Prospects for lower cost and more efficient IGCC power

By Junior Isles

MHI believes that the cost of electricity for IGCC plants with high-efficiency gas turbines and air-blown gasification could be almost 20% lower than for conventional coal-fired steam plants and more than justify their relatively higher capital cost.

Mitsubishi Heavy Industries (MHI) is leveraging engineering and operating experience acquired through more than 16,000 hours of in-service testing on the 250MW Nakoso demonstration plant in Japan for commercial IGCC projects.

With demonstration plant testing due to end in March 2013, MHI has been working on front end engineering studies for increasingly more efficient IGCC plants designed around 1500°C G-type and 1600°C J-type gas turbines. Representative design output and efficiency (LHV) levels:

☐ **Demo**. Nakoso air-blown IGCC plant powered by a 50 Hz 1,200°C D-class gas turbine is rated at 250MW and 42% efficiency.

☐ **G-type**. Around 450MW net plant output and 48% efficiency for a 60 Hz single-shaft M501G gas turbine plant design.

☐ **J-type**. Around 580MW for a 60 Hz single-shaft M501J plant and 780MW for a 50 Hz M701J plant, both at 50% efficiency.

There is a general belief that IGCC power generation is overly expensive. That is not the case, says Ichiro Fukue, Executive Corporate Advisor, MHI. "We have operated IGCCs in Japan for five years and been working to reduce costs. Initial costs are very attractive now and some big Japanese utilities are seriously considering commercial plants whose operating date is expected in 2019."

According to Fukue, capital investment and generating costs of IGCC plants can be competitive in cost with traditional coal fired plants. "Our commercial plants are less than 1.2 times the cost of a conventional coal plant and cost of electricity is cheaper."

Advancing to J-type technology

Current IGCC designs operate at gas turbine inlet temperatures of up to 1500°C. MHI believes there is scope to improve efficiency and reduce IGCC plant costs further with the application of new gas turbines.

The next step is to build plants that incorporate advanced gas turbines with even higher turbine inlet temperatures such as MHI's 1600°C J-gas turbine and next generation 1700°C-class machines.

The M501J gas turbine has been designed with a turbine inlet temperature of 1600°C by integrating the proven component technologies used in the 1400°C F-series and 1500°C G and H-series turbines.

Design and performance

The compressor is designed as an

Nakoso demo plant design targets and performance

The plant achieved an 84% availability factor between February 2011 and January 2012, MHI reports. Focus over the past year has been to increase operational flexibility while reducing maintenance and operating costs.

Performance	Design Targets	Achieved
Net plant power output	250 MW	250 MW
Net efficiency (LHV)	> 42.0%	42.9%
Carbon conversion	> 99.9%	> 99.9%
Emissions		
SOx	< 8 ppm	1.0 ppm
NOx	< 5 ppm	3.4 ppm
Dust	< 4 mg/m^{3}N	< 0.1 mg/m^{3}N
Operational Flexibility		
Start-up time	< 18 hr	15 hr
Minimum load	50.0%	36.0%
Ramp rate	3% per minute	3% per minute
Reliability		
Long term continuous operation	2,000 hr	2,238 hr
Long term reliability run	5,000 hr	5,013 hr

Source: MHI Update of Air-Blown IGCC & Gasification, December 2012 axial flow type with a pressure ratio of 23 to 1 based on the technology used in the H-series compressor, which has a pressure ratio of 25 to 1.

Advanced three-dimensional (3D) design techniques were used to improve performance and reduce shock-wave loss in the initial stages and frictional loss in the intermediate and final stages.

In addition, bleeding is used in the low-, middle-, and high-pressure stages during compressor start-up. Rotating stall on start-up has been suppressed and part-load performance for combined cycle operation improved by controlling the inlet guide vane (IGV) and three-stage variable stator vanes.

The M501J combustor is based on the proven steam cooling system used in G-series gas turbines. However, the turbine inlet temperature has been increased from 1500°C in the G-series to 1600°C and nitrogen oxide (NOx) emissions are limited to 25 ppm.

This is accomplished through the use of low-NOx technologies, such as reducing the local flame temperature in the combustion area by improving the combustion nozzle for more homogeneous mixing of fuel and air.

Turbine cooling

The M501J turbine section is an axial-flow, four-stage, high-load, high-performance turbine. Row-1 to row-4 rotating blades are air cooled.

