PSM
a Hanwha company

Innovative Clean Energy Solutions for Future Generations

Clean Energy Solutions

H_2-Ready Retrofits: Future-Proofing Gas Turbines for Tomorrow's Energy

PSM empowers power plant operators to attain their business profitability objectives, all while minimizing their carbon emissions to align with decarbonization targets.

Changing Energy Industry

Gas turbines play a vital role in the energy industry, providing reliable and flexible power generation to meet the demands of modern society. They also facilitate the integration of renewable energy sources, addressing the challenge of intermittency. This shift is reshaping the energy industry, driving innovation, and promoting a more sustainable and resilient power generation infrastructure.

At PSM, we specialize in assisting gas turbine owners in adapting to the rapidly changing energy landscape. Our expertise lies in retrofitting existing gas turbines with advanced technologies that enable the use of versatile fuels such as hydrogen and refinery off-gas (ROG).

Hydrogen as a Fuel

Hydrogen shows great promise as a fuel for gas turbines due to its ability to generate zero carbon emissions when burned. By utilizing hydrogen, gas turbines can significantly reduce the carbon footprint of power generation, making it a crucial technology in the transition to a sustainable and low-carbon energy system.

Refinery Off-Gas (ROG)

Refinery Off-Gas (ROG), a by-product of the refining process, can serve as a valuable source of heat or as feedstock for chemical production. When unused, however, it is typically burned off through flaring. By utilizing ROG as a fuel source in gas turbines, PSM helps reduce greenhouse gas emissions in the refining industry while offering a cost-effective and flexible solution for power generation.

Converting Gas Turbines

Converting a gas turbine to run on hydrogen involves:

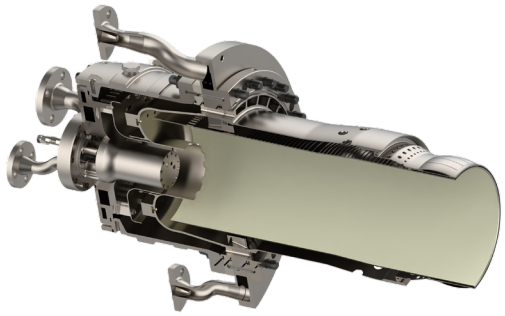
+ Retrofitting the combustor
+ Adapting mixing skids for the hydrogen-natural gas fuel mixture
+ Implementing real-time fuel mixture monitoring systems

A comprehensive evaluation of the plant, machinery, and decarbonization goals is necessary to determine the specific scope of the conversion.

FlameSheet™ Combustor

The FlameSheet™ Combustor utilizes an innovative design with a unique flame stabilization mechanism. This mechanism enhances combustion stability and allows for greater fuel flexibility. With this feature, efficient combustion of different fuel types, including hydrogen and refinery off-gas (ROG), is possible without compromising combustion stability or emissions performance. As a result, carbon emissions can be reduced, contributing to efforts to mitigate the effects of climate change.

