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New 1000 kW Gas Combined Heat and Power System Employing Cost Effective Technologies

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1. Abstract

Following the enormously devastating earthquake that hit the Tohoku region of north-eastern Japan in March 2011, there have been considerable changes about our attitudes and views on energy systems in Japan. Some of the major changes include raising pertinent questions about the long-term prospects for the configuration of the primary energy sources and how to provide energy in a more sustainable and efficient way.

In light of these questions, gas combined heat and power (CHP) systems have attracted attention as one of the solutions in preventing electricity shortages during power outages, and as effective energy-saving systems. However, the CHP share of total national power production is still only 3.5%, so there is further potential to expand the use of these systems.

With these circumstances in mind, the GS16R2 engine, a new 1000 kW gas CHP system with a 1000 rpm at 50 Hz capability, was launched on November 1, 2013. The engine was jointly developed by Tokyo Gas Co. Ltd and Mitsubishi Heavy Industries Ltd (MHI). The companies adopted the unique concept of lowering the engine's speed while increasing its output and efficiency. The following techniques have been shown to improve both electrical power output and total efficiency, while also reducing maintenance costs. This has considerably reduced the overall running costs of the system.

- **Longer maintenance intervals and lower maintenance costs**
  The intervals between maintenance periods for the new engine have been extended due to the friction wear of components being reduced by lowering the operating speed from 1500 to 1000 rpm. This low-friction technique makes it possible to reduce the engine maintenance frequency and costs by approximately 30%.
- **Increases in electrical efficiency and total efficiency**
  The upgraded engine control technologies and the high-efficiency turbocharger help the system achieve an electric power efficiency of 42.3%, which is the highest in the 1000 kW engine range. In addition, the total efficiency is further enhanced to 78.5% by using a two-stage intercooler system that recovers waste heat from the compressed fuel-air mixture.
- **Higher power output**
  To compensate for the lower engine speed, which usually reduces the power output, a longer piston stroke is used in order to increase the power generation capability. In addition, a high efficiency turbocharger increases the amount of compressed fuel-air mixture that enters the combustion chambers.
- **Ease of installation**
  The overall width of the system package is reduced by 500 mm (from 3000 mm to 2500 mm) to meet more customer requirements under varying installation conditions.

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2. Background

Combined heat and power (CHP), also known as cogeneration, is a system for the simultaneous production of electricity, and useful heat via steam and hot water. Therefore, it is generally much more energy-efficient than the separate generation of electricity and useful heat. CHP systems are mainly fuelled by oil or natural gas; they provide on-site electric power in either stand-alone units or connections to national grid. The by-product of useful heat energy, as well as providing steam and hot water, can be utilized in air-conditioning systems.

Given these features of CHP systems, we can utilize the waste heat energy effectively in areas where energy demand is high. CHP systems also help to save energy efficiently. Because CHP plays a role as a distributed energy system, it enables power peak cut operations to be carried out, and provides electric power to specific areas quickly when there is a blackout.

Natural gas offers a number of environmental benefits over other sources of energy, particularly other fossil fuels, such as oil and coal, because the exhaust volume of CO_2 and NO_x for natural gas is less than that for other fossil fuels. Also gas combustion emits very little sulfur oxides. Although the current world reserves-to-production ratio for natural gas is about 60 to 70 years, unconventional resources, such as shale gas and coal bed methane (CBM), are expected to increase the reserves-to-production ratio of natural gas to about 250 years; that is, if the current usage rate of natural gas remains constant [1]. This ratio is far higher than that for the other fossil fuels, so natural gas has the potential for being a sustainable energy source.