Unlike row-4 blades in the G-series turbine, which are not cooled, those in the J-series turbine are cooled to cope with the higher inlet temperature. Row 1-3 stationary vanes are also air-cooled.

As with the F- and G-series gas turbines MGA1400 alloy (Mitsubishi gas turbine alloy) is used for the rotating blades, while the vanes are made of MGA2400 alloy. Row 1-3 blades are made of a directional solidified superalloy.

The cooling structure was improved for the F-series and again for the G-series turbine. In addition, the J-series uses high-performance film cooling and advanced thermal barrier coating (TBC) developed in the national project, aimed at developing a 1700°C machine.

Test program

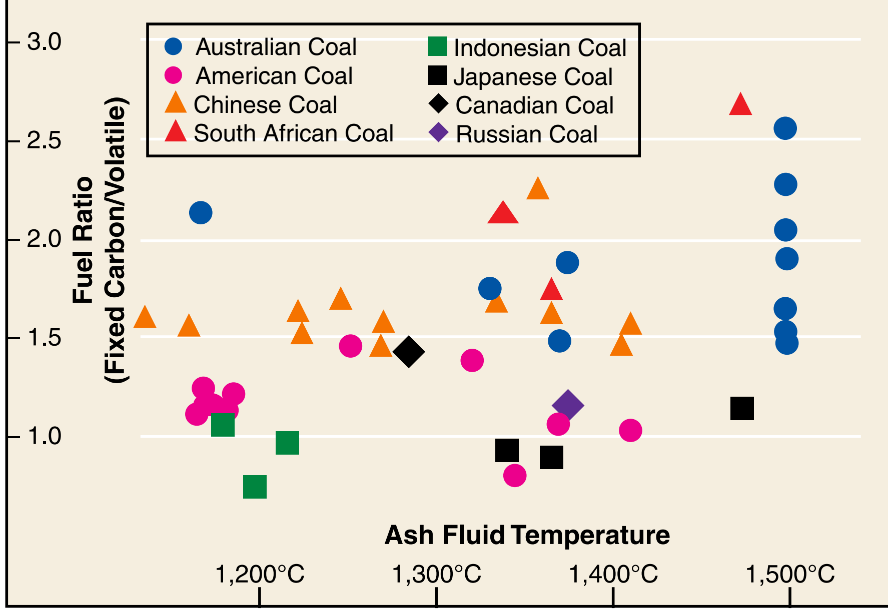
The new J engine design started in October 2010 and was based on the successful G frame. Operating tests of the first M501J gas turbine started in February 2011 at Machinery Works T-Point demonstration combined cycle power plant in Takasago.

The tests proceeded as scheduled with the first spin-up on February 2nd and first ignition on February 7th. The inlet temperature reached 1600°C on the seventh start-up. This first M501J gas turbine has now completed all phases of its trial operation.

The first commercial version of the M501J gas turbine, which was shipped to Kansai Electric Power

Nakoso IGCC demo plant coal experience

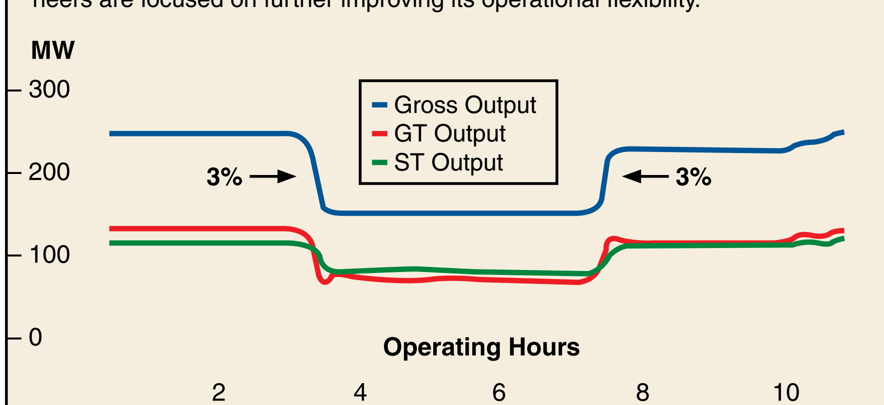
Over the last four years the Nakoso plant gasification system has been operationally evaluated on a wide variety of different bituminous and sub-bituminous coal feedstock from around the world.



