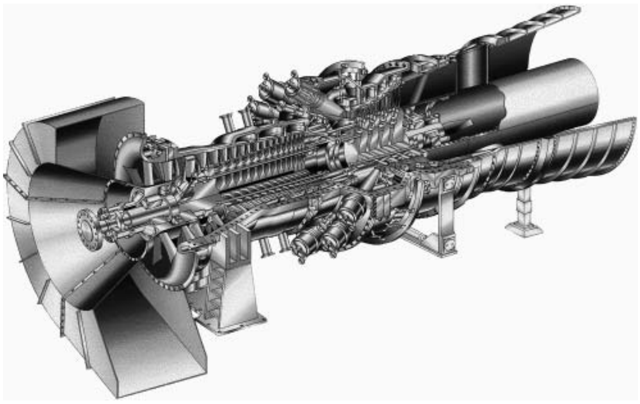

Energy Solutions through the Development of Power Generating Systems

AKIRA TOMINAGA
OSAMU WAKAZONO
MICHIO NAKAJIMA
TAKUJI FUJIKAWA
SUSUMU SATO
TOSHIO SUGITANI

1. Introduction

Electrical energy can be easily converted into power, heat, light, and radio wave. This makes it a very versatile form of energy that can be used in a wide variety of applications. Hence, its assured supply is an indispensable prerequisite for modern society.

To cope with the rapid increase in demand for electric power in Japan that has taken place since the 1960's and the two oil crisis of the 1970's, Mitsubishi Heavy Industries, Ltd. (MHI) has made great strides in increasing the capacity and improving the efficiency of electric power generating plants. MHI has also actively worked to develop coal-fired and LNG-fired power generating plants to replace oil-fired plants, particularly in light of the growing demand for versatile fuels that arose since the first oil crisis in 1973 as a turning point.

Increasing the capacity of power generating units means that any troubles that might occur can have a major impact on the power system as a whole and lead to emergency shutdown and other measures that result in the loss of power supply. Hence, it has become essential that all plant components, such as boilers and turbines, be as reliable as possible.

The demand for increased efficiency has led to the development and construction of gas turbine combined cycle plants. After the construction of a large capacity plant in 1984, efficiency has also been increased remarkably by increasing the operating temperature of the gas turbine itself.

In addition, MHI has promoted the development of integrated coal gasification combined cycle power plants (IGCC) for the efficient and effective use of abundant coal.

In order to realize the highly efficient use of energy, the spread of distributed power supply is under way which makes it possible to supply both electricity and heat. MHI has already delivered core equipment such as highly efficient diesel engines and gas engines in this field. Furthermore, MHI is moving ahead with the commercialization of fuel cells that are most expected in the future.

On the other hand, utility companies are being increasingly obliged to increase, by the RPS (Renewable Portfolio Standard) rule, the ratio of renewable sources of energy used such as wind power, photovoltaic power, and waste-fired power, in the field of energy generation, in order to help in preventing global warming. MHI has also delivered a wide range of products that meet the needs of customers in these fields, as well.

MHI activities in the past and future are introduced below.

2. Conventional Thermal Power Generation Technologies

2.1 Transition of Increase in Capacity and Steam Conditions

In order to meet the rapid increase in demand for electric power in Japan since 1960's, MHI has actively sought to enhance power generating efficiency by increasing the size of power generating units and improving the steam conditions (**Figs. 1** and **2**).

Thermal power generating plants, which first began operation as a result of the introduction of relevant technologies from overseas, soon underwent a remarkable development through MHI's own indigenous technologies. With the strong support of the utilities industry in Japan, MHI took the initiative in increasing capacity and performance of power generation to meet the needs of society.

To begin with, MHI delivered the Tokyo Electric Power Co. Kashima No. 5 boiler (commenced commercial operation in 1974, 24.1 MPa, 538/566°C as the first 1 000 MW unit in Japan, the Electric Power Development Co., Ltd. Matsuura No. 1 steam turbine (commenced commercial

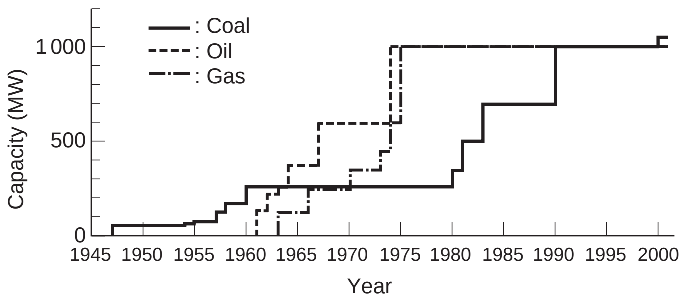

Fig. 1 Changes in unit capacity of thermal power plants
The figure shows the transition of unit capacity of thermal power plants in Japan over the years.

