

# BREAKING THE EFFICIENCY BARRIER

AT 60+% EFFICIENCY MITSUBISHI'S NEW J-CLASS TURBINE PROMISES A COMBINED CYCLE OUTPUT OF 460 MW

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In gas turbine development, output and efficiency are typically increased through higher firing temperatures and increased compressor pressure ratios. A higher pressure ratio requires more advanced technologies to protect against surge and maintain compressor efficiency. These technologies include new profile designs, better compressor sealing technologies, and tighter compressor clearances. A higher pressure ratio requires a higher fuel gas supply pressure.

Increasing the firing temperature induces more NO<sub>x</sub> emissions, hence requiring more efficient cooling schemes or other NO<sub>x</sub> mitigation strategies. It also pushes the envelope in the ability of the materials to withstand high temperatures.

Compared to air, steam is a more effective cooling media. Steam cooling of components enables higher temperatures. But it also involves integration of the bottoming cycle and the gas turbine, which in turn, can pose limitations on the operational flexibility of the combined cycle.

While introducing new models, gas turbine OEMs employ different trade-off strategies to achieve their design goals. For instance, Siemens has moved away from steam air cooling toward air cooling in its newest gas turbine offering, the SGT5-8000H. But, Mitsubishi, which has over 60 G-class units sold with steam cooling, has chosen to apply the same steam cooling scheme to the J-class, its latest gas turbine model (Figure 1). This steam cooling scheme is applied to stationary components only — the combustion liners and the first two stages of blade rings. Turbine cooling is based on air, just as in the G.

The Mitsubishi J features a 60-Hz simple cycle output of 320 MW and a combined cycle output of 460 MW. The J targets efficiencies of over 60% in combined cycle. So far, reaching 60% has been a goal for gas turbine OEMs.

The company believes that the “well over 60%” combined cycle efficiency promised by the J-series will make it an ideal choice to reduce greenhouse gases and replace other equipment generating baseload power. The OEM believes that, with today’s concerns about carbon emissions, an efficiency increase brings its own premium. The J-series combined