Source: MHI Update of Air-Blown IGCC & Gasification, December 2012

Nakoso demo plant ramp rate

While the 250MW Nakoso demo plant is capable of a 3 percent per minute load change, comparable to that of pulverized coal fired steam plants, project engineers are focused on further improving its operational flexibility.



Company's Himeji No. 2 power station, began commissioning in October 2012. It should be ready to start full commercial operation before mid-2013.

This is the first of six M501J combined cycle plants being installed at the Himeji power station. In combined cycle mode, the plant is ISO rated at 470MW gross base load output and 61.5% or higher LHV efficiency.

Next generation

Some of the technology used for the J-class turbine was derived from Japan's national program that started back in 2004 to develop the technology base for a 1700°C-class gas turbine.

The program began with basic laboratory testing. Now, module tests simulating conditions that are closer to actual operations are progressing, incorporating newly developed technologies in several key areas of engineering design application.

One is a combustor with exhaust gas recirculation (EGR) in order to keep NOx levels to a minimum at the higher firing temperature.

Combustion tests conducted on a 1,700°C-class combustor design under development have demonstrated the effective application of this new recirculation technology in suppressing NOx emissions.

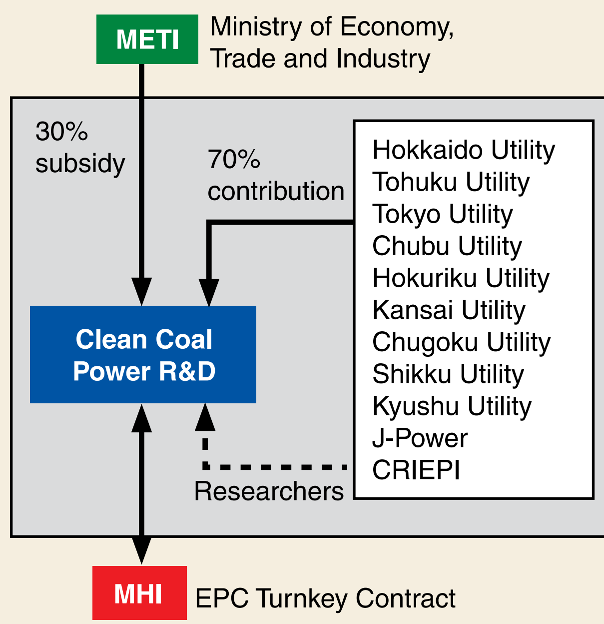
Both CO and NOx emissions were measured while the oxygen concentration at the combustion outlet was changed. Test results showed that a CO concentration under 10 ppm and a NOx concentration under 25 ppm could be realized with stable combustor operations.

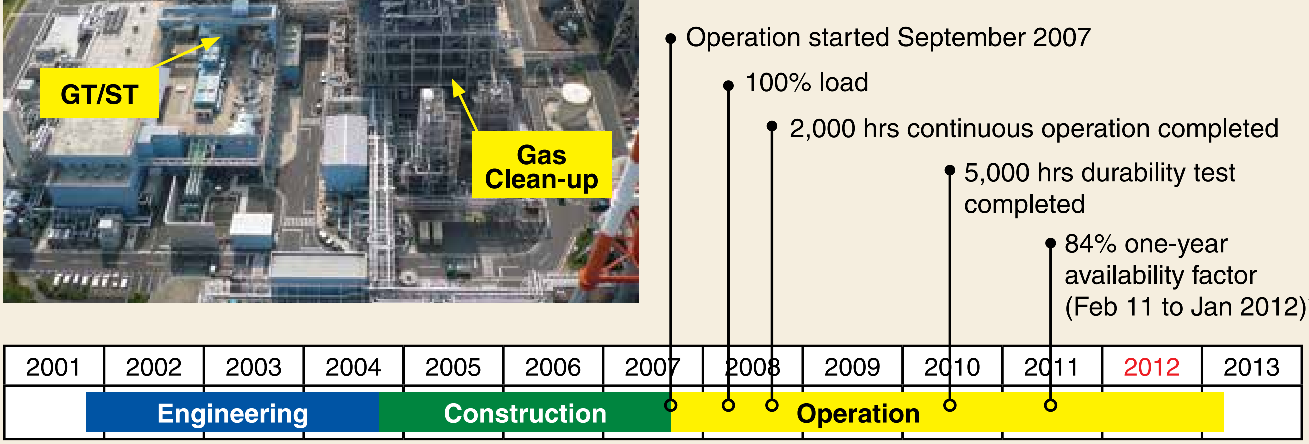
Turbine blade cooling

Turbine cooling is another critical area of technology. Blades and vanes of an ultra high-temperature gas turbine subjected to extreme thermal loads and stresses must be cooled.