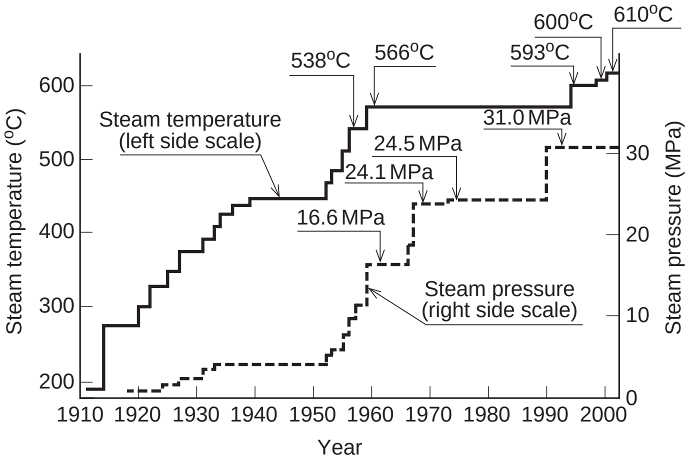

Fig. 2 Changes in steam conditions of thermal power plants
The figure shows the transition of the steam conditions of thermal power plants in Japan.

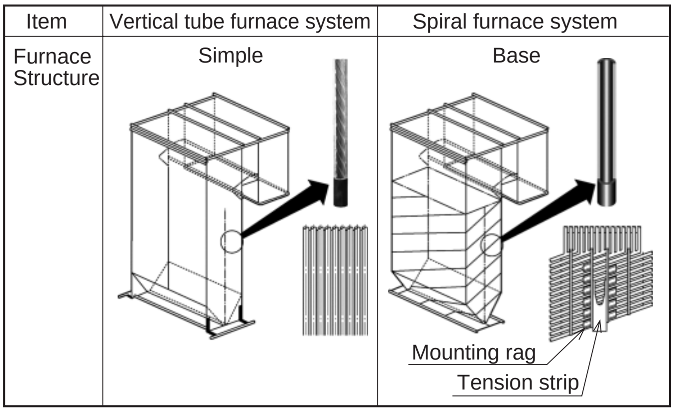

Fig. 4 Comparison of furnace structures
Vertical tube waterwall furnace structure using rifled tubes is adopted.

operation in 1990, 24.1 MPa, 538/566°C as the first 1 000 MW plant among 60 Hz plants in Japan), the Chubu Electric Power Co., Inc. Kawagoe No. 1 boiler (started to operate in 1989, 700 MW, 31 MPa, 566/566/566°C) which was the first large-capacity boiler to adopt the 30 MPa class ultra supercritical steam conditions in the world, and the Chubu Electric Power Co., Inc. Hekinan No. 3 steam turbine (commenced commercial operation in 1993, 700 MW, 24.1 MPa, 538/593°C) which was a large capacity unit machine in which 593°C reheat steam was first applied in Japan.

2.2 Boiler Technologies

MHI has played an important role in the transition of boiler technologies. MHI has striven to improve the technologies in a variety of fields concerning boilers, including increasing the reliability of furnaces and completeness of combustion, reducing NOx emissions and construction costs, as well as increasing capacity and improving steam conditions. The Chugoku Electric Power Co., Inc. Misumi No. 1 unit (1 000 MW) (**Fig. 3**), which began operation in 1998, is a plant in which advanced technologies have been adopted that permit the boilers to operate under steam conditions as high as 24.5 MPa, 600/600°C. The outstanding features of this plant are described briefly below.

A vertical tube waterwall furnace system has been adopted for the furnace structure. MHI is the only company in the world that has a construction experience for this type of system (**Fig. 4**). In the supercritical variable pressure operation once-through boiler, measures must be taken against reductions in the heat transfer coefficient for water and steam in the middle load zone where fluid pressures in the furnace reach sub-critical levels.

Nucleate boiling is maintained up to high dryness by adopting a rifled tube with grooves in the inner surface, and the temperature of the metal can be sufficiently suppressed by the vertical tube waterwall furnace structure. The advantages thus obtained are as follows.

(1) Mass velocity and pressure loss in the tube are lowered, with the result of flow stability improvement and operating power consumption saving.
(2) Due to the simplified structure of the system, reliability can be improved, installation is easier, and maintainability can be improved.
(3) Slag can fall down easily with the result that the amount of ash that adheres to the furnace wall can be reduced.

