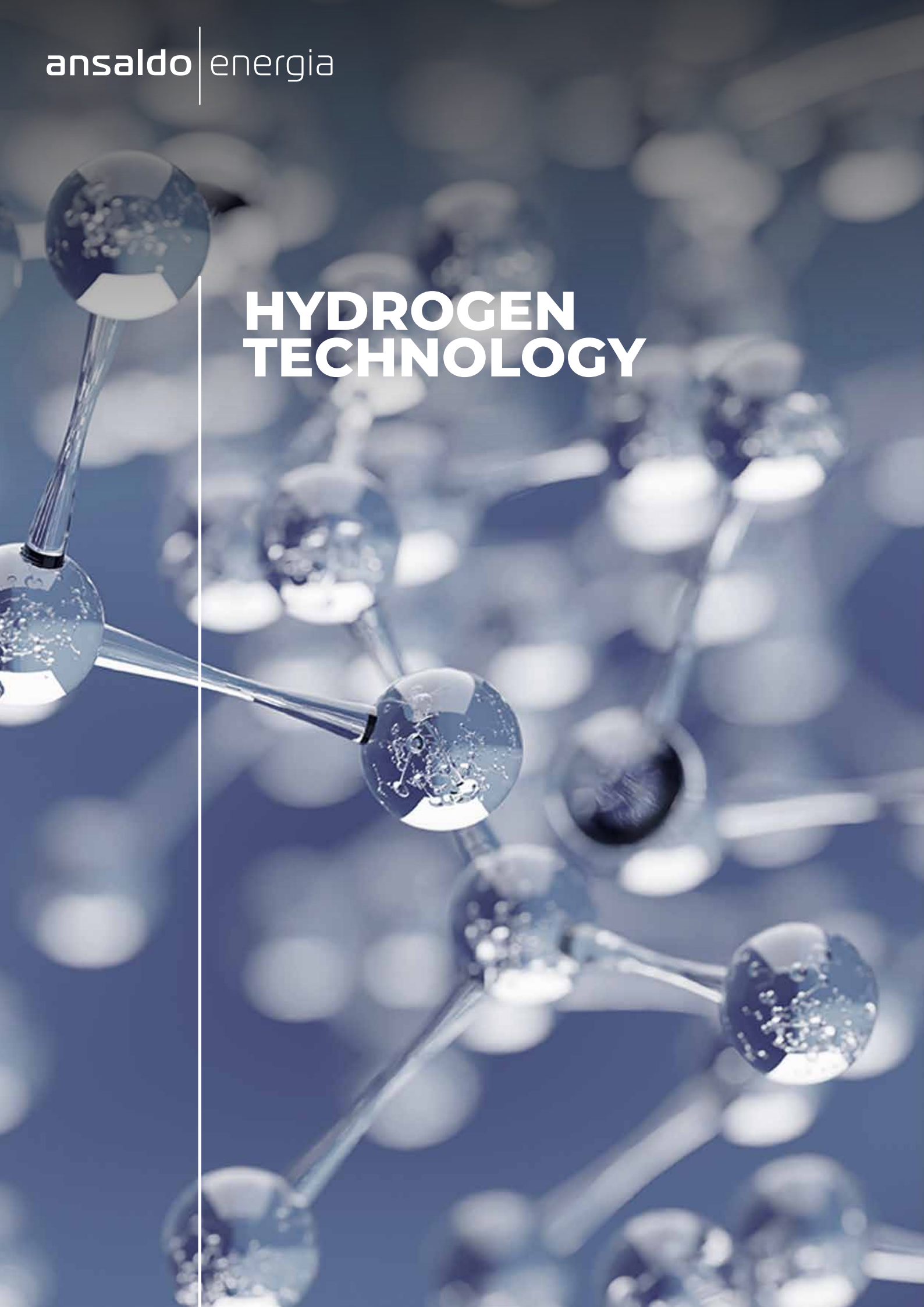


HYDROGEN TECHNOLOGY



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Ansaldo Energia solutions for Hydrogen combustion: fast-forward to a Hydrogen Fueled Future

Thanks to fast-paced technological advancements, the world is embracing new energy visions featuring hydrogen as a key driver in the energy transition, and so are plant owners, who are called to play a vital role in enabling the creation of an integrated, secure, environmentally sustainable energy system.

New renewables-driven scenarios envisage great opportunities to reduce cost and overcome barriers preventing green hydrogen from being a true game-changer in solving the security, storability and carbon neutrality challenges affecting the current energy landscape.

Despite there are still several steps to be taken at different levels to tear down the barriers to a hydrogen economy, the global energy landscape is turning in this direction. With hydrogen projected to meet increasing shares of the energy demand and the cost of green hydrogen production expected to drop sharply over the coming decades, a hydrogen-fueled future might be closer than we think.