250MW IGCC demonstration project (Nakoso) sponsors

Japan's METI, nine electric utilities, J-Power, Central Research Institute of Electric Power Industry (CRIEPI) and Mitsubishi collaborated in development and test of the Nakoso IGCC demo plant through Clean Coal Power R&D which they founded in June 2001 to run the project. MHI supplied the gasifier, syngas cleanup system, gas turbine, steam turbine and HRSG under an EPC turnkey contract for the entire IGCC plant.





Source: MHI Update of Air-Blown IGCC & Gasification, December 2012

*4-month Tsunami shutdown March 2011 to July 2011 not included in availability calculation.

To ensure operational reliability without sacrificing cycle performance, high cooling efficiency must be achieved by using the minimum amount of cooling air.

Furthermore, any hot spots caused by inadequate distribution of the film-cooling air on the surface of the turbine blade may develop into serious faults.

In addition to advanced blade cooling, MHI also says advanced nickel-based single crystal super alloys with advanced thermal barrier coatings will be necessary.

The 1700°C-class turbine is expected to have a compressor ratio of around 25:1. In a combined cycle, MHI says this will help deliver an electrical efficiency in the region of 62-65%.

When used in an IGCC plant, according to MHI, the gross power efficiency (LHV) will be greater than 55%. Corresponding net efficiency will exceed 50%.

Future development

MHI believes that IGCC power generation will play the most important role in coal-fired power generation in the 21st century due to the growing importance of coal resources and their utilization.

The reliability and high efficiency of MHI's air-blown IGCC have been demonstrated through successful long-term continuous operation at the Nakoso demonstration plant.

Now, more sophisticated high-efficiency, high-reliability air-blown IGCC commercial plants are in the development pipeline and ready for realization.

With costs already competitive with coal fired plants, according to MHI, further development of high temperature gas turbines could see IGCC playing a much greater role not only in Japan but in many other parts of the world. ■

Commercial prospects for Nakoso IGCC demo plant

The IGCC demonstration project at Nakoso has been running very successfully for more than 4 years now, providing valuable engineering and operating experience for the design development of commercial plants.

Nakoso began test operation in September 2007, first reached its rated base load output of 250 MW in March 2008. By September of that same year the plant completed more than 2,000 hours of continuous operation.

In early March 2011, the Nakoso facility was flooded and suffered a 4-months long forced outage as a result of the Tsunami, which damaged support facilities and auxiliary systems but not the main core of the IGCC system. The plant was restored to full service generating power to the grid by the end of July 2011.

To date, the demonstration plant has accumulated over 16,000 hours of operation including an endurance run of more than 5,000 continuous hours on low grade coal between 2010 and 2011.

During this summer's electricity shortage, the Nakoso plant was called on continuously with a high level of reliability to generate at full load output for long periods of time.

Final demonstration testing is to be completed by the end of March 2013 after which the Nakoso facility will be taken over by the Joban Joint Power Company Ltd (JJP) and continue operation as a commercial IGCC plant.

Joban Joint Power is intimately familiar with the Nakoso plant because it has been providing support services and personnel for IGCC operation of the demo plant since the start of its development.

It is expected that the company will continue to improve IGCC reliability and operating economies during commercial service and share that knowledge with the original demo plant project participants.

J-series gas turbine performance

Greater than 60% combined cycle efficiency for the J-series is made possible by 1,600°C turbine inlet temperature and 23:1 pressure ratio. Half the 100°C increase in TIT over the G-series has been offset by high-performance cooling technology and half by an advanced thermal barrier coating.

Design Parameter	M501J	M701J	M501G	M701G
Gross gas turbine output	327 MW	470 MW	267 MW	334 MW
Gross combine cycle	470 MW	680 MW	399 MW	498 MW
Comb cycle efficiency (LHV)	61.5% or more	61.7% or more	58.4%	59.3%
Turbine inlet temperature	1,600°C	1,600°C	1,500°C	1,500°C
Frequency	60 Hz	50 Hz	60 Hz	50 Hz
Pressure ratio	23 to 1	23 to 1	20 to 1	20 to 1

Source: Mitsubishi J-Series presentation, PowerGen Europe June 2012 and 2012 GTW Handbook design ratings