An advanced A-PM (Advanced-Pollution Minimum) burner has been adopted in the coal burner (**Fig. 5**). The

Fig. 3 Chugoku Electric Power Co., Inc. Misumi No. 1 (1 000 MW) Power plant

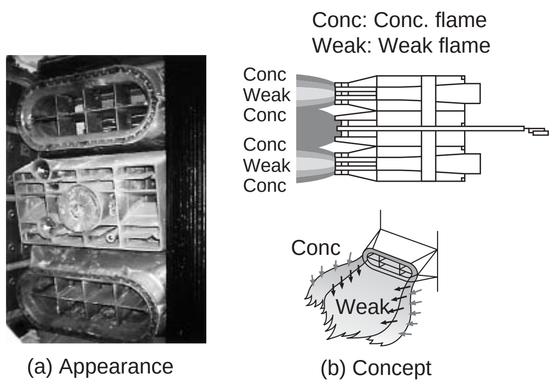

Fig. 5 A-PM burner
The figure shows the external appearance and the concept of the A-PM burner. The burner is low in NOx generation, has excellent ignition stability, is simple in structure, easy to maintain, and excellent in reliability and durability.

PM burner is designed so that its flame can be separated into a conc. flame with high coal-air ratio and a weak flame with low coal-air ratio, thereby lowering the amount of NOx generated. In the A-PM burner, the flame is separated into a conc. flame and a weak flame on the same axis in a single flame in order to realize even further improvement in ignition stability, reductions in the amount of NOx generated, and easy maintainability. In addition, sufficient space is kept over the main burner to assure reduced NOx emissions, by providing an additional air port, and the in-furnace denitration method MACT (Mitsubishi Advanced Combustion Technology) was adopted to reduce the amount of NOx generated even further by use of the entire boiler. With respect to the pulverizer, an MRS (Mitsubishi Rotary Separator) mill was adopted that achieves very fine grain size by use of a rotary separator. A remarkable reduction in the amount of coarse powder of 100 meshs pass in size or smaller is realized in the MRS pulverizer. The size of the fuel particles is one of the main factors affecting the occurrence of unburned carbon.

The adoption of the technologies described above resulted in reducing both NOx emissions and unburned carbon in ash by notable amounts, and made it possible to obtain boiler efficiency levels that were remarkably higher than the planned values by reducing the excess air ratio to 10%.

MHI is promoting the commercialization of comprehensive flue gas treatment technologies as one measure against environmental problems in the future. These technologies use activated carbon fibers (ACF) which allow the removal of NOx and SOx emissions in low temperature zones. The most noticeable feature of these technologies is that both soot and dust together with SO_2 can be removed at the same time at a low operating cost.

2.3 Steam Turbine Technologies

The change in steam turbine technologies is largely represented by an increase in capacity, improvement in steam conditions, enhanced blade path performance, development of long blades, and reductions in the number of casings.

Examples of increase in capacity, as mentioned above, include a 1 050 MW unit that is currently under operation for a thermal power plant, and a 1 371 MW unit that has already been produced for use in a nuclear power plant.

Although the era of steam conditions of 246 kg/cm^2 (24.1 MPa) pressure and a temperature of 566^{o}C continued for some thirty years, development to improve steam conditions mainly focused on increasing steam temperature with the aim of enhancing the efficiency. In recent years, a large number of steam turbines with a steam temperature of 600^{o}C have been manufactured. MHI has delivered three of five 1 000 MW class steam turbines that are currently in operation with main and reheat steam temperatures of 600^{o}C class, respectively. The Chugoku Electric Power Co., Inc. Misumi No. 1 unit 1 000 MW turbine shown in Fig. 3 was the first turbine to have the International System of

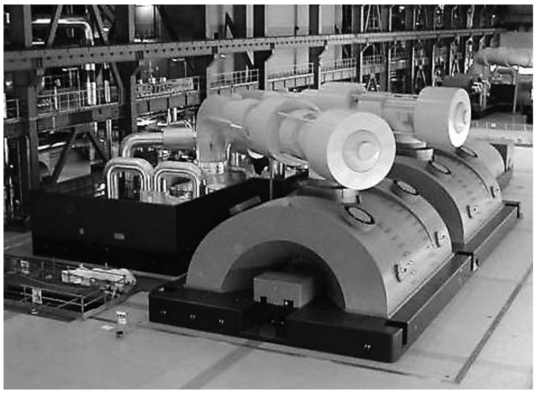

Fig. 6 Electric Power Development Co., Ltd. Tachibana-wan Power Station No. 2 (1 050 MW) turbine
The figure shows the appearance of the Electric Power Development Co., Ltd. Tachibana-wan Power Station No. 2 turbine. This is a 1 050 MW steam turbine and operates under the world's maximum level of steam conditions (25.1 MPa, 600^{o}C/610^{o}C). It has the maximum capacity in Japanese fossil fuel plants.