Based on two different technological platforms, Ansaldo Energia offers solutions to best suit each Customer's generation profile: its versatile gas turbines are capable to burn any hydrogen-natural gas blend as shown in the below table and they can comfortably handle intermittent or fluctuating H₂ supply maintaining full adherence to NO_x emission requirements.

Ansaldo Energia solutions for burning hydrogen

Technology	Application in Gas Turbine (No hardware modification on gas turbine)	H ₂ Capability: any blend between 0 up to max [vol %]	NO _x Emissions [ppmv @15%O ₂ , dry gases]
Sequential Combustion	GT36 New and service	70	15
Sequential Combustion	GT26 New and service	45	15
Single Stage Combustion	AE94.3A New and service*	40	25
Single Stage Combustion	AE94.2 New and service*	40	25
Single Stage Combustion	AE64.3 New and Service*	40	25

*including V94.3A/V94.2 technology

Sequential combustion

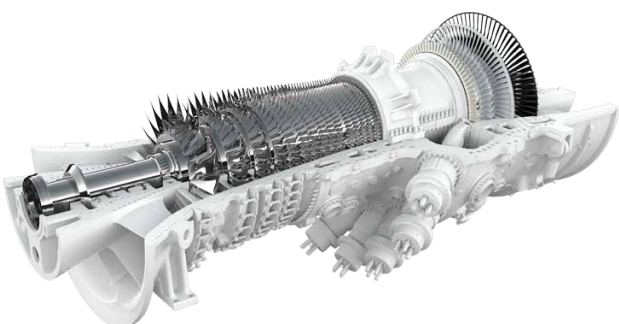
Hydrogen, no compromise

The main challenge of hydrogen combustion lies in its properties, first and foremost its increased reactivity. Compared to natural gas, during H₂ combustion the flame position moves upstream, thus increasing the risk of flashback. All conventional combustion systems fail to handle hydrogen's special features without compromising performance: by injecting less fuel, flashback risks are mitigated and the flame is moved back to the design position, but exit temperature gets lower and performance is severely reduced.

Ansaldo Energia developed a unique, unrivalled, state-of-the-art technology solution for safely burning very high H₂ contents while preserving top-level performance.

Ansaldo Energia's sequential combustion employs two combustor stages in series: one conventional stage followed by an auto-ignited second stage overcoming the limits of traditional combustion systems. A shift of fuel from the first to the second stage compensates the higher hydrogen reactivity on both stages: the first stage flame location is maintained thanks to its lower temperature, while the resulting lower inlet temperature of the second stage keeps its flame at the desired location despite an increased fuel flow. This is possible because the second stage flame is stabilized by auto-ignition, strongly driven by the inlet temperature and less sensitive to the flame temperature which can be maintained at full F and H class levels. This is key in unleashing H₂ combustion's full potential.

Ansaldo Energia has been at the forefront of hydrogen combustion development for many years, joining prominent European and international development projects. During their development both the GT26 and the new GT36 gas turbine combustors underwent detailed validation under full engine pressure at the DLR (German Aerospace Institute) in Cologne. Ansaldo Energia gas turbines and retrofit combustors can cope with any H₂-methane blend up to still unmatched maximum H₂ volume content up to 50%, with no need to change or adapt the existing hardware. This become particularly important when H₂ availability fluctuates due to intermittent production from renewables.



GT26 AND GT36:

a set of unique advantages without compromising performance, in compliance with emission requirements and over the full load range

Single stage combustion

Hydrogen, our experience

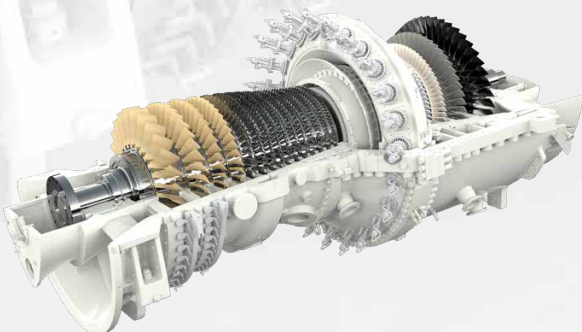
The single stage combustion is the typical configuration of the AE94.3A and AE94.2 gas turbines which, with millions of service hours, stand for one of the most representative fleets in the power generation field. Two AE94.3A, capable of burning a blend of natural gas and 15% H₂ by volume, started commercial operation in early 2006 in a combined cycle plant served by a refinery, reaching 215,000 EOH, using standard hardware with no special fuel system adaptation. Smooth, trouble-free operation and highly stable combustion behavior allowed for a gradual increase of the mixture's hydrogen content in several steps up to reach now 25% with a potential saving of 100,000 tons/year of CO₂ assuming a base load operating profile.