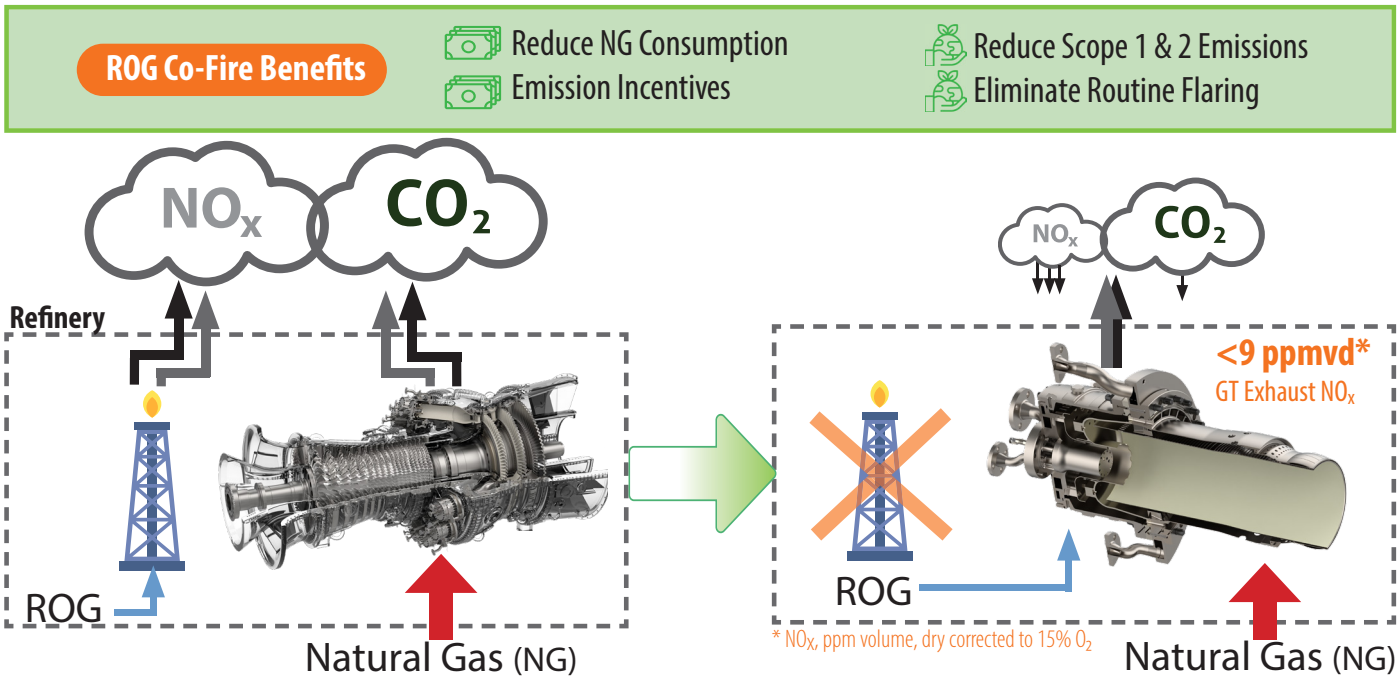
The FlameSheet™ Combustor is a scalable solution, designed for compatibility with a wide range of engine models across differnt OEMs, including popular frames like the GE Frame 5, Frame 6, E-Class, F-Class, as well as Siemens and Mitsubishi 501F.



CROSS SECTION VIEW - FLAMESHEET™ IS NOW AVAILABLE ON MOST ENGINE MODELS

FLAMESHEET™ PRODUCTION LINE - EACH UNIT IS TESTED PRIOR TO SHIPMENT

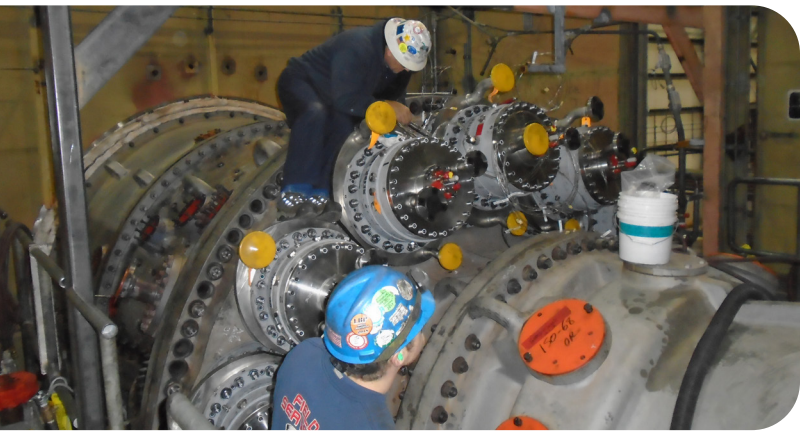
ROG Blend Fuel – Emissions Impact

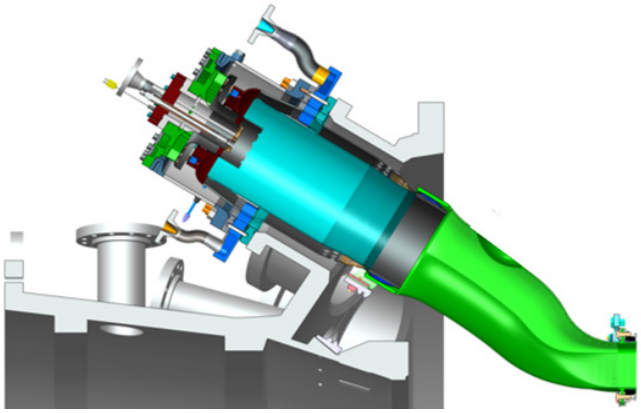


FlameSheet™ Combustor Platform

Superior Turndown, Fuel Flexibility, and Emissions Capability

Future-Proof your engine today! FlameSheet™ is the ultimate combustor solution to meet new operational needs. As the power generation market faces challenges from renewable energy penetration, low natural gas prices from fracking, and dynamic financial market changes, users must reevaluate their fleets to stay relevant. FlameSheet™ provides unparalleled flexibility, preparing your engine for both current operational demands and the future hydrogen economy.