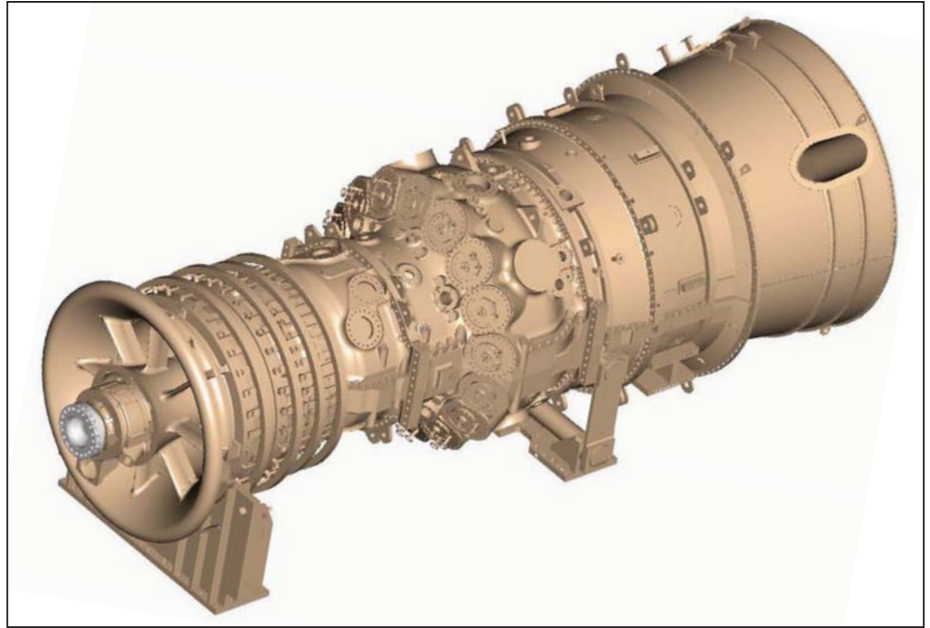


Figure 1: The Mitsubishi 60 Hz J-class gas turbine has an output of 320 MW

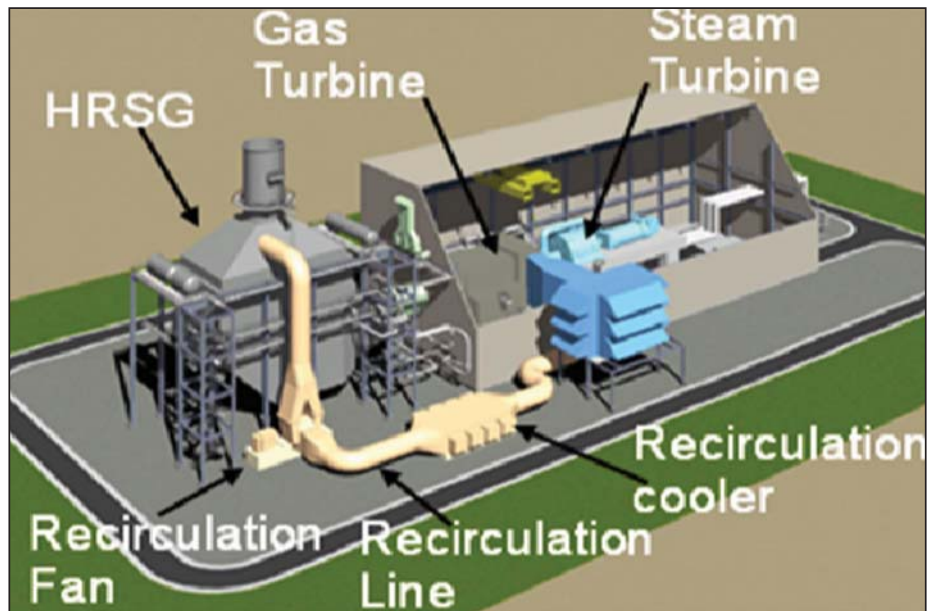


Figure 2: A Japanese national project aims to develop technology for a combined cycle plant based on a 1,700°C gas turbine, including exhaust gas recirculation to reduce emissions

cycle is said to achieve CO<sub>2</sub> emissions that are approximately 50% lower than conventional coal-fired power plants.

At the same time, the company is now offering an air-cooled version of its G-class to markets where combined cycles are employed in “highly” cyclical duties. For instance, a key target for the air-cooled

G is the U.S. market, where the oscillating fuel and MW/hour prices dictate the service factor of combined cycles.

## A leap in temperatures

Key features enabling the higher output and efficiency in the J-class are:

- A temperature of 1,600°C at the turbine

inlet — nearly 100°C more than Mitsubishi's G

- A compressor with a pressure ratio of 23:1, compared to 21:1 in the M701G2

The J-series compressor is based on Mitsubishi's H-class compressor that has a pressure ratio of 25:1. The OEM is currently involved in commercial production of the J machine. Delivery to the first client is said to be in 2011.

Mitsubishi Heavy Industries (MHI) introduces a new series of turbines for power generation every ten years. Observers expect the J-series to be the company's main turbine for the next ten years.

The J-series gas turbine is able to withstand 100°C higher temperatures than the existing 1,500°C-class G series through several engineering developments, including improved turbine cooling efficiency and an enhanced Thermal Barrier Coating (TBC). The combustion system in the J will be similar to the steam-cooled design used in the 50 Hz and 60 Hz versions of the G.

Several new technologies applied in the J are derived from a government-supported project in Japan that seeks to develop core technologies for a 1,700°C-class gas turbine with combined cycle efficiencies of 62% - 65% (Figure 2). Based on Japan's Basic Act on Energy Policy enacted in 2002, a Basic Energy Plan was approved by the Japanese Cabinet in 2003. In response, the nation's Ministry of Economy, Trade and Industry has been promoting the development of high-efficiency gas turbines for power generation. As part of the 1,700°C-class gas turbine project, core technologies are being developed and commercialized.

The component development phase of this government project took four years and was completed in 2007. During the first phase, Mitsubishi carried out several R&D efforts in the areas of:

- Exhaust Gas Recirculation combustor for lower emissions
- Higher cooling efficiency
- Thermal barrier coatings with low thermal conductivity
- Higher loading turbine aerodynamics
- Higher pressure ratio compressor
- Advanced turbine materials

Mitsubishi has demonstrated incremental improvements in efficiency with its G-class combined cycles. For instance, its G2 achieves more than 59% efficiency in site conditions at a Tokyo Electric Power Company plant (p. 24, Nov./Dec. 2008). While achieving "well above 60% efficiencies (lower heating value), the power generation capacity of the J combined cycle will be about 1.2 times that of the G," says Mitsubishi.