Units of the 600^{o}C main and reheat steams in place of the conventional US System of Units of 593^{o}C (1 100^{o}F) main and reheat steams. The Electric Power Development Co., Ltd. Tachibana-wan No. 2 unit 1 050 MW turbine shown in **Fig. 6** employs what is currently the highest steam condition in the world at 600/610^{o}C for main steam/reheat steam, respectively. The turbine has been operating satisfactorily since December 2000.

In order to increase the performance of the blade path, twisted blades were used in stead of conventional parallel blades to increase efficiency. In addition, a complete three-dimensional blade (bow blade) formed by stacking the blade profiles like a bow in the height direction was developed recently to increase efficiency even further.

The development of long blades is indispensable for reducing exhaust loss that increases as the capacity of the steam turbine is increased. MHI has developed an integral shroud blade (ISB) formed by integrating the blade with the shroud in place of the conventional group blade since the early 1990s, and completed a lineup of these blades for 50 and 60 Hz use. In the long ISB developed completely by fully three-dimensional design, not only is performance increased but also forming continuously coupled blade structure during running at high speed so as to simplify vibration characteristics. Vibration stress is reduced by the damping effect caused by the frictional force that acts on the contact face between the shrouds adjacent to each other.

Development of compact design technologies would make it possible to reduce the number of casings used for steam turbines that would be capable of producing the same output. Conventional large capacity turbine had four casings: one for high pressure, one for intermediate pressure, and two for low pressure. The number of casings was reduced to three by utilizing a high- and intermediate-pressure integrated turbine. In addition, the development of long blades has made it possible for even a low-pressure turbine to be formed with one casing. At present, a 600 MW turbine with two casings for Tokyo Electric Power Co. Hirono No. 5 Unit is being produced, uses 3 000 rpm 48 inch blades, as can be seen in **Fig. 7**.

2.4 Control Technologies

MHI positions, controllers as important pieces of equipment that affect the performance and maneuverability of the plant in the same manner as major plant equipment and machinery such as boilers, turbines, and generators. The MHI's advanced DIASYS Netmation control system with a Microsoft Windows(R) based operating screen can monitor more information collectively. Another advantage of the DIASYS Netmation is that remote maintenance support service can be supplied for the plants of MHI's customers through the Internet. Any change in state or condition that is transmitted from the large-sized gas turbines and windmills used for power generation delivered to various sites located in Japan and North America, remote from any maintenance centers can always be monitored and controlled in real time. Even if any trouble occurs, advice can be given to operators at the site immediately thereby contributing significantly to an increase in reliability.

MHI also dedicates to its continuous development of high-precision real-time simulation technologies. Transitional behaviors can be simulated in each part of plant equipment. This technology contributes for prior verification for reduction of the plant minimum load, and the modification of the existing plant's operation (such as the modification of SH sliding pressure operation) , and provides solution to trouble analysis for MHI units and others.

MHI has developed and commercialized a simulator covering an entire plant through use of these simulation technologies. The company has delivered a large number of simulators to the Tokyo Electric Power Co. Training Center and other locations. The panorama vision simulator delivered to the Tohoku Electric Power Co., Inc. Training Center shown in **Fig. 8** is a multi-functional one that incorporates model software for ten plants and that can be used by switching the model software.

Fig. 8 Tohoku Electric Power Co., Inc. Training Center
The figure shows a view of the panorama vision simulator.

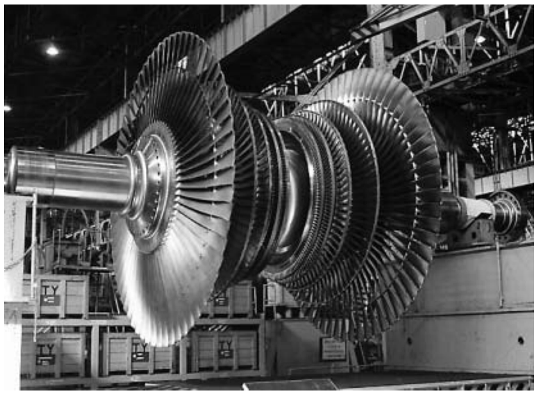

Fig. 7 Low-pressure turbine using 3 000 rpm 48 inch blades
Low-pressure turbine with one casing was realized for 600 MW turbine because of the development of 3 000 rpm 48 inch blades.

