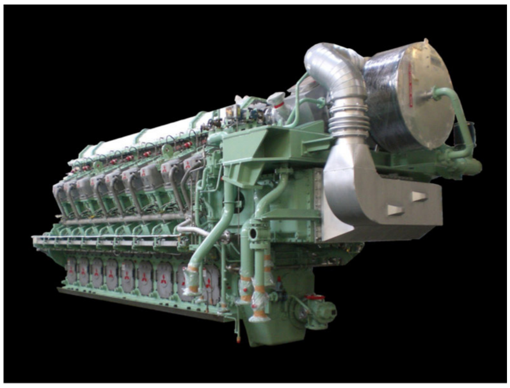
Technologies to Improve Efficiency, Utilize Exhaust Heat of KU30GSI Gas Engine for Distributed Generation System



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An increase in the number of power generation facilities with gas engines is expected with the development of shale gas, as well as the utilization of gas pipe lines in addition to the expanding need for the effective operation of power generation facilities such as the distributed generation system and smart grid. Mitsubishi Heavy Industries, Ltd. (MHI) covers a wide power range of lean-burn gas engines, from the high-speed GSR model to the mid-speed KU30GSI model.

This report will mainly describe the efficiency improving technology of the KU30GSI-PLUS engine, which has achieved a generation efficiency of 48.8%, placing it at the top level in the world among the engines in the same class. Technological development to utilize this energy in a co-generation system, as well as the application technology, will also be introduced.

1. Introduction

Natural gas resources are attracting attention as a main fuel in the future against a background of reducing environmental impact, as is shale gas development. In addition, the revolving momentum of electricity policies in many countries, and enhanced interest in distributed power generation, which is effective against natural disasters, will increase the importance of the effective utilization of energy (the so-called “smart energy network.”) Gas engines, which can use various gas fuels including natural gas, have the features of good startability, load following capability and flexible applicability of waste heat. They are also used in various applications including Combined Heat and Power Plant (CHP), and are considered as an optimal selection to provide an efficient energy solution in consideration of the social background noted above.

MHI has prepared a lineup of gas engines, a high-speed GSR model covering 305 to 1500 kW and a mid-speed KU30GSI model covering 3750 to 5750 kW, which are applicable to small-scale distributed power generation, co-generation in facilities or plants and dedicated utility power generation. These gas engines enjoy a high reputation and expanding orders in the marketplace for their high performance and reliability.

This report will introduce the efficiency improvement technologies at MHI, in particular the latest technologies of the KU30GSI-PLUS engine with its power generation efficiency of 48.8%, as well as gas engine applications including waste heat utilization.

2. Gas engine lineup

We started selling the KU30G and GSR model pre-chamber lean burn gas engines with spark ignition at the beginning of the 1990s. Since then, we have explored the improvement of efficiency and output. In 2000, the micro pilot ignition system was adopted, and the high-efficiency and

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high-output KU30GA model gas engine entered the market, attaining a large domestic market share. The latest four stroke-cycle KU30GSI and GSR engines are high-efficiency, lean-burn spark-ignition engines with pre-combustion chambers.

The KU30GSI gas engine has a high power generating efficiency, and with the increase of the exhaust temperature, a high total efficiency is achieved, making it appropriate for applications such as exhaust heat regeneration and Combined Heat and Power (CHP) generation. The KU30GSI engines, which have a maximum output of 5750kW, are also used in applications for the utility and independent power generating businesses, in addition to CHP use. To meet these needs, a new model of the KU30GSI-PLUS engine, which has achieved the world's top level of generation efficiency at 48.8%, was added to the lineup. The KU30GSI engine shares many parts with other KU series models including diesel engines, and has approximately 80% of its parts in common with the KU30GA engine, which realized a high reliability through its extensive track record of more than ten years.

The GSR gas engine is a high-speed gas engine that achieves high reliability and part supply efficiency by utilizing common parts with the SR diesel engines, the same as the KU30GSI development method. The lineup of GSR gas engines includes engines with radiator cooling specifications to cope with the increasing demand for Business Continuity Planning (BCP) after the Great East Japan Earthquake, in addition to those with cooling tower specifications aiming for the high power generating efficiency ordinarily required in Japan. Both specifications have the function of Black Out Start (BOS: Immediate starting in case of blackout), and applicable to the anti-disaster and security preservation operations. The "MEGANINJA® (Mitsubishi Energy Gas Package NINJA Series)" containerized generator set has also been added to the lineup. The concept of the series is "rapid transportation, rapid installation and rapid generation" through the adoption of a portable radiator, compared to conventional generator sets which require the installation of the engine, generator and auxiliary equipment independently, in addition to the piping and wiring work. A conventional generator set needs at least 30 days from installation to the start of electric transmission. MEGANINJA can easily start power transmission and supply the demand in a short period of time in areas without sufficient grid infrastructure, even overseas.

