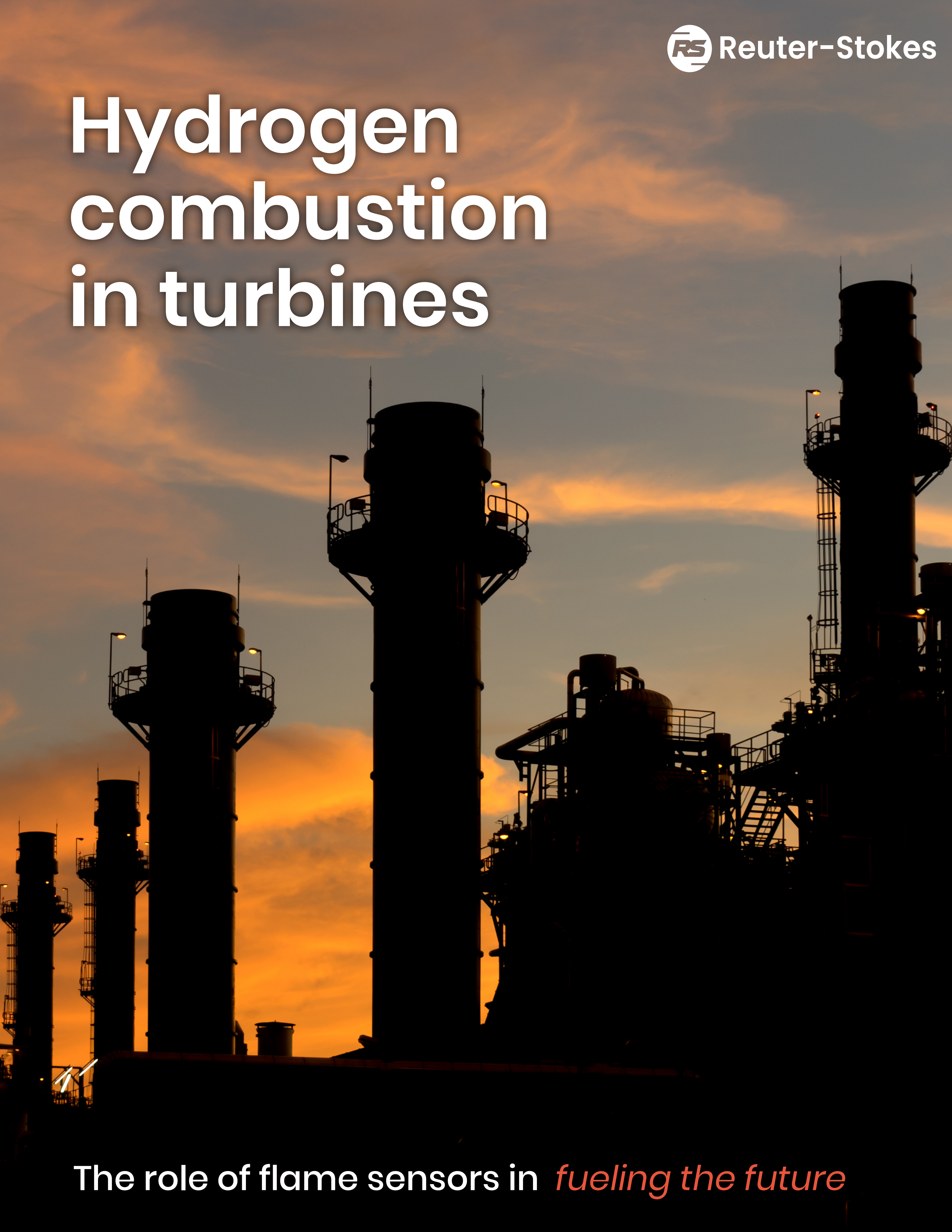
Reuter-Stokes

Hydrogen combustion in turbines



The role of flame sensors in *fueling the future*

In an era where environmental concerns and the pursuit of sustainable energy solutions are at the forefront of global agendas, integrating hydrogen (H_2) and hydrogen/natural gas mixtures as alternative fuels in gas turbines emerges as a promising avenue of carbon dioxide (CO_2) emission reduction.

Harnessing hydrogen for combustion will include challenges. There are risks inherent in the development of new technology, new infrastructure, and hydrogen in particular. Flame sensors play a vital role in mitigating those risks.

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Fueling the future

The current landscape of hydrogen investment

Gas turbines powered by fossil fuels have been widely used for power generation and mechanical drive for many years, owing to their compact mechanical structure, high power-to-weight ratio, and quick start-up. However, due to its high calorific value and low emissions, many Original Equipment Manufacturers (OEMs) expect hydrogen to gradually replace fossil fuels, assuming the necessary infrastructure is in place.

