# $CO_2$ Emission Reduction Method Through Various Gas Turbine Fuel Applications

TOYOAKI KOMORI*1
SHIGEHIRO SHIOZAKI*1
NOBUYUKI YAMAGAMI*1
YOHSUKE KITAUCHI*1
WATARU AKIZUKI*1

## 1. Introduction

When discussing measures to prevent global warming, reducing carbon dioxide ($CO_2$) emissions, which have the largest influence on the warming problem, is the most important issue. Measures against $CO_2$ emissions are largely divided into two fields, $CO_2$ emission reduction and $CO_2$ recovery. In addition, $CO_2$ emission reduction methods can be divided into two categories, improved efficiency of the energy conversion equipment and fuel conversion into hydrogen-rich fuel gases with less $CO_2$ emissions.

In power generating plants the improvement of thermal efficiency is already in progress through the introduction of gas turbine combined plants using high-performance gas turbines. For further progress in $CO_2$ emission reductions, the next generation of gas turbines with improved thermal efficiency must be developed.

On the other hand fuel conversion can be effectively addressed by modifying the design of combustors by use of existing gas turbine technology. Depending on the fuel properties after fuel conversion, a significant contribution to $CO_2$ emission reductions can be expected.

Regarding these needs, Mitsubishi Heavy Industries, Ltd. (MHI) has been continuously working for a long time on the development of hydrogen-rich gas fuel for gas turbines. Currently, it already operates more than 10 commercial units. In this paper, we introduce the operational experience and design outline of hydrogen-rich gas firing and low-calorific gas firing gas turbines with relation to the various fuel applications.

**Table 1 Types of fuel actually used in MHI gas turbines**

| Fuel | Number of units |
|---|---|
| 1. Single fuel | |
| (1) Natural gas or LNG | 187 |
| (2) Oil refinery offgas/LPG | 19 |
| (3) Steel plant offgas | 25 |
| (4) Diesel oil | 63 |
| (5) Others | 1 |
| 2. Dual fuels | |
| (1) Natural gas/diesel oil | 157 |
| (2) Natural gas/heavy oil | 6 |
| (3) Oil refinery offgas/diesel oil | 7 |
| (4) LPG/diesel oil | 7 |
| (5) Steel plant offgass/diesel oil | 3 |
| (6) Coal gasification gas/diesel oil | 1 |
| (7) VR gasification gas/diesel oil | 1 |
| Total | 477 |

(As of December 2006)

## 2. Actual applications of various fuel gases

**Table 1** shows the types of fuel actually used in MHI gas turbines. There were 477 gas turbines as of December 2006. **Figure 1** shows the ranges of the calorific values of gas fuels.

Figure 1 shows the achievements obtained in the use of gas fuels with various ranges of calorific values, 2.5 MJ/m$^3$N to 84 MJ/m$^3$N. It should be noted that 11 low-calorific gas firing gas turbines of 4 MJ/m3N or less have been delivered to customers.

## 3. Development and evolution of gas turbines for hydrogen-rich gas

**Figure 2** shows the operational experience of our hydrogen-rich gas firing gas turbines whose hydrogen gas contents are 20 vol% or above. These gas turbines can be divided into three types based on their fuel source, the coke oven gas (COG) type, the oil refinery offgas type and the gasification gas type.