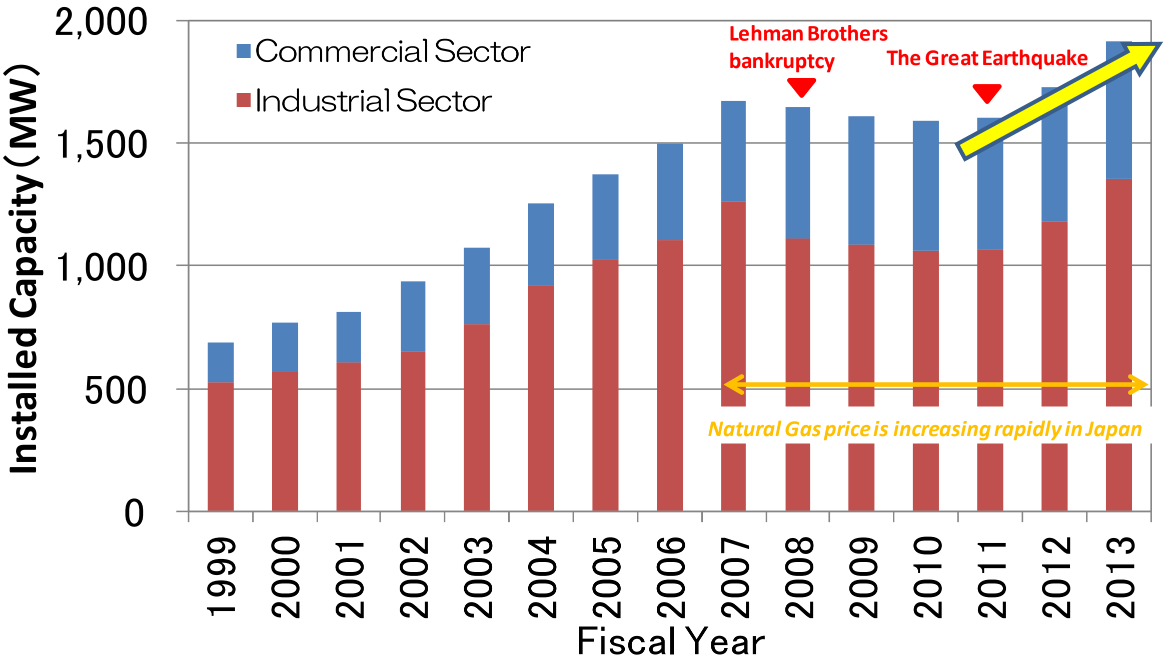


Figure 1: Installed capacity of natural gas CHP in Tokyo Gas Co. Ltd distribution area

Figure 1 shows the installed capacity of natural gas CHP in the Tokyo Gas Co. Ltd distribution area. In addition to the fuel price increases, the financial crisis triggered by the Lehman Brothers bankruptcy forced investors to turn to more conservative investments, and consequently, the installed capacity of CHP was reduced. However, following the devastating earthquake of March 2011, CHP has drawn attention as one of the solutions in preventing electricity shortages during power outages and as effective energy-saving systems. Under these circumstances, the installed capacity of CHP in the company's distribution area increased dramatically in 2013 to 1890 MW. The company expects that customer demand for CHP will increase further due to the need for energy security schemes and effective energy-saving systems.

Figure 2 illustrates the CHP share of total national power production. Even though CHPs are currently being installed in hospitals, hotels, factories, office buildings and district heating and cooling systems where thermal energy demand is higher, the CHP share of the total national power production is still only 3.5%. Thus, there is further potential to expand the use of CHP systems.