Leading energy companies, utilities, turbine manufacturers, and technology providers are making significant commitments and investments in hydrogen-related projects, pilot demonstrations, and research initiatives. Many OEMs have introduced gas turbines or upgrade programs that permit burning hydrogen/natural gas mixtures (known as hybrid fuels) today.

The combustion properties of hydrogen are quite different than those of natural gas.

Hydrogen has a high energy content per unit mass, making it an attractive option for fueling gas turbines. However, on a volume basis, hydrogen is one-third less energy-dense than methane (CH_4) so it takes three times the volume flow of hydrogen to provide the same energy input as natural gas.

Fuel flow into gas turbine is typically defined in terms of volumetric flow, and the emissions are mainly based on the reaction temperature.

The oxidation of hydrogen produces water vapor as a byproduct, resulting in zero carbon dioxide emissions. This characteristic of hydrogen combustion is desirable for reducing greenhouse gas emissions and mitigating climate change. Gas turbines producing power from "green" hydrogen (created by electrolyzers powered by renewable electricity) have operations with zero carbon emissions. The dispatchable electricity produced by combined cycle plants burning green hydrogen complements the growth of carbon-free yet intermittent renewable generation (Figure 1).

Replacing natural gas with green hydrogen is feasible for generating carbon-neutral power. However, many technological challenges remain.

In the meantime, substituting some natural gas with hydrogen, where available, can significantly reduce carbon emissions in the short run.

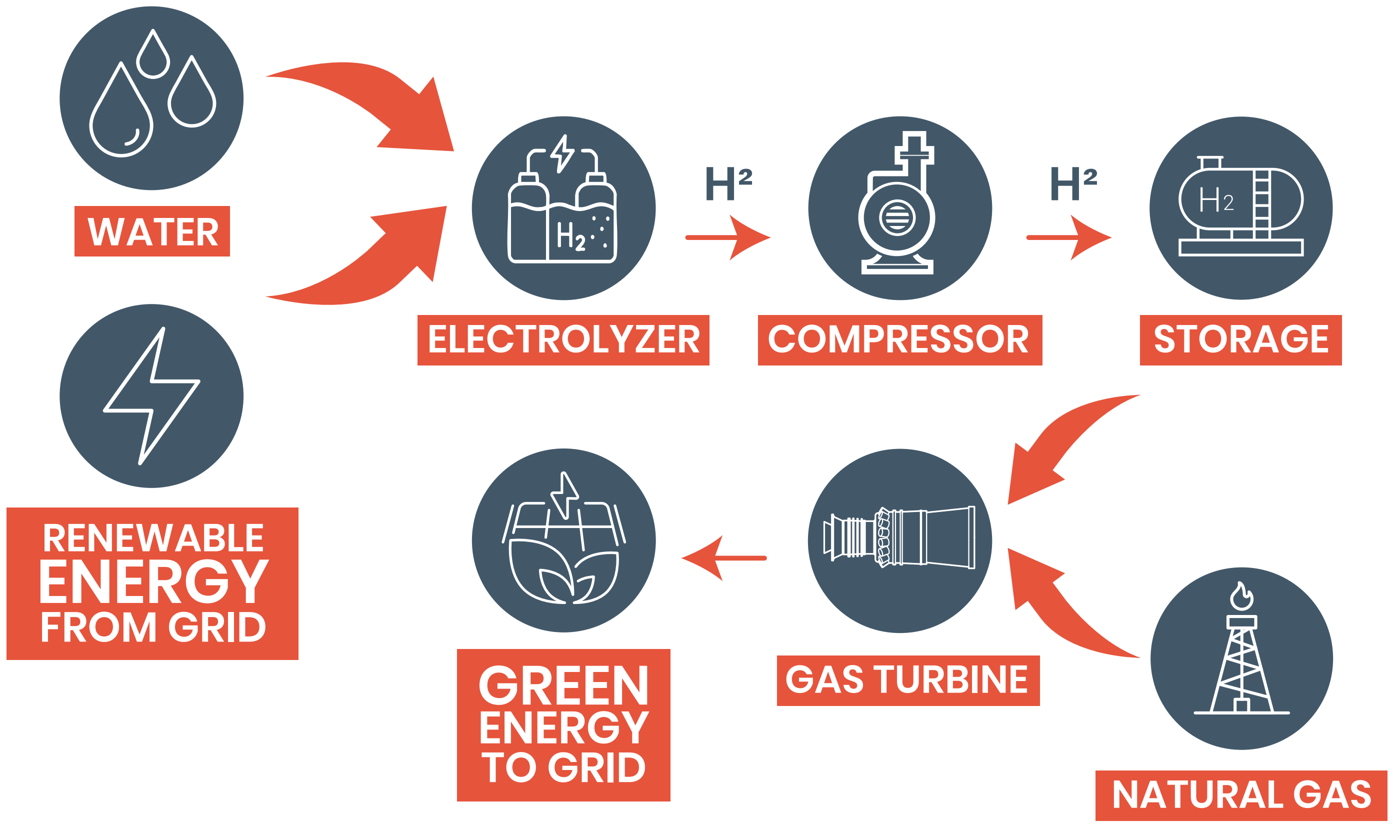
Hybrid fuels offer a practical way of transitioning from burning carbon-based natural gas to a fully decarbonized power generation system, especially in grid systems mainly relying on intermittent renewable energy resources. Several large-frame OEMs currently offer dry low nitric oxide (DLN NOx) gas turbines that can burn hybrid fuels, with a few models capable of up to 40-50% hydrogen by volume capacity. However, 30% appears to be the current standard. One frame gas turbine OEM has recently completed demonstration tests that have reached up to 38% hydrogen by volume, while staying within the permitted NOx limits without water or steam injection.