In these multiple engine applications combining KU30GSI and GSR engines, effective power generation corresponding to demand is possible, and power generation plants that can start supplying power in the absence of a power supply grid can be realized. **Figure 1** shows the MHI gas engine, and **Table 1** shows the main specifications.

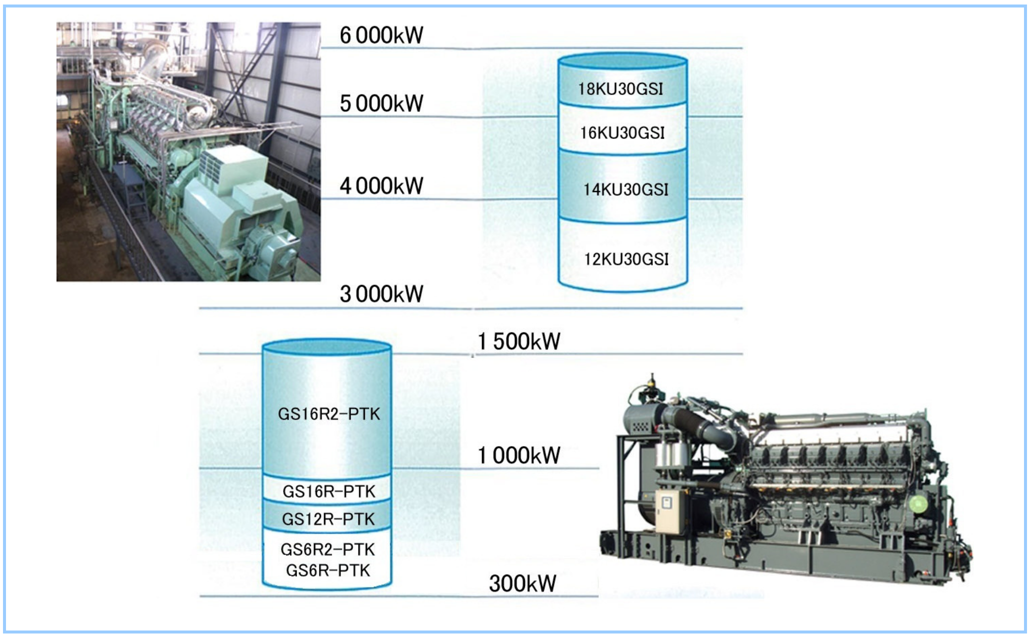

Figure 1 MHI Gas Engine

Table 1 Main specifications

Model		GSR	GSR2	KU30GSI	KU30GSI -PLUS
Number of cylinders		6 - 16		12 - 18	
Bore/Stroke	mm	170×180	170×220	300×380	
Engine speed	min^{-1}	1000-1800	1000-1500	720/750	
Generator output*	kW	305 - 1015	380 - 1500	3650 - 5750	
Generation efficiency*	%	41.0 - 43.4		46.5	48.8
NO_X (O_2=0%)	ppm	< 320		< 320	
Engine weight	t	2.2 - 8.1		40 - 60	

*Using a standard gas complying with ISO3046 and MHI recommendations

3. Power generation technology of high-efficiency gas engines

The utilization of the Miller cycle has been the general trend to improve efficiency in recent years. Higher combustion and supercharging pressures are required for more effective utilization of the Miller cycle. In other words, sufficient margin to knocking and the retention of a high supercharging efficiency at high pressure ratio are technical problems.

In the KU30GSI-PLUS engine, the technical target was stable and rapid combustion to ensure sufficient margin to knocking, and the design concept was the elimination of late flame transfer and uneven fuel/air mixture in the combustion chamber. The City Gas 13A used in Japan has a methane number of 65, which is lower than that of natural gas. Consideration to ensure the knocking margin is important to increase the efficiency.