2.5 Service Technologies for Existing Equipment

MHI provides customers with comprehensive plant services such as the engineering for boilers, turbines, and control technologies as well as to start-up engineering and laboratory services. In recent years, MHI opened remote support centers as "home doctors" in the Takasago, Nagasaki, and Yokohama factories. By utilizing its technologies, these centers provide prompt, and high quality service.

On the other hand, nowadays, the concept of repair trends seems to be changing, from an emphasis on preventive maintenance to the realization of optimum repair, in response to the deregulation of electric power supply requirements. One of the ways in which MHI accommodates this tendency is through the presenting of a repair menu that utilizes the optimum maintenance planning system (FREEDOM), which has been developed exclusively by MHI.

Gas turbines for overseas plants are already being maintained under long-term service agreements (LTSA). MHI also establishes effective maintenance technologies that match the needs of customers.

3. Gas Turbine Combined Power Generation Technologies

In addition to promoting increases and improvements in the efficiency of the above-mentioned series of conventional thermal power plants, MHI is now also actively working to increase the operating temperature of gas turbines.

In 1984, MHI developed a large capacity gas turbine model M701D with a turbine inlet temperature of 1 150°C, and installed a large-sized combined cycle plant in the Tohoku Electric Power Co., Inc. Higashi Niigata Thermal Power Station No. 3 series. This turbine showed a comprehensive thermal efficiency that was as high as 44%, which was a record value in those days. Since then, MHI has further increased the temperature of gas turbines and, in 1989, developed gas turbine models M501F (60 Hz) and M701F (50 Hz), both having a turbine inlet temperature of

1 350°C. More than 110 units of M501F and M701F gas turbines were ordered from MHI as main units for combined cycle plants both inside and outside of Japan. These models developed an excellent record for superior quality performance, and have a total operating record in excess of 1.3 million hours.

According to social demand for a comprehensive increase in the thermal efficiency of thermal power plants, MHI's drew upon its vast store of experience in the development of high-temperature gas turbines, and in 1993, began the development of G series gas turbine (See the photo on the first page of this paper). These turbines have an inlet temperature of 1 500°C, making them large capacity, high-temperature gas turbines for the next generation. The M501G gas turbine (60 Hz) commenced demonstration operation at the long-term reliability demonstration facility (**Fig. 9**, T point) installed at the Takasago Machinery Works of MHI in June 1997. Since then, it has continued to demonstrate a high level of performance and long-term reliability for five years, while supplying power mainly during the summer season when power consumption is high. In addition, the M701G gas turbine (50 Hz) was adopted in the Higashi Niigata thermal power plant No. 4 series (**Fig. 10**). It began operation on July 1999 and has achieved a plant efficiencies of 55% (LHV) or higher. Though the turbine was a first unit for operation, it is continuing to update its record of 100% reliability. There have already been orders for 47 G-series gas turbines with a total cumulative operating record of about 80 000 hours.

A summary of the changes that have taken place in these gas turbines in terms of increased capacity and efficiency is shown in **Fig. 11**. The H series gas turbines have been developed to further promote an increase in capacity and efficiency based on a great store of experience on the operation of these plants.

Unlike conventional gas turbines, the H series gas turbines are characterized by the fact that the gas turbine blades and vanes are cooled by steam from the bottoming cycle. This feature makes it possible for both output and plant efficiency to be remarkably increased over those of the same size of G series gas turbines. During trial operations in 2001, the heat run of these turbines was performed at an output of 330 MW, which was the approved output of the MHI demonstration plant.

Fig. 9 Long-term reliability verification plant
The figure shows the verification plant in Takasago Machinery Works where trial-operations of the H series gas turbines were performed.

Fig. 10 Tohoku Electric Power Co., Inc. Higashi Niigata Thermal Power Station
The figure shows an external view of the Tohoku Electric Power Co., Inc. Higashi Niigata Thermal Power Station. No. 4-1 series adopts a gas turbine with a turbine inlet temperature of 1450°C It was the first commercial power plant of its type in the world.

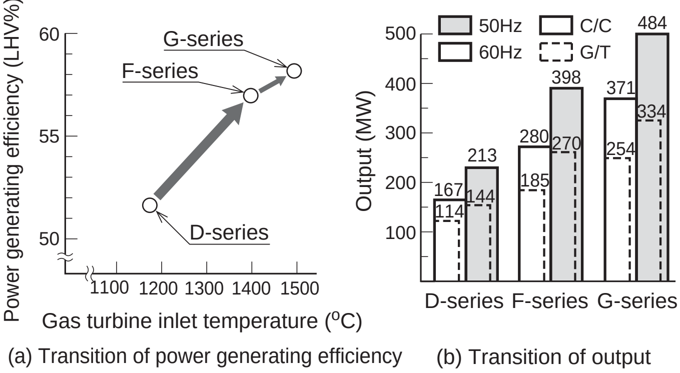

Fig. 11 Transition of increase in capacity and efficiency of gas turbines
The figure shows the transition of gas turbine inlet temperature and variations in power generating efficiency and output.