Another OEM frame gas turbine successfully tested 30% hydrogen mixed with liquified natural gas (LNG).

Aeroderivative OEMs also offer DLN-equipped gas turbines that can burn mixtures of hydrogen and natural gas with up to ~30% hydrogen.

Optimistically, most OEMs with hydrogen development programs have set a common goal to equip specific gas turbine models with 100% hydrogen capability by 2030.

Figure 1:



Hydrogen combustion challenges

Hydrogen and natural gas are both valuable resources for energy production, yet mixtures possess distinct properties that warrant further analysis when considering their use as gas turbine fuels. Understanding these properties is crucial for assessing the feasibility and implications of transitioning towards hydrogen-rich fuel mixtures in gas turbines.

The high reactivity of hydrogen can increase the risk of auto-ignition in the premixing section of combustion systems, particularly in systems with very high air inlet temperatures. Further, burning fuels with a high concentration of hydrogen increases the risk of flashbacks, which are caused when the flame speed is higher and the ignition delay time is shorter than with natural gas. During flashbacks, the flame enters the fuel nozzle, overheats it, and causes damage.

Hydrogen flames also exhibit different thermoacoustic behavior than natural gas flames due to their higher flame speed, shorter ignition delay time, and distinct flame stabilization mechanisms. This results in different flame shapes, positions, and reactivity. The high flame speed of hydrogen can result in rapid heat release rates and increased turbulent flow within the combustion chamber.

Additionally, hydrogen-burning gas turbines are at higher risk of combustion dynamics, such as self-sustained high-pressure pulsations at or near the combustion chamber's acoustic frequency. This results in undesirable phenomena such as combustion instability, flashback, and stress-related component damage. Advanced combustion control strategies and design modifications are generally required to manage the dynamic behavior of hydrogen combustion and ensure the stable and efficient operation of gas turbines.

The science of NOx emissions

There is also the possibility of increased NOx emissions when burning hydrogen. The increase in thermal NOx production in a gas turbine may be surprising. For instance, if a typical natural gas-fired turbine producing 25 ppm NOx of natural gas were to burn a 30% hydrogen mixture, NOx production would increase to approximately 40 parts per million (ppm). Burning a 100% hydrogen mixture would produce approximately 60 ppm NOx, assuming no design changes with the combustor.

Therefore, burning hydrogen could pose an environmental risk due to the increased NOx production unless additional mitigation measures are deployed, such as selective catalytic combustion (SCR). Further, thermal NOx is a precursor to regulated pollutants like ozone and particulate matter (PM2.5), regulated environmental pollutants.

Component design for hydrogen applications

Burning hydrogen can also impact combustion component design. When hydrogen is burned instead of natural gas, the exhaust becomes more humid. Moisture in the combustion gases leads to increased heat transfer to the hot gas path components. As a result, the cooling system must be adapted to prevent overheating of these components. Furthermore, the higher moisture content increases the likelihood of hot corrosion.

When burning 100% hydrogen or hydrogen/natural gas mixtures in a gas turbine, these combustion phenomena require many physical design changes. In the fuel delivery system, components must be made of materials compatible with hydrogen to prevent degradation, embrittlement, or hydrogen-induced cracking. Enhanced leak detection systems and protocols are necessary to detect and prevent hydrogen leaks, due to its high diffusivity and flammability. Fuel injectors or nozzles within the combustion chamber may need to be modified or replaced. Optimizing these parameters can help reduce emissions and improve environmental performance.