FlameSheet™ Benefits

+ Up to a 30% increase in GT operating load range with single digit NOx and CO
+ Optional low-load HRSG protection setting
+ Superior Fuel Flexibility:
  - » 30% Modified Wobbe Index
  - » Ideally suited for alternate fuel operation, including hydrogen, ethane, and propane
    - + Up to 100% Hydrogen blend (frame dependent)
    - + Up to 40% Ethanes (C2)
    - + Up to 10% Butanes (C4-C6)
    - + Up to 20% Propane (C3)
+ No diluent (water or steam) required
+ Peaking power at constant NOx emissions
+ Dual fuel capable (Distillate oil as backup)
+ Inspection intervals up to 32K hours / 1,250 starts
+ Compatible with existing GT controllers and fuel skids
+ Turndown as low as 26% (even lower with Exhaust Bleed!)

FlameSheet™ = TWO Combustors in ONE

FlameSheet™ employs a simple, two-stage radially-inflow "combustor-within-a-combustor" concept, allowing staged operation at various load conditions. At high loads, both combustors are used, with the outer combustor flame structure forming an annular "sheet of flame" around the inner combustor. At low loads, the outer combustor is predominantly used. Leveraging trapped vortex stabilization aerodynamics, the outer combustor operates with excellent stability and remains sufficiently hot at very low loads to consume CO (which typically limits low-load operation). The outer combustor operates with excellent stability and remains sufficiently hot at very low loads to consume CO (CO typically limits low load operation).

LEC III™ Combustor Platform

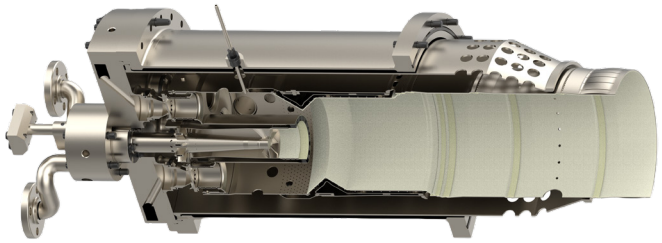
PSMs' Low Emission Combustion (LEC) technology is a proven and reliable solution for gas turbine combustion systems. It allows for the utilization of different fuels, such as low-emission fuels, hydrogen blends, and syngas. With over 100 installations globally, LEC III™ technology provides gas turbine owners with a cost-effective retrofit option that can effectively reduce emissions and enhance performance. It serves as a valuable tool in facilitating the shift towards a more sustainable and decarbonized future.

LEC -III™

+ Guaranteed emission levels: sub-5ppm NOx
+ Gas-only operation with enhanced fuel flexibility using PSM's SFN
+ Operational capability: 24,000 hours / 900 starts

LEC-NextGen

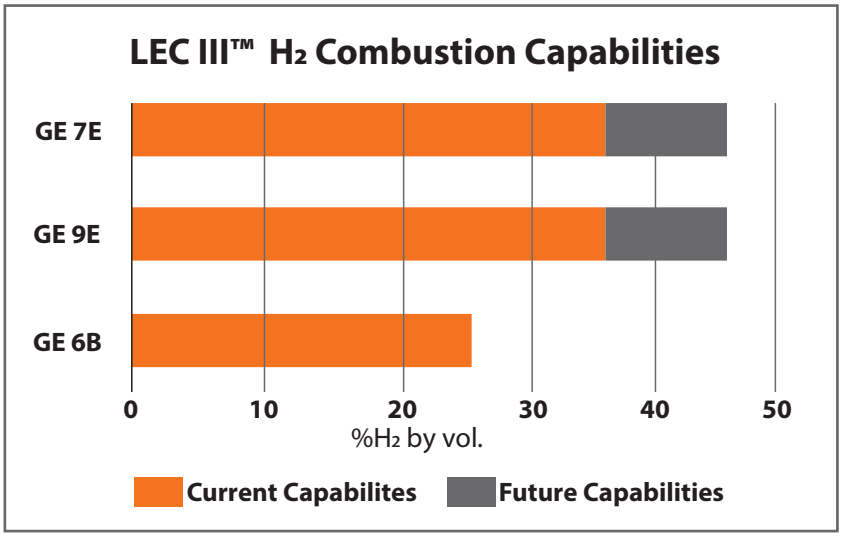
+ Guaranteed emission levels: sub-7ppm NOx with PSM's SFN (9ppm with DLN SFN)
+ DLN 'drop-in' compatible with gas and dual fuel applications
+ Operational capability: 32,000 hours / 1,200 starts