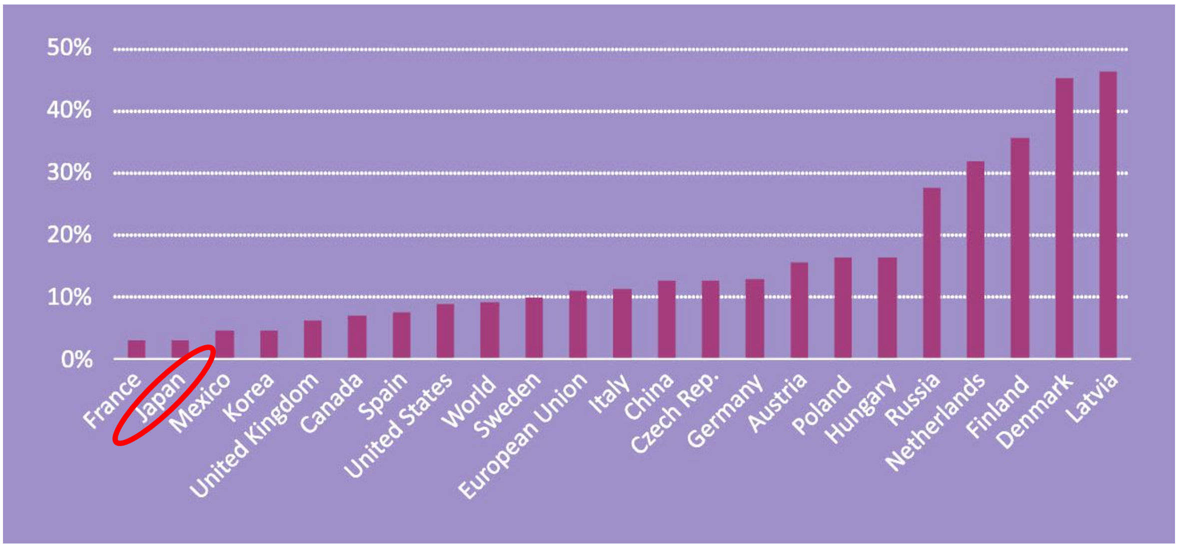


Figure 2: CHP share of the total national power production for each country [2]

Figure 3: Tokyo Gas Co. Ltd plan for installed capacity CHP, "Challenge 2020 Vision"

Figure 3 shows Tokyo Gas Co. Ltd plan for the projected installed capacity of natural gas CHP by the year 2020. This is called the "Challenge 2020 Vision". In this vision, CHP total capacity in the company's area is set to rise from its present base level of 1800 MW to a total of 4000 MW by 2020.

In addition, as renewable energy sources are to be employed rapidly in Japan, CHP could play an important role. The electrical output of photovoltaic cells and wind generation fluctuates depending on the weather. Therefore, it is necessary to compensate for these fluctuations to maintain the integrity of the electricity supply. As one of the solutions to aid in reducing such fluctuations CHP is applicable. CHP systems are also more efficient and economical than battery storage systems.

In order to respond to customer expectations it is essential to improve efficiency, reduce running costs and expand the product lines of CHP systems. Thus, with these considerations and current national circumstances in mind, the GS16R2 engine, a new 1000 kW gas CHP system operating at 1000 rpm, was launched on November 1, 2013. The system was jointly developed by Mitsubishi Heavy Industries Ltd and Tokyo Gas Co. Ltd. The companies intend to promote the new system to medium-size factories, large hospitals, district heating and cooling plants and urban redevelopment areas.

3. Features of the newly developed 1000 kW gas engine

3.1 Overview

The new system has been developed based on the conventional 930 kW gas engine CHP system, but the engine maintenance interval has been extended compared with that of the conventional system. Thus, the new system achieves a higher electrical efficiency. This system can be utilized either indoors or outdoors, and has an option for a steam or hot water boiler unit.

Figure 4 shows a photograph of the new system package. The partner companies utilized their extensive experience in gas CHP development and adopted the unique concept of lowering the engine speed while increasing the output and efficiency. In addition, the available test facilities for CHP systems enabled several thousand hours of endurance testing to be undertaken. An island mode test, using a load resistor and a harsh summer/winter condition test, using ambient control facilities, were carried out to verify the durability, reliability and performance qualities of the GS16R2 engine.

Figure 5 shows the configuration diagram of the new engine. The electrical output of this CHP system is 1000 kW, and it produces 1608 MJ/h of hot water and 583 kg/h of steam at 0.78 MPa. Table 1 shows the comparison between the new system and the conventional one. In the new system the friction wear of the engine components is reduced by lowering the engine speed from 1500 to 1000 rpm, which ultimately results in a reduction in engine maintenance frequency and cost. Compared with the conventional system, the new one achieves an electrical efficiency of 42.3%, which is the highest level of efficiency in the 1000 kW range. Steam recovery efficiency has been improved from 14.8% to 17.3%, and hot water recovery efficiency increased to 18.9%. Thus, the total efficiency achieved is 78.5%, a significant increase on the previous value of 73.2%. Through the reduction of maintenance costs, by approximately 30%, and the improvement of efficiency, the system's running costs are reduced considerably. As a result, the simple payback period (SPB) of this new system can be shortened by approximately three years when compared with the conventional system.