4. Enhancement of the Use of Energy

4.1 The Challenge of Fuel Diversification

In recent years, fuels have become increasingly diversified in thermal power plants. MHI actively works to develop effective combustion technologies for various types of fuels such as coal, Orimulsion(R), oil coke, biomass, and waste. There is a need in Japan to introduce thermal power generation facilities at a specified rate that utilize coal with high reserve and excellent cost stability for energy security. However, since the reduction of CO_2 discharged into the environment is essential to protect the global environment, use of coal is restricted. Accordingly, coal-fired power generation with high efficiency and low load on the environment is indispensable, and IGCC (Integrated coal Gasification Combined Cycle) is attracting attention as a core technology for this purpose. The development of the IGCC in Japan is being promoted as a national project. MHI installed a range of test facilities such as a pulverized coal feed system, gasifier, porous filters, gas clean up system, as well as a gas turbine combustor in the Nagasaki Research & Development Center. MHI has performed comprehensive verification tests to verify the reliability of the equipment and the stable operation of the total system. The test results are reflected to the design of the 250 MW class demonstration plant (**Fig. 12**) which is planned by the Clean Coal Power R & D Co., Ltd.

With regards to Orimulsion(R), MHI has modified four existing units for Orimulsion(R) firing since the modification of the Kashima Kita Electric Power Corp. No. 2 boiler, at first in Japan in 1991. In 1999, MHI completed the Kashima Kita Electric Power Corp. No. 5 boiler which was newly designed to fire Orimulsion exclusively.

In the field of oil coke, MHI delivered a newly designed 75 t/h exclusively-fired boiler for Mitsubishi Rayon Co., Ltd. Toyama Plant in 1985, and also delivered twenty boilers, including those that had been modified.

With regards to biomass energy utilization technology, MHI has already realized power generation by firing biomass in a boiler. In addition, MHI has been active in the development of biomass fuel power generation technologies, including the "biomass gasified methanol synthesis system" in which biomass material is gasified at high temperature to convert it quickly and efficiently into new easy-to-store and easy-to-transport liquid fuel such as methanol. Currently, MHI performs process verification tests using a 240 kg/day test plant for the Ministry of Agriculture, Forestry, and Fisheries. MHI is also constructing a 2t/day verification plant for a national project adopted by the New Energy and Industrial Technology Development Organization (NEDO) from fiscal 2001 to 2004.

With regards to waste usage, MHI is developing fluidized-bed boilers that use fuels derived from such sources as wooden waste of architectural waste, waste tires and RPF (Refuse Paper and Plastic Fuel).

4.2 High Efficiency Power Generation

Power generation technology with higher efficiency is required from the viewpoint of reducing CO_2 emissions and reducing fuel consumption. There are high expectations for fuel cells that are now under development. High-temperature (1 000°C) solid oxide fuel cells (SOFC) used in combination with a gas turbine can realize highly efficient power generation with 70% (LHV) or more efficiency when LNG is used.

In addition, even if fuel cells are combined with the coal gasification (IGFC: Integrated Coal Gasification Fuel Cell Combined Cycle) mentioned above, a tremendously high levels of efficiency of 60% (LHV) or more can be expected.

In a joint research project carried out between the Electric Power Development Co., Ltd. and MHI, a tubular SOFC system achieved the initially planned continuous operation of 700 hours or more using a 10 kW class pressurized internal reforming module (**Fig. 13**) in 2001. In a joint research project carried out between the Chubu Electric Power Co., Inc. and MHI, a planner type SOFC, which is called as MOLB (Monoblock Layer Built) type SOFC, achieved operation of a cumulative total of 7 500 hours by the operation test of a atmospheric pressure 10 kW class module (**Fig. 14**) in 2001. MHI is developing an SOFC power generation system for early commercialization.