By implementing advanced combustion control strategies, design modifications, and emission control technologies, the full potential of hydrogen as a clean and efficient fuel for gas turbines can be realized.

Flame sensors are essential

Many aspects of the combustion system will need to change to accommodate hydrogen fuel. Each change adds some risk, which increases the need for flame supervision. Flame sensors are essential safety components of the combustion system, providing critical flame detection as an input to the safety functions of the control system. By continuously monitoring the presence of a flame and providing real-time feedback to the control system, flame sensors help ensure safe, stable, and operationally efficient combustion operation in gas turbines.

Flame sensors are positioned strategically to monitor a flame's presence during the combustion process. They use various detection methods to detect a flame's characteristic radiation.

Flame sensors also provide real-time feedback to the turbine control system, allowing operators to monitor combustion stability. By continuously monitoring the flame status, flame sensors help ensure that combustion is stable and consistent, minimizing the risk of flameout.

In the event of a flameout, where the flame is extinguished or fails to ignite, flame sensors immediately detect the absence of a flame and trigger appropriate safety measures. Automatic shutdown systems may be activated in response to flameout events to prevent the continued flow of fuel into the combustion chamber and exhaust system.

Gas turbines usually incorporate redundant flame sensors, positioned at multiple locations, to enhance reliability and safety. Redundant flame sensors provide backup functionality and ensure continuous flame monitoring, even if one sensor fails or malfunctions.

Detecting and monitoring hydrogen flames

Detecting and monitoring hydrogen flames in combustors presents several technical challenges, due to the unique properties of hydrogen and the characteristics of hydrogen combustion. These challenges stem from factors such as the visibility of the flame, the spectral characteristics of hydrogen combustion, and the potential for combustion instabilities. Overcoming these challenges requires specialized flame detection technologies and robust sensor validation methods tailored to the characteristics of hydrogen combustion. Incorporating redundancy and fault-tolerant design features in flame sensor systems enhances reliability and safety in hydrogen-rich combustion environments. Installing multiple sensors at different locations on the gas turbine provides backup functionality and ensures continuous flame monitoring, even in the event of sensor failures.

Reuter-Stokes flame sensors have successfully detected flames in gas turbines across a spectrum of hydrogen/natural gas mixtures, ***particularly during transitions from natural gas to hydrogen fuel blends.***

Our Flame Tracker Dry 325 (FTD 325) is used on turbines that can start-up and burn gas blends up to 100% hydrogen, as well as switch from natural gas to blends or 100% hydrogen with no hardware changes.

Closing thoughts

The outlook for adopting hydrogen-based fuels in gas turbines is promising.

The global imperative of reducing greenhouse gas emissions drives decarbonizing the energy sector and transitioning toward sustainable energy sources. Several factors contribute to a positive outlook for hydrogen-based fuels in gas turbines.

Ongoing advancements in electrolysis, steam methane reforming with carbon capture and storage, biomass gasification, and other hydrogen production technologies are increasing the availability and affordability of low-carbon or green hydrogen. The scaling up of electrolyzers and the decreasing costs of renewable electricity makes green hydrogen increasingly competitive with conventional production methods.

Governments and regulatory agencies worldwide are implementing policies, incentives, and emissions reduction targets to promote the adoption of hydrogen-based fuels and accelerate the transition to a low-carbon economy.

Initiatives such as carbon pricing, renewable energy mandates, and investment incentives create market opportunities to drive investments in hydrogen infrastructure and technology development.

Continued research and development efforts drive technological innovations in gas turbines, fuel systems, combustion chambers, and emissions control technologies tailored for hydrogen-rich fuels. Advancements in materials science, combustion modeling, and sensor technologies are enhancing the advancement of hydrogen combustion, efficiency, and safety in gas turbines.

Hydrogen is increasingly recognized as a versatile energy carrier that can complement intermittent renewable energy sources, provide energy storage solutions, and decarbonize the hard-to-abate power generation and industry sectors. Integrated energy transition strategies promise to deliver a resilient and low-carbon electricity grid through green hydrogen-fired gas turbines with effective and reliable flame sensors for flexible power generation, suitable infrastructure for the safe transportation and storage of hydrogen and developing hydrogen hubs.

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Contact us

Reuter-Stokes specializes in harsh environment sensing technology to provide reliable flame supervision in the most extreme conditions. We leverage the expertise of our engineers and scientists to develop flame sensors that enhance safety, operational efficiency, and accuracy.

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