To increase the Miller cycle effect, a greater amount of air corresponding to the effect is required. In addition, a high supercharging pressure, while retaining a high supercharging efficiency, must be attained. The MHI MET-MB model turbocharger developed for high supercharging pressure and efficiency was installed on the KU30GSI-PLUS engine to realize high power generation efficiency.

Moreover, considering the reduction of unburnt gas in the exhaust, the thorough reduction of dead volumes in the combustion chambers including the pre-combustion chamber and piston, the optimization of pre-combustion chamber jet diameter and angle and the piston shape improvement drastically reduced the Total Hydro Carbon (THC) emissions.

3.1 Sufficient margin to knocking and improvement of combustion stability

Generally, a high output and high efficiency gas engine with a pre-combustion chamber is operated within a very narrow air fuel ratio squeezed between the knocking and misfiring region. Therefore, the cycle to cycle fluctuation of mixture formation in both the main and pre-chamber can lead to a larger combustion fluctuation. In many cases, such combustion fluctuation is controlled by an anti-knocking governor, etc. In the development of the KU30GSI-PLUS, we sought a technical solution by stabilizing the combustion while not relying on the avoidance control.

We have optimized the combustion chamber shapes including that of the pre-chamber, and were able to obtain combustion stability and high efficiency. **Figure 2** shows a comparison of Cov-Pmax, which indicates combustion pressure fluctuation, before and after the improvement. Cov-Pmax decreased significantly by approximately 40%, and stable operation with a higher efficiency was realized, even when City Gas 13A was used as a fuel. The optimization reduced the fluctuation among cylinders, and resulted in a very uniform and stabilized combustion throughout the entire engine.

As a result of the above, a sufficient knocking margin is ensured by reducing the fluctuations among cylinders and stroke cycles, even under the higher combustion pressure conditions associated with the strong Miller concept, thereby attaining higher power generation efficiency.

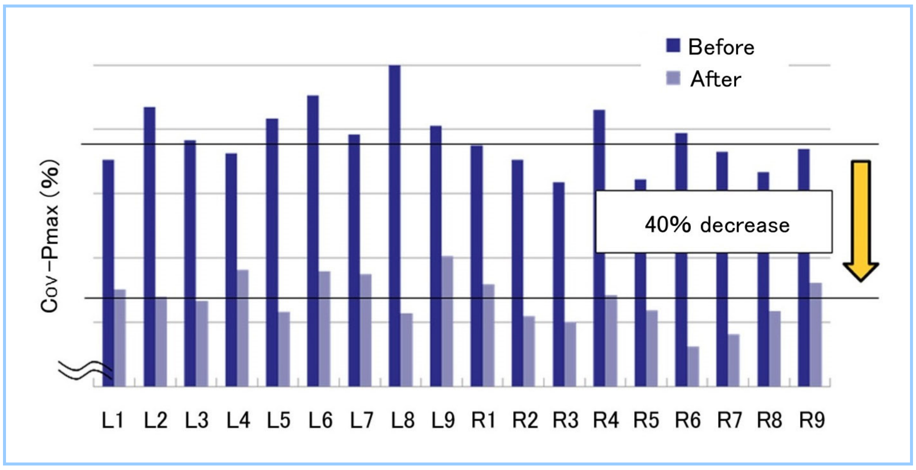

Figure 2 Cov-Pmax comparison before and after improvement

3.2 Reduction of dead volume

A reduction in dead volume is a common technique in the gas engine designing field. In particular, the air fuel mixture propagated into the narrow space and clevis in the combustion chamber and the unburned mixture in the later phase of combustion will not only result in degradation, but will also trigger abnormal combustion such as knocking. Dead volume reduction has been considered in the KU30GSI engine, such as eliminating the starting valve passage and reducing the clearance between the liner and cylinder head. In the case of the KU30GSI-PLUS engine, we concentrated on further reduction of the dead volumes, such as the clevises around the pre-chamber and the topland of piston crown, and the clevises around the intake and exhaust valves. (**Figure 3**) As a result, the total dead volume was reduced by 27%, and a 23% reduction of unburned fuel emissions was achieved.