**Figure 3: Mitsubishi tests new gas turbine models and components at its inhouse commercial verification facility at Takasago, Hyogo Prefecture**

### Verifying, commercially

Mitsubishi produces gas turbines on a vertically integrated basis, from conceptual and detail design to verification and manufacturing, at its Takasago Research & Development Center and Takasago Machinery Works in Takasago, Hyogo Prefecture. At the Takasago Works, MHI has a verification facility for gas turbine combined cycles (Figure 3).

Before commercializing, the company conducts verification tests of large-size gas turbines and their core technologies under actual generating conditions. The G-series gas turbine was designed and developed through the verification process. To date, 62 units of G-series gas

of \$6.1 - \$7.1 billion. "We aim to deliver 50 units per year," says Tsukuda.

Observers say that steam cooling is obviously the way to go to increase output and efficiency. "But steam cooling demands a 'very' tight integration between the air and steam cycle," says Klaus Brun, Section Manager, Rotating Machinery, South West Research Institute (San Antonio, TX).

"The steam cooling concept involves integration, but the Equivalent Availability Factor (EAF) of our G fleet is 94.5% and the starting reliability exceeds 99%," says Carlos Koenke, Technical Service Manager of Mitsubishi Power Systems. "These num-

## With the J-class, Mitsubishi plans to increase its share in the global gas turbine market from 10% to 30% — equivalent to annual sales of \$6.1 - \$7.1 billion

turbines have been sold worldwide, including Japan and the U.S., and their cumulative operating time exceeds 750,000 hours. The J will undergo a similar series of extensive verifications under commercial operating conditions.

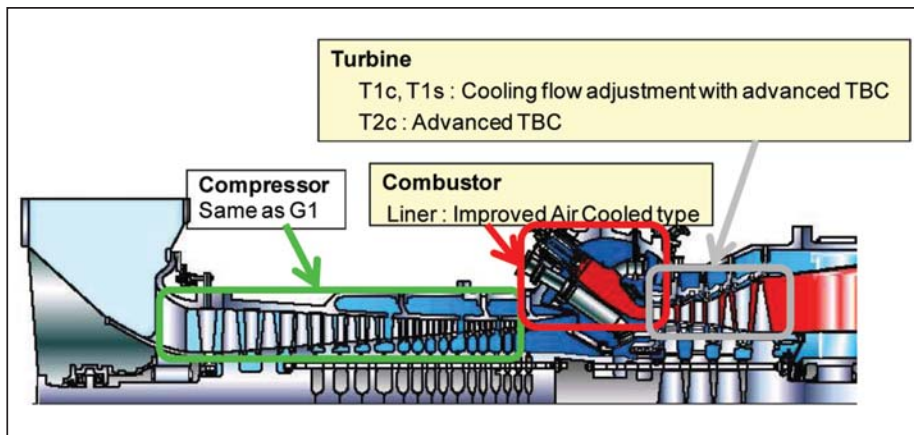
Mitsubishi estimates that its share of the global market for gas turbines in power generation is 10%. "We hope to increase that to 30% during 2012 to 2015 through the introduction of the J-series turbine," says Yoshiaki Tsukuda, MHI's Executive Vice President for power generation. Thirty percent of the global share is equivalent to annual sales

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bers indicate that the integration does not impair the reliability of the units."

Bottoming cycle issues, especially those related to steam by-pass valves, can affect the starting and shut down sequence. In the Mitsubishi models, "redundant steam supply sources are provided to maintain a steam cooling back-up source at all stages of operation," says Koenke, who adds, "Units in our fleet with close to 1,000 start cycles confirm that the integration can be designed reliably."



**Figure 4: M501 G1 to M501GAC**

over 200 MW as peakers. Other components of the combined cycle, such as the Heat Recovery Steam Generator, suffer more from cycling than the gas turbine.

SWRI's Brun says that any degradation of steam cooling flows (due to fouling of internal passages, corrosion, or erosion) can cause rapid failures at these high temperatures. But Mitsubishi points to its 60+ G fleet as a testament to its mastery of steam cooling. "We have found that the steam-cooled components that have completed their lifecycle in our fleet are in good condition, to the point that we will soon offer longer operating intervals between maintenance for them," Koeneke adds.