Figure 4: Photograph of the new system package

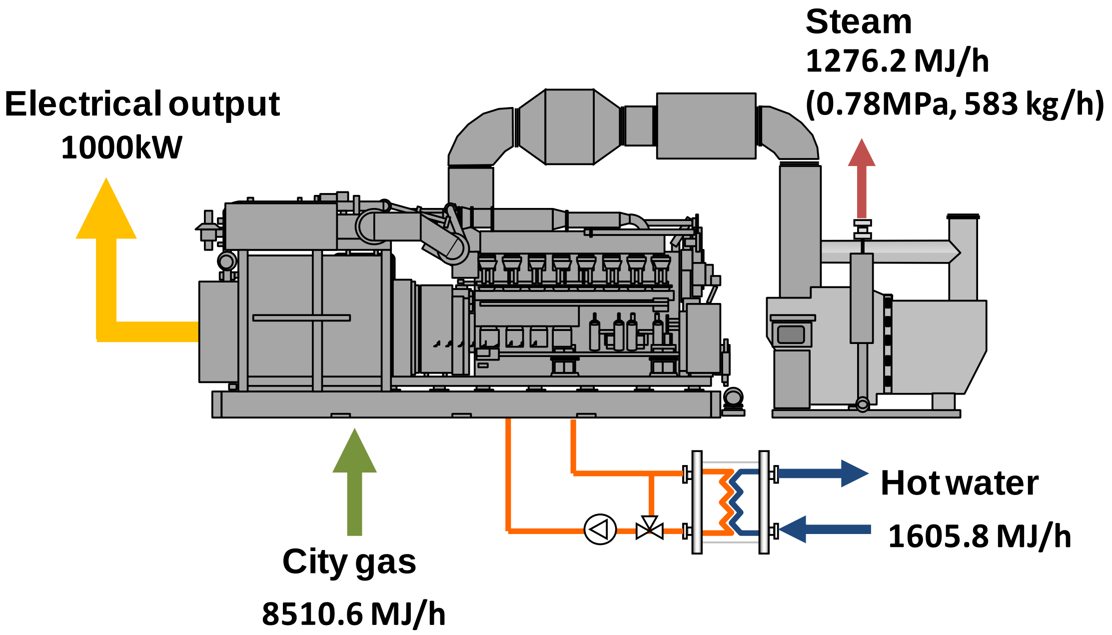


Figure 5: Configuration diagram of the new 1000 kW engine

Table 1: Specification overview

Item	Unit	New System	Conventional System
Engine model	–	GS16R2	GS16R
Dimensions of package (width × height × depth)	mm	2500×4600×7500	3000×4400×6300
Output	kW	1000	930
Engine speed	rpm	1000	1500
Electrical efficiency	%	42.3	40.0
Steam recovery efficiency	%	17.3	14.8
Hot water recovery efficiency	%	18.9	18.3
Total efficiency	%	78.5	73.2

Efficiency values assume the use of city gas with a lower heating value (LHV) of 40.63 MJ/Nm^3

3.2 Longer maintenance intervals and lower maintenance costs

The electrical frequency in eastern Japan is set at 50 Hz. Therefore, 1000 kW CHP engines are likely to have engine speeds set at 1500 rpm to produce the required electrical output. The new system is able to run at the lower engine speed of 1000 rpm because of the reduction in friction wear of the engine components. Thus, compared with the conventional system, the minimum maintenance interval has been extended to 1.5 times, and the minimum interval for top overhaul has been extended to 1.9 times of that of the conventional system. Overall, these low-friction techniques make it possible to reduce the engine maintenance frequency and maintenance costs by approximately 30%.

3.3 Increases in electrical efficiency and total efficiency

Sophisticated engine control systems, such as a knocking control system and air-fuel control system, aid in achieving an electrical efficiency of 42.3%, the highest level in the 1000 kW engine range, as shown in Figure 6. In addition, this efficiency is greater than the average efficiency of fossil-fuel power stations in Japan.

The knocking control system improves the detection and aids in the avoidance of engine knocking in a more precise way, thus enabling an increase in power output. The sophisticated air-fuel control system provides stability of combustion in all conditions. These new control systems make it possible to achieve an electrical power efficiency of 42.3%.