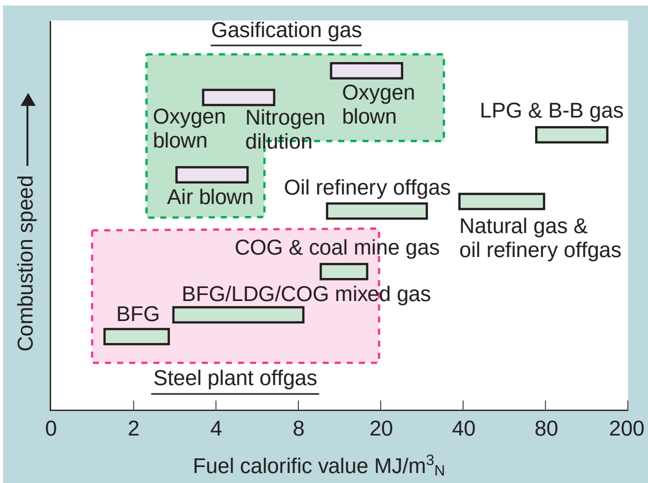


**Fig. 1 Actual experience of fuel gas**

*1 Takasago Machinery Works

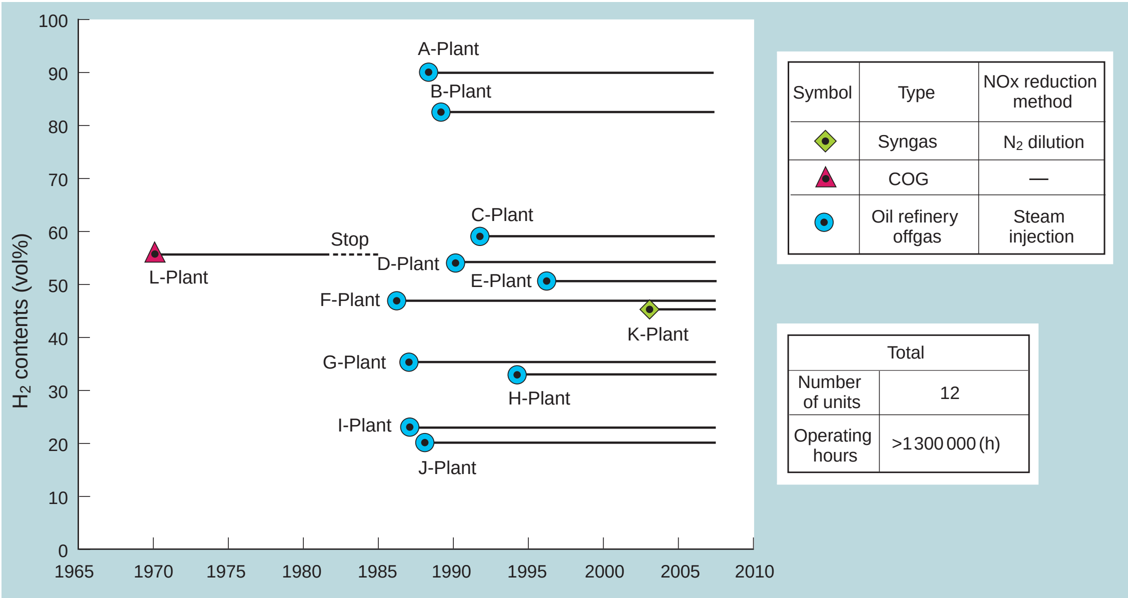


**Fig. 2 Operational experience of hydrogen-rich gas (20 vol% or above) firing gas turbine**

**Table 2 Main specifications of 431MW VR gasification gas firing combined cycle plant**

| | | |
|---|---|---|
| | Gross plant output (MW) | 431 |
| | Net plant output (MW) | 342 |
| Gas turbine | Fuel main/auxiliary | VR gasification gas/kerosene |
| | Type<br>Output (MW)<br>Rotation speed ($min^{-1}$) | Simple open cycle, single shaft M701F<br>301<br>3 000 |
| Steam turbine | Type<br>Output (MW)<br>Rotation speed ($min^{-1}$)<br>Steam conditions<br>Main steam<br>Reheat steam<br>Medium pressure steam | Single cylinder, down exhaust condensing reheat type<br>130<br>3 000<br>Steam turbine inlet<br>9.8 MPaG x 538°C<br>2.9 MPaG x 538°C<br>0.7 MPaG x 313°C |
| Power generator | Type<br>Capacity (kVA)<br>Voltage (kV)<br>Rotation speed ($min^{-1}$) | AC three phase/synchronous, $H_2$ cooling type<br>479 390<br>23<br>3 000 |
| Heat recovery steam generator | Type | Reheat triple pressure vertical natural circulation type |