4.3 Distributed Power Supply

The use of heat from a large-scale integrated power supply such as thermal power plants is not easy, since it is installed in a remote area apart from its users (private

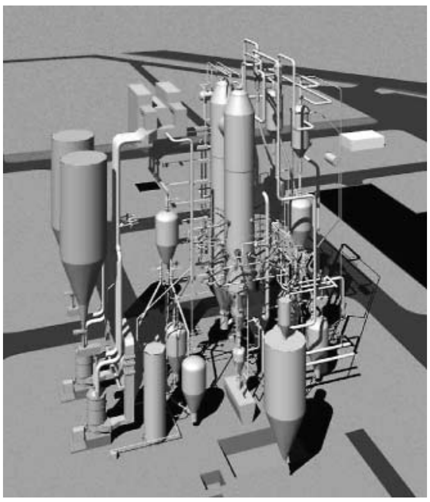

Fig. 12 IGCC demonstration plant
The figure shows a bird's eye view of the coal gasification equipment. Clean Coal Power R& D Co., Ltd. plans to construct a 250 MW class coal gasification combined power generation (IGCC) demonstration plant.

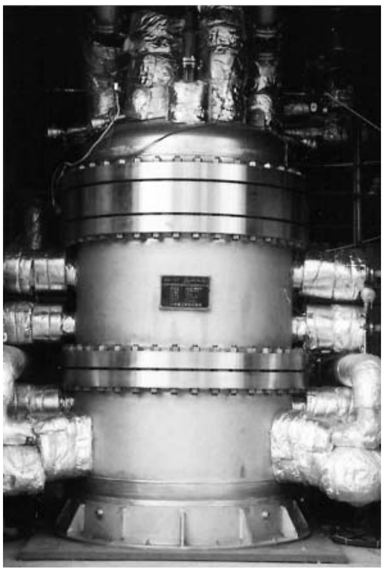

Fig. 13 Tubular type SOFC pressurized 10 kW class module
The figure shows a pressurized, internally reformed 10 kW class module.

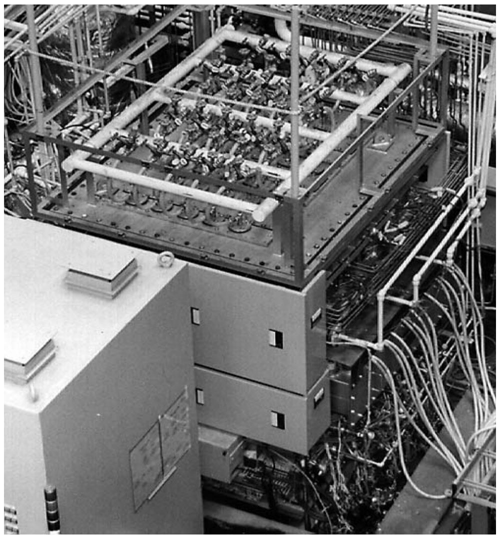

Fig. 14 MOLB type SOFC atmospheric pressure 10 kW class module
The figure shows an atmospheric pressure 10 kW class module.

houses, factories, etc.). Accordingly, some 50 to 60% of the input energy is discharged into sea water etc. As a result, a small capacity distributed power supply (onsite power supply) close to its users is coming to attract growing attention as a means of preventing global warming and increasing energy use efficiency. MHI is developing the distributed power supplies of conventional types of systems such as diesel engines, gas engines, small turbines, and various types of power generation ranging from those utilizing solar power and wind power to fuel cells.

As for conventional types of distributed power supplies, since environmental control values are becoming stricter, gas fuel that emits less CO_2 and harmful substances such as NOx and ash and dirt attracts more attention than liquid fuel, which has been and continues to be the mainstream source of energy. Large-sized gas engines which has achieved low NOx and high efficiency by lean burn system, has been growing over the last several years. In 1990, MHI developed an spark plug prechamber lean burn gas engine in which a rich air-fuel mixture is formed in the prechamber and ignited by an spark plug, and has had a track record. MHI then developed the pilot ignited low pollution high efficiency gas engine MACH 30G (Mitsubishi Advanced engine of Clean & High efficiency) as its successor to the above type of engine. In this system, the lean air-fuel mixture is surely ignited using very small amounts of liquid fuel as source of ignition. Moreover, the engine has achieved efficiency levels as high as 43.5% and has reduced NOx emissions (**Fig. 15**). In addition, MHI has achieved the world's highest level of efficiency for diesel engines at 47% (LHV) in Model KU30B using advanced technologies.

4.4 Recyclable Energy Utilization Technologies

The power generating system utilizing natural energy which was first developed by MHI was a hydraulic power generation system. MHI then developed a geothermal power generation and, since 1980, has been actively involved in wind power generation. Recently, MHI has also been actively engaged in solar power generation and generating power using biomass.

MHI has delivered a large number of various types of turbines for hydraulic power generation over many years. In the year 2000, it delivered Japan's largest capacity (412 MW) power plant with the world's highest head (728 m) to the Tokyo Electric Power Co. Kazunogawa Power Station.