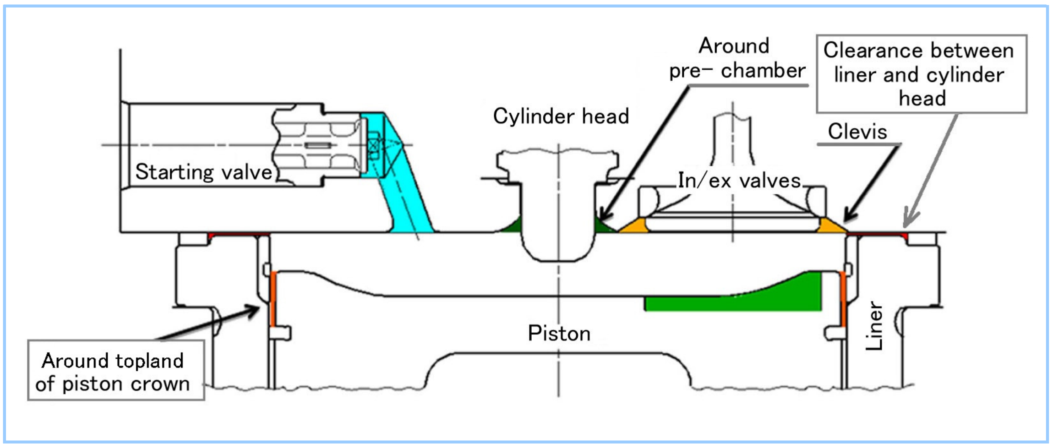

Figure 3 Dead volume

3.3 Adoption of turbocharger with high pressure ratio

The MHI MET42MB turbocharger, which is optimized for the Miller cycle and can sustain high turbocharger efficiency in a high pressure ratio zone, is employed for the KU30GSI-PLUS engine. The MET42MB turbocharger has optimized its impeller and turbine peak efficiencies, while maintaining reliability in the high-speed rotating range, and the sustainment of high turbocharger efficiency at a high pressure ratio is achieved. Turbocharger efficiency equivalent to the MHI MET42MA, which was used on the conventional KU30GSI engine, is ensured in the higher pressure ratio range of 4.0 to 4.5, and higher efficiency with a strong Miller cycle is realized. **Figure 4** shows a comparison of turbocharger efficiency.

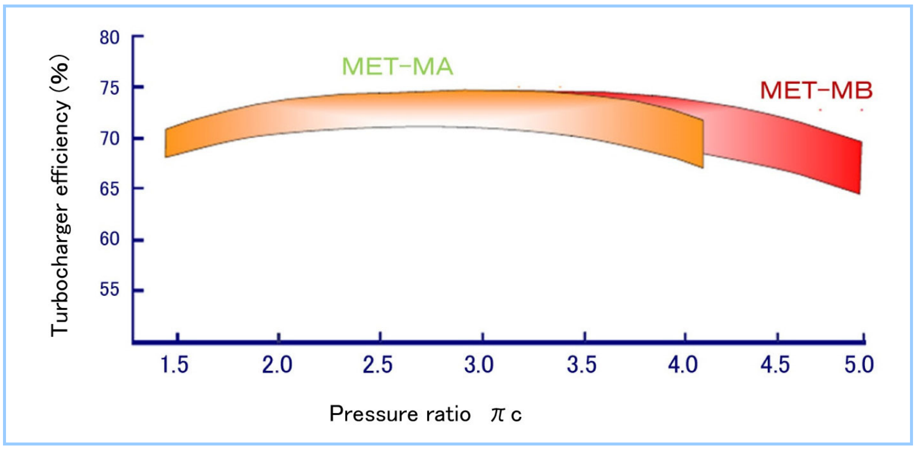

Figure 4　Turbocharger efficiency

4. Waste heat utilization technology of gas engines energy

We have developed gas engine technologies applicable to the improvement of the efficiency of waste heat recovery, not only gas engines, but also auxiliary equipment, for the effective utilization of energy.

4.1 Effective utilization of engine cooling water energy

In a gas co-generation system, total efficiency exceeding 80% is possible considering waste heat recovery from steam, hot water and cooling water. In some cases, however, the recovered hot water energy cannot be effectively used, such as in a self-generating plant for a factory, because the recovered temperature level of the hot water is too low. From the perspective of this kind of need, suggestions on how to enhance the utilization of hot water from the viewpoint of the effective utilization of energy is one task for the future.