Brun also says that the baseload market — the target for the J — is not necessarily the strongest one right now. But Koeneke argues that it would depend on which geographical market is being considered. For instance, Japan is a signatory to Kyoto Protocol, and Japanese power generators place a high value on efficiency when evaluating alternatives to replace existing equipment.

In the U.S., the combined cycle market was originally configured as baseload, but as natural gas prices increased, these units became cyclic dispatch units to meet the daily demand cycle — as many as two starts a day and shut down over the weekend. In recent times, natural gas prices have dropped, and they currently hover below \$4/MMBtu, compared to a high of \$12/MMBtu.

The fly in the ointment has been wind power, which has not always been able to deliver capacity vs. demand. Utilities in the U.S. have used their installed assets, and this has spurred a demand for natural gas units. "But today much new capacity is 45 MW - 50 MW units that are quick-start-and-load aeroderivatives, or even large gas-fired internal combustion engines, which offer up to 45% efficiency. These machines offer better value in

operation and first cost, and can be operated unattended, so even the large combined cycle plants are being equated with the peakers," says Septimus van der Linden, Independent Consultant and President of Brulin Associates LLC.

A game changer would be the U.S. signing the Kyoto protocol or making other commitments to decreasing carbon emissions by instituting a cap-and-trade scheme or a carbon tax. The J-series is Mitsubishi's combined cycle product for a carbon-constrained future. "With a global view, MHI has made gradual inroads with their advanced technology gas turbines, and many nations are in need of gas-fired baseload capacity, including Europe where coal and nuclear plants are being phased out," says Van der Linden.

### Targeting cyclical markets

In the air-cooled G, Mitsubishi is retrofitting existing G1 technologies with the F-class air-cooled combustion system. This results in an upgraded G-class engine that retains the 1,500°C turbine inlet temperature. By using an open air cooling scheme, this upgraded machine, the 60 Hz M501GAC (Figure 4), targets highly cyclic applications with G class efficiency, while the steam-cooled counterpart will be offered for more baseload applications. "The 'GAC' retrofit is a smart move for the U.S. combined cycle market," says Van der Linden.

After R&D tests, the verification process for the M501GAC has moved to component-testing in the inhouse verification engine at Takasago, which is a commercial plant dispatching power into the local grid while testing new technologies. The final verification test prior to commercial operation is scheduled for 2009.

The combustor in the GAC is a modification of Mitsubishi's Ultra Low NOx (ULN) system in which steam cooling

limits emissions below 15 ppm at 1,500°C. Consistent with the precursor F class gas turbine, the ULN combustion system consists of one pilot nozzle for the diffusion flame at the center of the fuel nozzle and the eight main nozzles surrounding the pilot nozzle for pre-mixed flame.

The F and G gas turbine use a fin cooling structure for the combustor wall, however the transition piece cooling is different between these two models. In the case of the G gas turbine, steam extracted from the bottoming cycle is applied in a closed-loop circuit for cooling of the combustor liners, whereas the F gas turbine uses compressor discharge air.

Similar to the F design, the air-cooled combustor for the M501GAC uses compressor discharge air for combustor cooling and does not require any external cooling air source. The key technologies applied for the combustor are:

- Cooling air management to produce a more uniform flame temperature profile while maintaining the turbine inlet temperature
- Reduction of the peak flame temperature to decrease NOx emissions

These technologies have been verified and applied in the latest steam-cooled G combustor. The cooling air is induced into the combustor, which reduces the combustion gas temperature. As a result, higher flame temperatures are needed to achieve the same turbine inlet temperature, which may result in higher NOx emissions. Therefore, the cooling air for the combustor should be minimized while maintaining the durability of the components. These counteracting requirements are the main challenge to introducing the air-cooled combustor in the 1,500°C class gas turbines. To minimize the impact of air cooling on NOx emissions, the following technologies are used:

- Improved TBC application
- Leakage air reduction
- Improved cooling technology

The air-cooled combustor for the M501GAC has been tested in a high-pressure combustion rig in Takasago. Tests have shown that the new combustor is capable of maintaining NOx emissions below 15 ppm. Durability of the new TBC coating applied on the turbine parts for better performance was also tested. The M501GAC is expected to deliver a power output of 404 MW in a 1 X 1 combined cycle configuration, which introduces a 1.3% relative improvement to the current M501G1, while maintaining 15 ppm NOx. ■