Cross section view - LEC-III™ is now available on B&E-Class engine models

Addtional Features

+ Turndown with Inlet Blead Heat (IBH) ~50% of baseload
  - » Add Sequential Fuel Injection (SFI) 35% turndown
  - » Add Exhaust Bleed (ExB) for an additional 5-10% turndown to achieve <30% of baseload
+ Turndown with Sequential Fuel Injection (SFI) as low as 35%
  - » Combined turndown with IBH and ExB: <35%
+ Fuel flexibility: Up to 60% hydrogen while maintaining stable emissions
  - » Additional turndown capability with H_2 mixing
+ AutoTune 3.1 and FlexSuite
  - » Automated tuning for emissions and dynamics
  - » Power+ / Peak+ / Extended Turndown modules specifically developed to extend the operating range
  - » Virtual FlameScanner: Eliminates the need of secondary flame scanner hardware



LEC III™ and LEC-Next Gen Combustors

Air-Fuel Mixing is the Key

To achieve low NOx and CO emissions in the PSM LEC III™ combustion system, it is crucial to have a thorough and efficient premixing of the fuel and air before the combustion process. Three key design features in the LEC III™ set it apart from the OEM:

+ Forward-flowing venturi
+ Effusion cooling technology
+ Advanced secondary fuel nozzle (SFN).

System Differentiations of LEC-III™ and LEC-NextGen

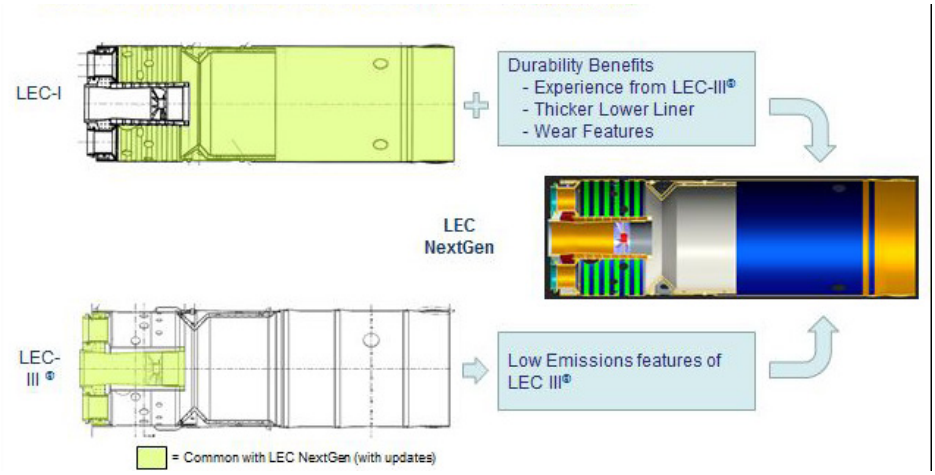
The primary hardware difference between the two systems is the combustion liner. PSM's LEC-III™ system, originally designed for ultra-low emissions, features a unique design with a forward-flowing venturi and effusion cooling technology, making it gas-only. To accommodate dual fuel users, PSM developed the LEC-NextGen system, first released in 2015. The LEC-NextGen system is compatible with PSM's upgraded transition piece, fuel nozzles, and flow sleeves, as well as traditional DLN systems, allowing for greater flexibility.

The LEC-NextGen liner includes upgraded features such as an advanced flowing combustion cap, a thicker lower liner, and enhanced wear characteristics while utilizing a standard flow venturi. This design makes the system more flexible in operation, though it has a slightly higher emissions output compared to the LEC-III™ system, with levels as low as sub-7ppm.

Benefits

+ Reduces NOx and CO emissions to meet increasingly stringent environmental regulations.
+ Increases power output, allowing operators to generate more electricity without increasing fuel consumption.
+ Extends GT maintenance intervals, reducing downtime and maintenance costs.
+ Designed to improve reliability, reducing the likelihood of unplanned outages and increasing overall uptime.