Ambient temperature: 15°C, atmospheric pressure: 0.1013MPa, relative humidity: 60%

The first hydrogen-rich gas firing gas turbine started commercial operation in 1970 as a 30 MW gas turbine using COG as fuel and with the inlet temperature of 700°C. This COG is a by-product gas produced in coal chemical plants whose hydrogen content exceeds 50 vol%. In addition to its high hydrogen content, as COG contains impurities, various measures were taken for the gas turbine combustor and the fuel treatment and supply systems.

Since the beginning of the 1980s and especially after the oil crises, the industry has become very aware of energy saving and the need for the petrochemical industry to use hydrogen-rich gas from oil refinery processes as gas turbine fuel has increased. Along with this, due to the need to supply high-temperature, high-pressure steam from gas turbine exhaust gas by using a heat recovery steam generator, a 1,250°C class gas turbine was developed which was a great achievement at that time.

Flashback in the gas turbine combustor was one of the important issues when hydrogen-rich gas was used as fuel for high-temperature gas turbines and it was successfully overcome by adoption of a fuel nozzle configuration.

Ten hydrogen-rich gas (oil refinery offgas) firing gas turbines were delivered and are still operating successfully today.

Based on the operational experience of these units and the operational experience of the low-calorific gas firing gas turbines described in Section 4, we delivered a hydrogen-rich gas (VR gasification gas) firing gas turbine combined plant with a capacity of 431 MW, the world's largest gas turbine, to Negishi Refinery of Nippon Oil Refining Company in 2003.

**Table 2** and **Fig. 3** show the main specifications and an outline of this plant. Here, NOx control was the major issue to be addressed for the fuel of this plant.

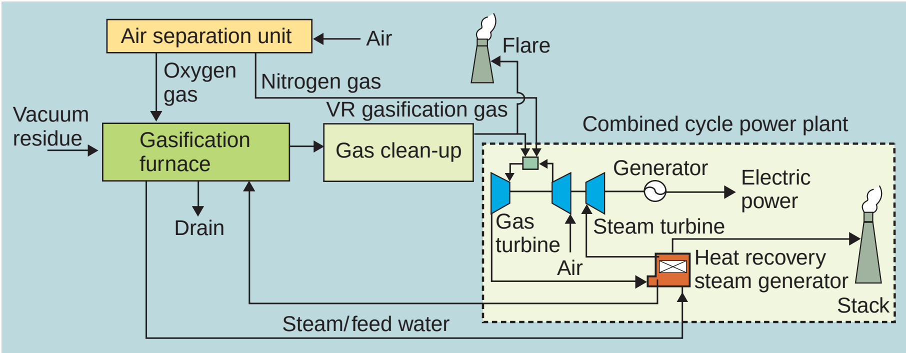


**Fig. 3 Outline of 431 MW VR gasification gas firing combined plant**

The VR gasification gas produced in a gasification furnace has a very high adiabatic flame temperature and will generate a high NOx level if burned without NOx reduction. Therefore, in this plant, nitrogen supplied from the air separation unit is mixed with VR gasification gas and this mixed gas is used as the gas turbine fuel. This mixed gas, compared with liquefied natural gas (LNG), has a low calorific value and adiabatic flame temperature, which contributes to reducing NOx emissions. Because of its high hydrogen content, it has a higher combustion speed and wider flammability ranges. Because of these fuel characteristics, the NOx level at the gas turbine outlet can be reduced to a level as low as that for a premixed combustor of natural gas even if a diffusion combustor is used. Thus, this plant has adopted the use of a diffusion combustor which provides stable combustion even with changes in the fuel properties.

Also, in this plant, as the gas turbine needs to be started in advance by kerosene fuel before the gasification furnace is started, the combustor has been designed to support the dual fuel firing of gas and oil.