In addition, thermal efficiency has been improved to 78.5% by upgrading the one-stage intercooler used in the conventional system, to a two-stage intercooler unit. This unit recovers waste heat from the compressed fuel-air mixture, as shown in Figure 7.

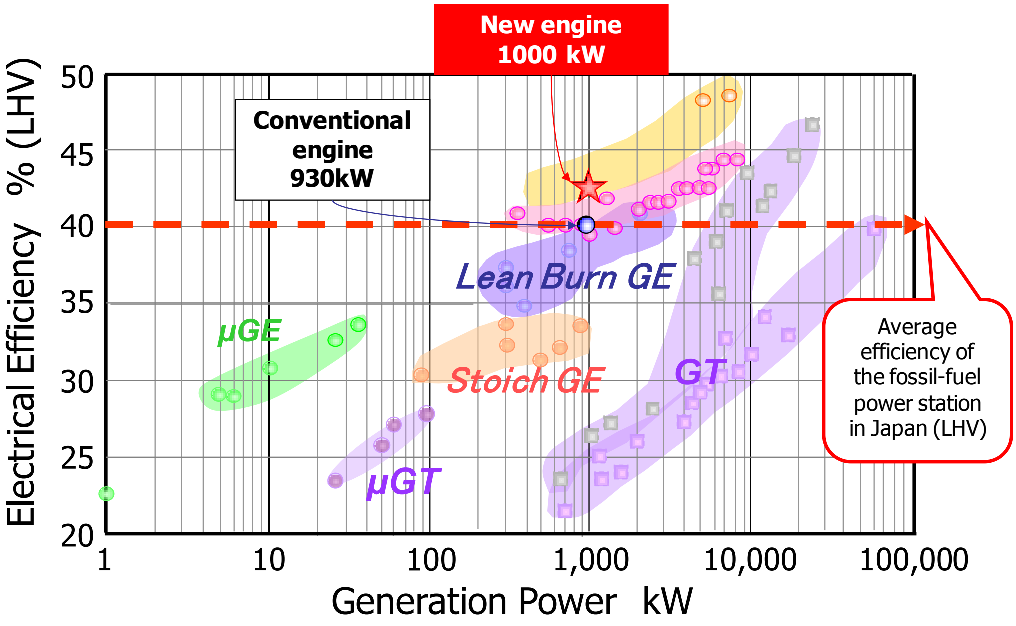


Figure 6: Electrical efficiency of gas CHPs in Japan

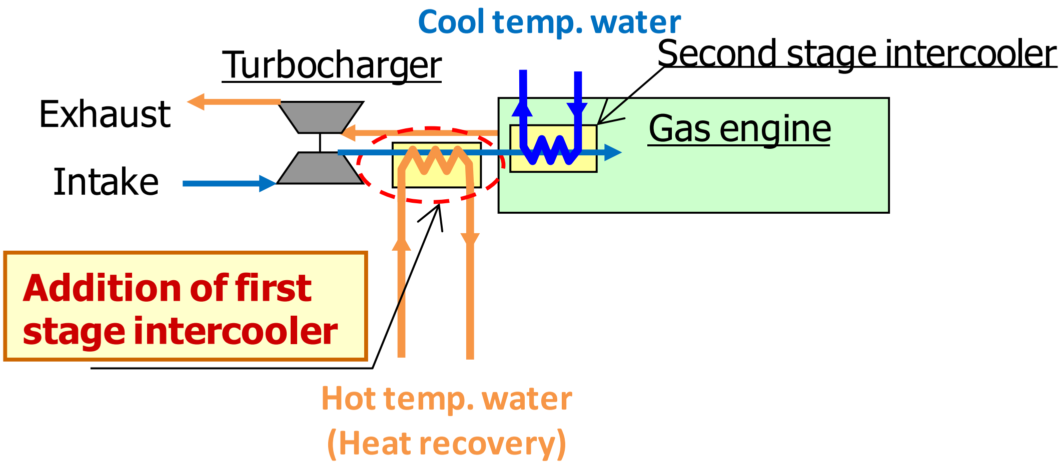


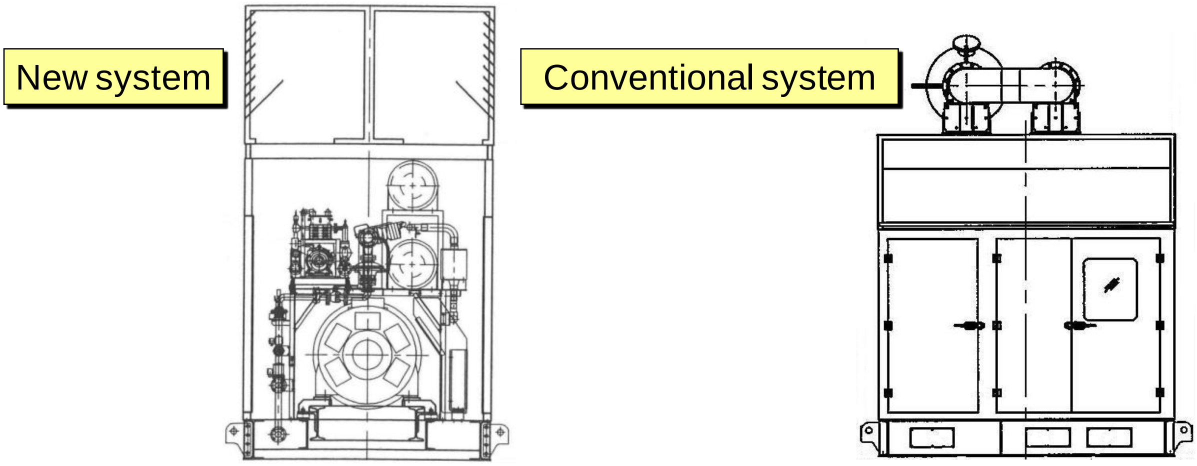
Figure 7: Two-stage intercooler system

3.4 Higher power output

Lowering the engine speed of a system normally leads to a corresponding reduction in power output; however, the new system is able to generate a higher power output at a lower rpm. This is because the piston stroke of the engine has been extended by approximately 20% compared with that of the conventional system; also the exhaust volume has been increased. In addition, a high efficiency turbocharger has increased the amount of compressed fuel-air mixture supplied to the combustion chambers; this results in an increase in the brake mean effective pressure (BMEP) of 30% compared with that of the conventional system. Although a high BMEP is known to induce engine knocking and obstruct smooth running in general, the new air-fuel and knocking controls enable the system overcome these concerns in that they detect, control, and avoid this problem efficiently. In this way the new system achieves a lower engine speed while increasing power output from 930 kW to 1000 kW.

3.5 Ease of installation