Technical development to utilize the energy of engine cooling water is under way aiming to expand the effective utilization with the KU30GSI-PLUS engine. In this development, the cooling water temperature at the engine outlet is raised to 110 - 115ºC, in order to generate steam under at atmospheric pressure. Combustion testing was completed with a single-cylinder test engine, and verification testing using a multi-cylinder engine began from 2013. The combustion tests and the engine reliability study have already been completed, and durability testing of the engine and auxiliary equipment are now under way. We plan to finish the study at the end of 2013, and to launch the product.

If the aforementioned cooling water temperature can be achieved, and the flash steam at atmospheric pressure is pressurized with a steam compressor by adding steam from the exhaust gas boiler, an increase in energy of more than 10 %pt (pcp) is expected as the amount of steam recovery, including the loss power required by the equipment. (**Figure 5**)

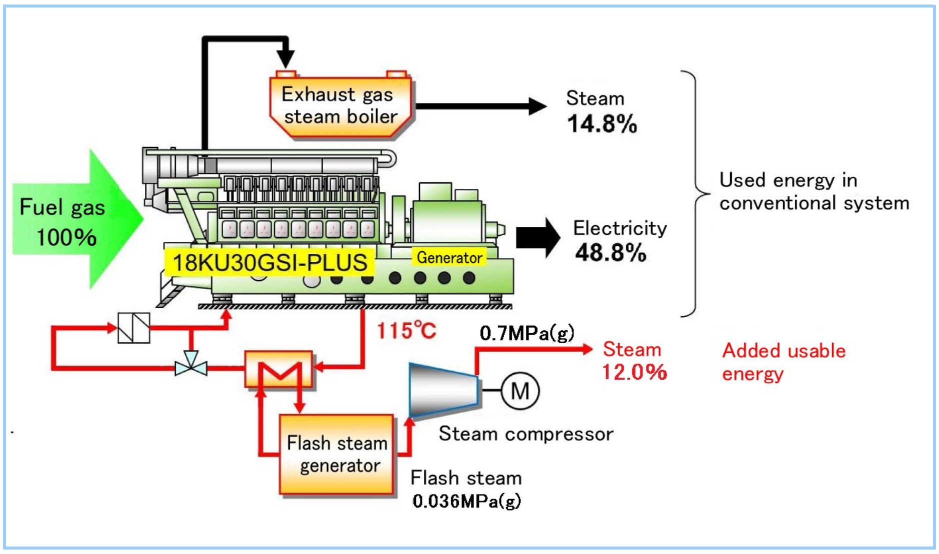

Figure 5　Effective use of engine cooling water energy

4.2 Application examples of various waste heat recovery implementations

As mentioned above, efforts for the more effective use of high temperature cooling water have progressed. In addition, there are some application examples where cooling water at existing temperature levels has been effectively used.

Figure 6 shows an example of a gas engine plant, where an 18KU30GSI engine using natural gas fuel has been installed and chilled water of 5.6°C is generated with a multi-energy absorption chiller. This plant was constructed at a university in the United States, and has been in operation since 2012. The generator end electricity of 5500kW, and chilled water corresponding to approximately 3500kW supplied from this plant, greatly contribute to the energy savings of the university, especially during the summer.

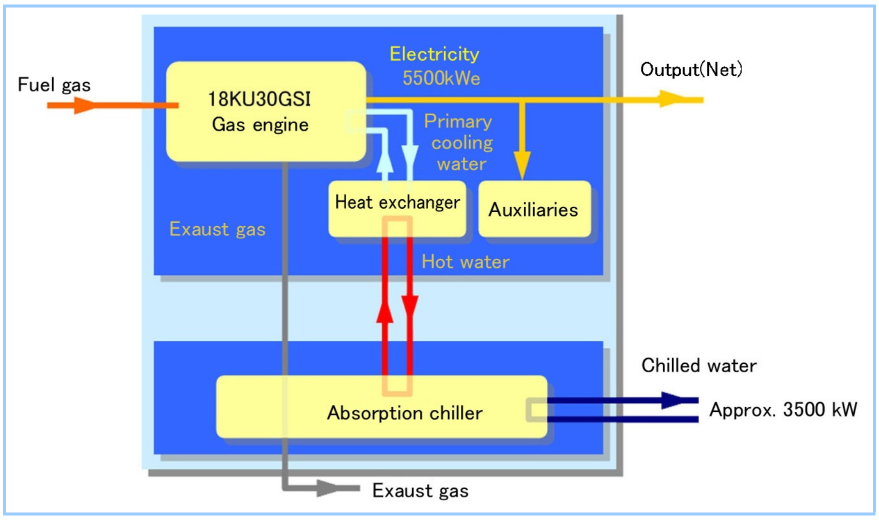

Figure 6 Example of exhaust heat use (KU30GSI)