MHI has always been very active in developing advanced technologies for use by geothermal power plants. The company delivered Japan's first hot water type geothermal power plant to the Kyusyu Electric Power Co., Ltd. Otake Power Station. The plant has been operating satisfactorily for 35 years. MHI has also delivered the world's first two-phase-flow transportation double flush cycle power plant to the Kyusyu Electric Power Co., Ltd. Hachoubaru Power Station. In addition, MHI has delivered 84 geothermal turbines to twelve countries around the world.

Since the development of the Japan's first 40 kW plant in 1980, MHI has continued to develop wind power generation plants in response to the demands of the times while reducing costs and increasing reliability. The company has done so using own technologies as Japan's sole large-sized wind turbine manufacturer. Since the latter half of the 1980's when MHI received orders for a large number of 300 kW class plants, the company has produced the blades, which are a key component of such systems, on its own. In a development project for large-sized wind power generation systems for NEDO, MHI completed a 500 kW wind turbine in 1996, constructed the base for wind turbine upsizing technology, and developed a 600 kW wind turbine (**Fig.16**) in 1998, as well as Japan's first 1 000 kW wind turbine in 1999. As a result, MHI has thus far delivered a total of approximately 1 400 wind turbines, representing a total output of some 620 MW of power, all around the world as of April 2002.

From the beginning of development, an inexpensive induction generator has been used for the wind turbine. However, the development and introduction of a variable

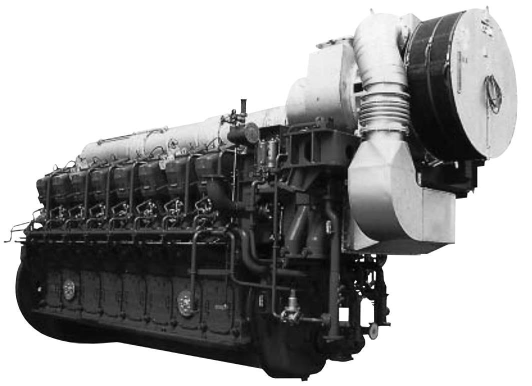

Fig. 15 Highly efficient gas engine MACH-30G
The figure shows the appearance of the advanced MACH-30G gas engine, which achieved the world's maximum level of power generating efficiency of 43.5% at NOx 200 ppm (converted to O_2 0%).

Fig.16 Mitsubishi Wind Turbine Generator
The figure shows Mitsubishi 600 kW Wind Turbine Generators for a wind farm in USA.

speed synchronous generator wind turbine, which can finely control the output of the wind turbine and is power system-friendly, has also been advanced by MHI. MHI has also developed a permanent magnet variable speed gearless synchronous windmill in joint research work with Mitsubishi Electric Corporation. The 300 kW plant has been in operation since 2000, and a 600 kW plant has been in operation since 2002. A 2 000 kW synchronous generator wind turbine is due to start operation in 2003.

In addition, MHI has developed a new 1 000 kW wind turbine with longer blades so that a sufficient amount of power can be generated even in areas of low wind velocity.

Solar power generation has attracted much attention, particularly in this century. For its part, MHI has commercialized a highly efficient amorphous silicon solar cell (**Fig. 17**) based on its exclusive high-speed plasma CVD technology. The amorphous silicon solar cell can be expected to be economical in the future, since its material can be obtained easily. MHI began mass-production of the solar cell using equipment with a capacity of 10 MW per year, constructed at the Nagasaki Shipyard & Machinery Works. An integrated panel with an area as large as 1.4 m x 1.1 m has been the focus of attention because of its ease of design and workability. Technologies related to solar panels are now under development with an aim to further increase the efficiency.

Fig. 17 Highly efficient amorphous silicon solar cell
The figure shows an example of the installation of an amorphous silicon solar cells. The solar cells can contribute to environmental protection even in a home.

5. Conclusion

Today, energy consumption is ever on the increase with the construction of a more affluent society. Accordingly, there has been sharply growing interest in issues concerned with global warming, and energy security all over the world.

To address these issues, MHI has continually striven, ahead of its time, to increase the efficiencies of power generation equipment and diversify applications of fossil fuels. MHI is also looking forward to promoting ever-greater increases in the efficiency of power generating systems and the development of environmentally friendly technologies in the future. These efforts include research and development of new energy systems such as next-generation gas turbines, wind turbines, solar cells, biomass utilization, coal gasification, and fuel cells, and so on. We, MHI, will challenge to innovate energy systems continuously for tomorrow.

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Akira Tominaga


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