9E LEC-III™ Conversion



Successful Installations

Frame 7F FlameSheet™

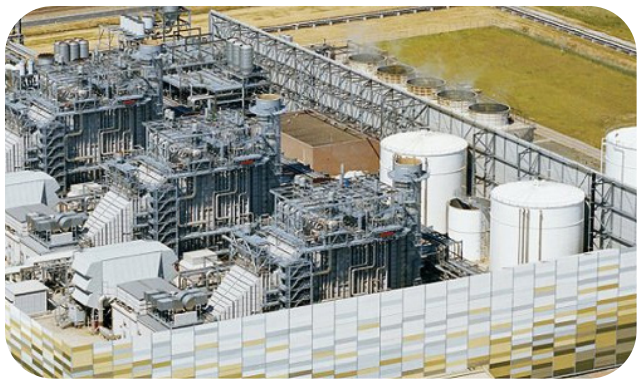
+ 1 X 7F unit in USA
+ Up to 25% H_2/vol at part load
+ Up to 90% ROG blend at part load with enhanced turndown
+ Operating since 2018 on 5% H_2 ROG (supply limit)
+ Liquid fuel backup capability

Frame 7E FlameSheet™

+ 1 X 7E unit in KoreaAchieved 60% H_2 at Baseload & 100% H_2 @FSNL
+ Single digit NOx and CO emissions
+ Commissioned in April 2023

Frame 9E LEC-III™

+ 3 X 9E units in the Netherlands
+ Up to 35% H_2/vol capability
+ Single digit NOx and CO emissions
+ Combustion retrofit for lower NOx emissions, operating since 2018 on 25% H_2 ROG (validated up to 35%)



Frame 9E LEC-III™

+ 1 x 9E unit in the Netherlands
+ Combustion retrofit, new gas supply and lower NOx requirements, targeting blend up to 30% H_2
+ Decarbonization for gas assets for owner

PSM - A Hanwha Company

The growing interest in the hydrogen economy is driven by the need to address climate change and transition to sustainable energy sources. However, challenges remain, including high production and storage costs, and extensive infrastructure requirements for distribution and transportation.

As a Hanwha subsidiary, PSM is uniquely positioned to leverage the expertise and resources of the Hanwha family to accelerate hydrogen development and adoption as a clean energy source. Hanwha's global presence and diverse business interests in areas like solar energy and defense provide PSM access to a wide array of technologies, markets, and partnerships.

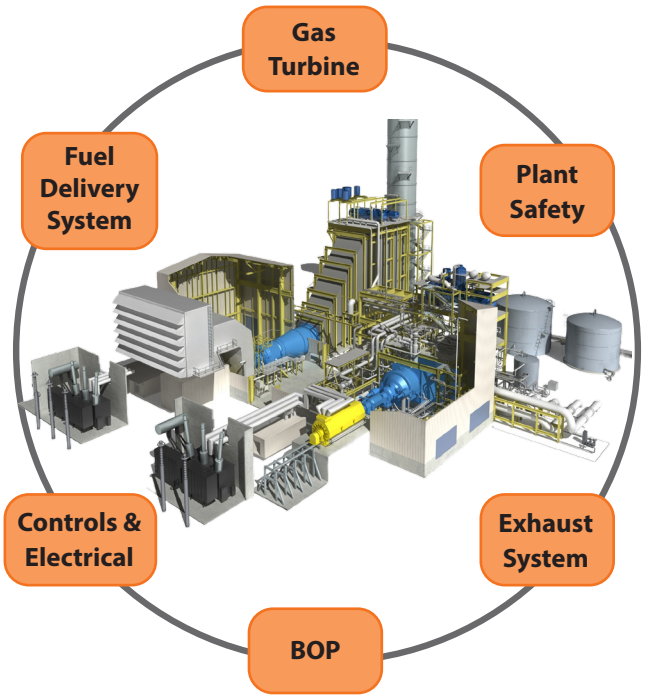
Collaboration with Hanwha Q CELLS, a leader in large-scale solar projects, enables PSM to integrate hydrogen production with solar energy systems, fostering more sustainable and efficient energy solutions.

Hydrogen Ready

As gas turbine combustion technology advances, the need to prepare power plants for hydrogen combustion becomes evident. PSM offers a holistic approach and extensive evaluation to assist power plants in making a future-proof investment in hydrogen fuel. This contributes to a cleaner and more sustainable energy future. Converting power plants to use hydrogen as fuel requires a detailed assessment of plant specifications and the customer's decarbonization goals.

This evaluation is crucial in determining the scope of work and establishing a realistic timeline for the conversion project. Our expertise in retrofit solutions makes us the ideal partner during the energy transition.

Contact PSM today to learn more about our Clean Energy solutions and schedule an energy transition consultation.



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