An example of the combination of the exhaust heat recovery application and BCP mentioned above is shown in **figure 7**. This plant has a GS16R engine generator installed, as well as a gas supply facility of Liquefied Propane Gas (LPG), in preparation for a disruption in the daily supply of city gas supply in a disaster. This plant also features a system to utilize waste heat. The waste heat is used in various ways as steam utilization from an exhaust gas boiler, as air conditioning with an absorption chiller and as a room heater and hot water supply using high temperature cooling water through a heat exchanger.

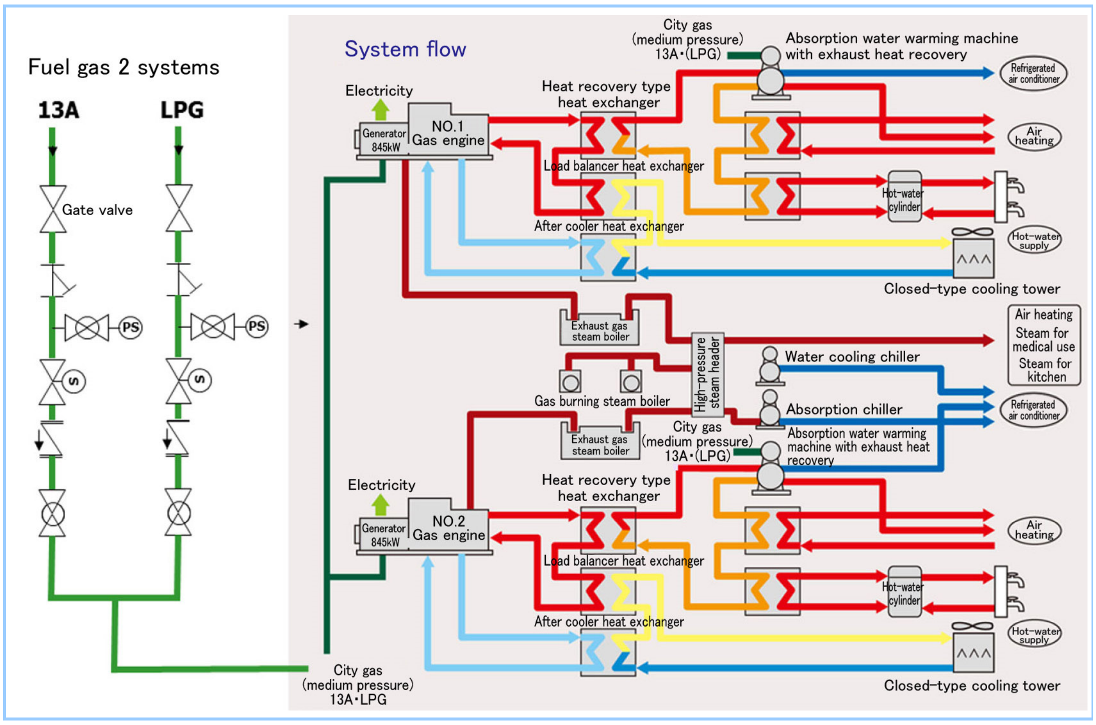

Figure 7 Example of exhaust heat recovery (GS16R)

These are just some examples, and MHI gas engines have been developed not only for high power generation efficiency, but also for flexible application in order to realize high total heat efficiency.

5. Conclusion

Our company has prepared a lineup consisting of the high-speed GSR and mid-speed K30GSI gas engines, and is able to meet the demand of a wide range of flexible applications. The latest KU30GSI-PLUS engine has a high load-following capability such as a starting time of 7 minutes or less, as well as favorable environmental performance. The engine realizes a good power generation efficiency of 48.8%, even using the City Gas 13A (methane number 65) fuel unique to Japan. The engine will contribute to the cost reduction of power generation while LNG is attracting global attention as a fuel in the future, and will also help to facilitate the reduction of environmental load and the effective use of energy resources.

From the start of development work, MHI gas engines have been developed to meet the needs of society and our customers. We will continue the development of useful technologies, and provide various solutions.

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