment can look like: efficient, reliable, and far less harmful to the climate.

Conclusion

The LIFE SF_6-Free HV Breaker project demonstrates that the transition away from SF_6 in high-voltage equipment is not only necessary, but achievable. By combining an innovative switching and insulating gas technology, advanced design work, rigorous testing and close engagement with utilities, the project has created a credible pathway towards SF_6-free circuit breakers for outdoor transmission applications up to 420 kV (the European grid backbone).

Its importance lies in the balance it achieves. The project reduces environmental impact while preserving the technical performances that power networks require. It is therefore a strong example of how industrial innovation can support climate policy in a practical and measurable way. For the electricity sector, this is not just a technical development. It is a meaningful step towards a cleaner and more sustainable grid.

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Summary

The LIFE SF6-Free HV BREAKER project aimed to develop a 420 kV / 50 kA SF_6-free high-voltage circuit breaker using GE Vernova's alternative gas technology. The project was intended to provide a robust and scalable solution for SF_6-free high-voltage equipment and supported the wider decarbonization of electrical grids. It also created a technical pathway for the future development and replication of live tank technology at other voltage levels, including 170 kV and 362 kV.

Partners

The project was led by GE Vernova's Grid Solutions business, with the main research and development activities based in Villeurbanne, France. The project also involved collaboration with key partners and stakeholders supporting testing, validation and future deployment of SF_6-free high-voltage technology.

Project lead profile

Joël Ozil is Circuit Breaker and GIS Development Manager at Grid Solutions and leads the research team on SF_6-free technologies in Villeurbanne, France. He has more than 25 years of experience in high-voltage switchgear development and holds an engineering degree from Grenoble INP (France).