## 4. Development and evolution of gas turbines for low-calorific gas

The Japan's first BFG firing gas turbine (output: 850 kW) was delivered to Yawata Iron & Steel Co. (now Nippon Steel Corporation) in 1958 and the MW171 gas turbine (output: 15 MW) was delivered to Sumitomo Metal Industries, Ltd. Wakayama Works. Subsequently, the thermal efficiency of the gas turbine itself has been improved by increasing the turbine inlet temperature and by improving the efficiency of each component. Further, the increased gas turbine exhaust gas temperature has contributed to improving the energy recovery efficiency of the heat recovery steam generator.

In the evolution described above, a M151 gas turbine (with a turbine inlet temperature of 1,000°C or above) plant was delivered to Nippon Steel Corporation, Kamaishi Works in 1982, and a 145 MW class gas turbine combined cycle plant was delivered to JFE Steel Co., Ltd., East Japan Works (Chiba) in 1987.

Based on our operational experience of this large-capacity combined cycle plant, we delivered a plant of the same size equipped with a DA type gas turbine which has a 100°C higher turbine inlet temperature than D type to Kurashiki Power Plant and Fukuyama Power Plant of Setouchi Joint Thermal Power Co., Ltd. in 1994 and 1995. In addition, through the integration of these technologies, with Kimitsu Power Plant of Kimitsu Corporative Thermal Power Company, Inc., we delivered a high-efficiency, large-capacity, BFG firing, combined cycle plant which, as the world's first F type gas turbine, realizing a turbine inlet temperature of 1,300°C, the highest temperature of all BFG firing gas turbines. Along with the recent rapid growth of the iron industry in China and South Korea, the number of BFG firing gas turbines delivered has been increasing. **Table 3** shows the delivery record.

## 5. Effect of $CO_2$ emission reduction in BFG firing combined plant

Carbon dioxide ($CO_2$) emissions are interrelated with the BFG/COG quantity of the by-product gas from iron works. As the BFG/COG quantity is determined by the crude steel production, $CO_2$ reductions need to be evaluated not only in terms of the power plants using these by-product gases but also by including the surrounding equipment. The following shows an evaluation plan:

In developing countries, BFG is not currently used for power plants but is flared into the atmosphere. A comparison of this with the situation after the introduction of gas turbine combined plants (GTCC) is shown in **Fig. 4**.