As shown in Figure 8, the width of the new system package has been reduced by 15% (from 3000mm to 2500mm) to improve the convenience of indoor installation, especially in buildings with limited space, such as hospitals, hotels and office buildings. Although a higher-output system generally requires increased ventilation and capacity for auxiliary equipment, the optimal arrangement of the components in the new system saves space, taking up less area than the conventional system.



Item	Unit	New System	Conventional System
Length	mm	7500	6300
Width	mm	2500	3000
Height	mm	4600	4338
Installation space	m^2	18.75	18.90

Figure 8: **Comparison of CHP package size**

4. Summary

Tokyo Gas Co. Ltd and MHI have jointly developed a new 1000 kW gas engine CHP system; both companies began sales of this on November 1, 2013. In recent years business continuity plans (BCP) and electric power conservation efforts have helped in growing customer interest in energy-saving and environmentally friendly gas engine CHP systems. In response, Tokyo Gas Co. Ltd and MHI have utilized their extensive experience in gas engine CHP development and adopted the unique concept of lowering engine speed while increasing output and efficiency.

Tokyo Gas Co. Ltd and MHI intend to promote this highly efficient new system to hospitals, hotels, factories, office buildings and district heating and cooling systems. We will continue to develop CHP systems to expand the lines available and so contribute to an environmentally sustainable society.

5. References

1. IEA, World Energy Outlook 2011 “Are We Entering a Golden Age of Gas?” p.49 (2011)

2. IEA, Tracking Clean Energy Progress 2014, p.74 (2014)

6. List Tables

7. List of Figures