Known for its superior flexibility and originally designed for mastering the combustion of unconventional fuels, the AE94.2 was the natural choice for the following dedicated validation campaign.

With more than 500,000 EOH running on hydrogen-rich fuels from refineries, steelworks or other chemical plants and capable to burn almost unlimited quantities of H₂ mixed with steam or other NO_x abatement aggregates in diffusion mode, the AE94.2K provided a solid ground on which to build a fleet of gas turbines with enhanced hydrogen combustion capabilities.

Thanks to the combination of AE94.2K's long-standing experience in syngas-fueled operation with the excellent results achieved with the AE94.3A, customers are now offered the possibility to burn H₂ in the same way as natural gas, with no need to use steam and keeping NO_x in compliance with legal requirements.

Indeed, the AE 94.3 A and AE 94.2 are currently capable of burning 40% in pre-mix mode.



2006: 15% H₂ burned

2010: 18% H₂ burned

2017: 25% H₂ burned

2023: TARGET 40% H₂ BURNED

Installed fleet

Hydrogen, future proof your assets

Ansaldo Energia can offer a wide range of specific solutions for the installed and operating gas turbines to increase the amount of hydrogen that can be burnt in an installed plant, lowering emissions and reducing the overall carbon footprint. Ansaldo Energia gas turbines and combustor upgrades can cope with extremely broad H₂-methane blend up to still unmatched maximum H₂ content of 30% vol and more. The versatility of Ansaldo Energia gas turbines allows for easy adaptation of the fuel system, requiring limited changes of the already installed hardware configurations. The capability to easily retrofit solutions for burning varying H₂ content becomes particularly important when H₂ availability fluctuates due to intermittent production from renewables. This expands plant operation horizons with no compromises on efficiency or performance. In addition, strikingly low NO_x emissions levels ensure full environmental compliance.

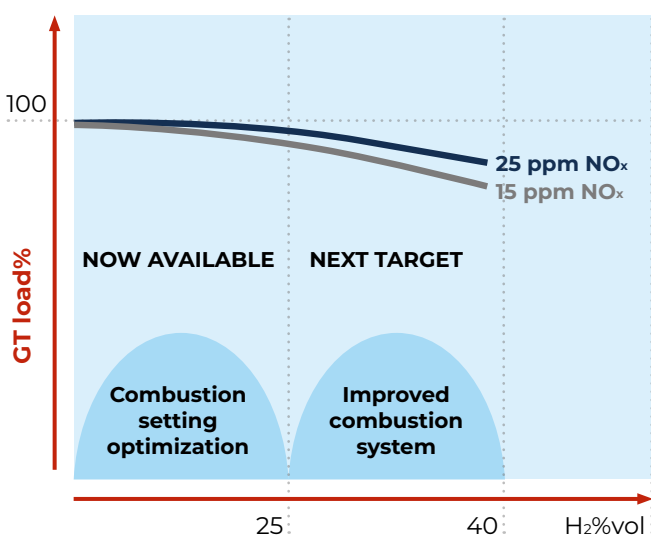
Retrofit solutions for GT26

Thanks to its sequential combustion architecture, GT26 enables an enhanced management of continuously increasing hydrogen content. Its well-known combustion stability and combustor configuration (up to Rating 2006 and earlier) allow to burn hydrogen without any modification up to approximately 25%, without any compromise on power output and efficiency.

By implementing the latest SEV burner generation (post Rating 2006), the GT26 gas turbine can operate with higher hydrogen content (30%) while maintaining emissions under control and without jeopardizing efficiency or power output. Higher hydrogen content can also be achieved while only partially compromising on cycle performance.

Retrofit solution for AE/V94.2 / AE/V94.3A / STG5-2000E / SGT5-4000F

Ansaldo Energia's portfolio of single-stage hydrogen combustion solutions employs an extremely versatile technology allowing an easy retrofitting on the entire installed fleet of AE/V94.3A, AE/V94.2, STG5-2000E & SGT5-4000F gas turbines. Current and future customers are therefore offered a unique opportunity to convert their plant assets to run on hydrogen up to and beyond 25% with minimal hardware changes. Ansaldo Energia can thus help customers embracing the world's new energy trends.



GT26 RATING 2006 AND EARLIER:

- Up to 15% H₂ content without engine derating
- Up to 30% H₂ content with minor engine derating and validation instrumentation

GT26 POST RATING 2006:

- Up to 30% H₂ content without engine derating
- Higher contents can be achieved with minor hardware adaptation and/or derating

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