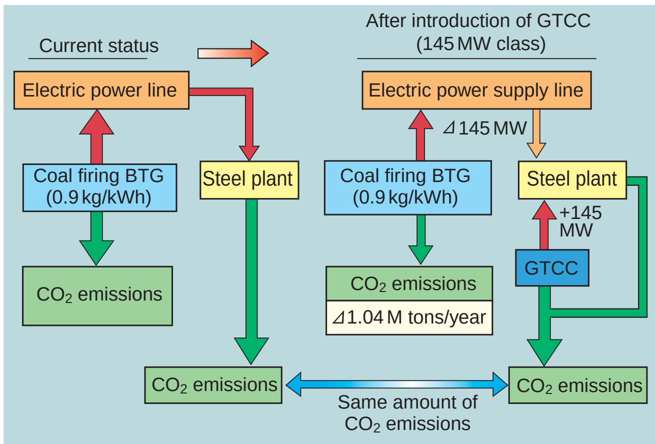


**Fig. 4 Schematic diagram of $CO_2$ reduction in a steel plant**

**Table 3 Delivery record of low calorific gas firing gas turbines**

| Client | Plant | Start-up date | Type | Plant output | Fuel | | Combustion unit |
|---|---|---|---|---|---|---|---|
| | | | | | Main | Auxiliary | |
| Yawata Iron & Steel Co. (Yawata) | Air blower | 1958 | - | 0.85MW | BFG (3.2MJ/m$^3$N) | - | Single can |
| Yawata Iron & Steel Co. (Yawata) | Air blower | 1964 | - | 4MW | BFG (3.2MJ/m$^3$N) | - | Single can |
| Sumitomo Metal Industries, Ltd. (Wakayama) | Cogeneration (WHB, G-M, BLOWER) | 1965 | MW171 | 15MW | BFG (3.1MJ/m$^3$N) | - | Single can |
| Shikoku Electric Power Co., Inc. (Sakaide) | Combined cycle | 1970 | MW301 | 225MW | COG (18.8MJ/m$^3$N) | - | Multi can |
| Mistubishi Coal Mining Co. (Minami Oyubari) | Cogeneration | 1970 | MW101 | 9MW | Coal mine gas (20MJ/m$^3$N) | Oil | Multi can |
| Nippon Steel Corporation (Kamaishi/Oita) | Combined cycle (Utilization of an existing ST) | 1982 | M151 | 16MW | BFG (2.8MJ/m$^3$N) | - | Single can |
| JFE Steel Corporation (Chiba) | Combined cycle (single shaft type) | 1987 | M701 | 149MW | BFG/COG (4.2MJ/m$^3$N) | - | Multi can |
| Mitsubishi Gas Chemical Company, Inc. (Mizushima) | Cogeneration | 1988 | MF111 | 16MW | BFG/COG (10MJ/m$^3$N) | Oil | Multi can |
| Nisshin Steel Co., Ltd. (Kure) | Combined cycle (Utilization of an existing ST) | 1989 | M251 | 32MW | BFG (2.9MJ/m$^3$N) | - | Multi can |
| Nippon Steel Corporation (Hirohata) | Combined cycle (Utilization of an existing ST) | 1989 | M251 | 30MW | LDG (7.6MJ/m$^3$N) | Oil | Multi can |
| Nakayama Steel Works, Ltd. (Funamachi) | Combined cycle (single shaft type) | 1991 | M151 | 37MW | BFG/LDG (4.2MJ/m$^3$N) | - | Multi can |
| Setouchi Joint Thermal Power Co., Ltd. (Kurashiki) | Combined cycle (single shaft type) | 1994 | M501DA | 149MW | BFG/COG (4.0MJ/m$^3$N) | - | Multi can |
| Setouchi Joint Thermal Power Co., Ltd. (Fukuyama) | Combined cycle (single shaft type) | 1995 | M501DA | 149MW | BFG/COG (4.0MJ/m$^3$N) | - | Multi can |
| NUON (Netherlands) | Combined cycle (single shaft type) | 1997 | M701 | 145MW | BFG/COG (4.2MJ/m$^3$N) | - | Multi can |
| Nippon Steel Corporation (Oita) | Combined cycle | 2001 | M251 | 67MW | BFG (2.9MJ/m3N) | | Multi can |
| Nippon Oil Refining Co. (Negishi) | Combined cycle (single shaft type) | 2003 | M701F | 431MW | Syngas+N2 (5.9MJ/m$^3$N) | Oil | Multi can |
| Kimitsu Cooperative Thermal Power Co. (Kimitsu) | Combined cycle (single shaft type) | 2004 | M701F | 300MW | BFG/COG (4.4MJ/m$^3$N) | - | Multi can |
| Zhanggjiagang Hongchang Plate Co. (China) | Combined cycle | 2006 | M251 | 30MW x 4 | BFG (3.1MJ/m$^3$N) | - | Multi can |
| Anshan Steel Co. (China) | Combined cycle (single shaft type) | 2007 | M701F | 300MW | BFG/COG (4.4MJ/m$^3$N) | - | Multi can |
| Handan Steel Co. (China) | Combined cycle | 2006 | M251 | 30MW x 2 | BFG (3.1MJ/m$^3$N) | - | Multi can |
| Maanshan Iron & Steel Co. (China) | Combined cycle (single shaft type) | 2007 | M701DA | 153MW | BFG/COG (4.4MJ/m$^3$N) | - | Multi can |
| POSCO (South Korea) | Combined cycle (single shaft type) | 2007 | M501DA | 146MW | FOG (5.7MJ/m$^3$N) | - | Multi can |
| Clean Coal Power R&D Co., Ltd. (Nakoso) | Combined cycle (single shaft type) | 2007 | M701DA | 250MW | Syngas (4.2MJ/m$^3$N) | Oil | Multi can |
| Lianyuan Steel Co. (China) | Combined cycle | 2007 | M251 | 30MW | BFG (3.1MJ/m$^3$N) | - | Multi can |
| Baotou Steel Co. (China) | Combined cycle (single shaft type) | 2008 | M701DA | 138MW x 2 | BFG/COG (4.4MJ/m$^3$N) | - | Multi can |
| IUD (Ukraine) | Combined cycle (single shaft type) | 2009 | M701DA | 151MW x 2 | BFG/COG (4.4MJ/m$^3$N) | - | Multi can |

When 145 MW of power is generated by a BFG firing GTCC, 145 MW being generated in a coal firing steam power plant (BTG) can be reduced. If the annual generating duration of a coal firing BTG is assumed to be 8,000 hours, the $CO_2$ emissions from this coal firing BTG, which amounts to 1,040,000 tons/year of $CO_2$, can be reduced.

When compared to a newly established BTG, a GTCC will yield a further reduction of about 200,000 tons/year as shown in **Fig. 5**.

As described above, from the viewpoints of improved plant efficiency and the emission control of $CO_2$ through the effective use of BFG, the advantages of the gas turbine combined cycle plant can be confirmed.

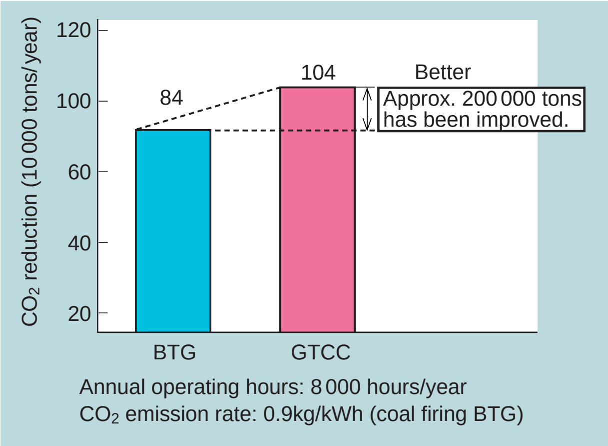


**Fig. 5 Comparison of $CO_2$ reductions**

## 6. Conclusion

Power generation plants based on hydrogen-rich gas firing gas turbines and low-calorific gas firing gas turbines (mainly BFG) have already accumulated extensive operational experience and the construction of many more power generation plants are scheduled both overseas and in Japan in the near future. The development of this technology, we believe, can greatly contribute to society by responding to demands for the effective use of energy and global environmental measures. We are fully determined to continue our efforts in technological development and continue working as pioneers in this field.

**References**


(1) Matsuda, H., Oka, Y., Large Capacity and High Efficiency Combined Cycle Plant F Type Gas Turbine with BFG Firing, Mitsubishi Heavy Industries Technical Review Vol. 41 No. 5 (2004)

(2) Komori, T., Yamagami, N., Update on Design and Operating Experience of BTU Gas Firing Gas Turbine for Steel Works, 2005 Asian Congress on Gas Turbines (ACGT2005)

(3) Komori et al., BFG Firing Combined Cycle Plant, Journal of the Gas Turbine Society of Japan Vol. 34 No. 35•(2006)

(4) Sonoda et al., Development of M701F Gas Turbine for Integrated VR Gasification Combined Cycle Plants, Mitsubishi Heavy Industries Technical Review Vol. 41 No. 1 (2004)







Toyoaki Komori    Shigehiro Shiozaki    Nobuyuki Yamagami    Yohsuke Kitauchi    Wataru Akizuki