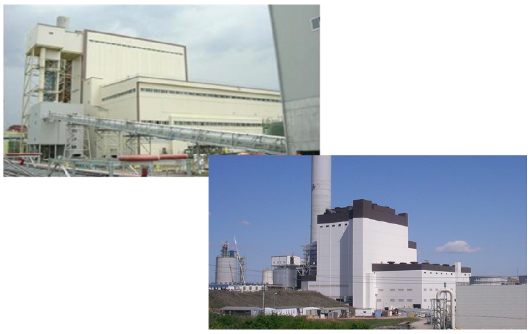
Mitsubishi Hitachi Power Systems Ltd. Boiler Business and Technology Development



YASUHIRO UKEGUCHI*1 KAZUHITO SAKAI*1
SHIGEHARU KOKURYO*2 KAZUHIKO SAITO*3
TAKAYUKI SUTO*4 TAKATOSHI YAMASHITA*5

Mitsubishi Hitachi Power Systems, Ltd. (MHPS) was established by merging the thermal power generation business sectors of the two companies: Mitsubishi Heavy Industries, Ltd. (MHI) and Hitachi, Ltd. (HITACHI). Both companies had separately pursued technologies for the effective and clean utilization of coal by employing their own firing systems. In addition to their business histories regarding the development of such technologies and the latest technological trends, this report also addresses our future direction as MHPS in the development of boiler technologies.

1. Introduction

Merging the thermal power generation business sectors of MHI and HITACHI, MHPS was thus founded in February 2014. Before this consolidation, the two companies had separately developed and advanced their own technologies to realize the cleaner utilization of coal-derived energy, by employing circular or opposed firing systems in thermal power generation boilers. This report introduces the business histories of such technological development, along with the latest trends of clean coal technologies. Our business activities as MHPS for the development of boiler technologies, which have been enhanced through the synergetic effects of the consolidation, are also reported.

2. Clean coal technologies

2.1 Ultra-supercritical (USC) power plants

From the 1990s, the use of inexpensive coal as a fuel became common, increasing the need for establishing environmentally-sound power plants. Accordingly, MHPS improved the efficiency of steam power generation by elevating the temperature and pressure of applicable steam conditions. The latest plants have enabled a steam condition called USC (i.e., exceeding both the pressure of 24.1 MPag and the temperature of 593°C). USC power generation is considered to be a technology for the realization of the highly efficient and environmentally-sound use of coal. USC power plants are becoming more common in other countries, as well as in Japan.

Figure 1 shows the steam conditions of MHPS-supplied steam power generation facilities and their operation commencement years. In 1968, we manufactured and installed our first supercritical (SC) oil-fired boiler at Unit 3 of the Chita Thermal Power Station of Chubu Electric Power Co., Inc. (500 MW, 24.1 MPag and 538/538°C) and thereafter, changing the applicable fuel from oil to gas and eventually to coal. In 1981, we provided our first SC coal-fired boiler to Unit 1 of the Matsushima Thermal Power Station of J-POWER (500 MW, 24.1 MPag and 538/538°C). In the 1990s, the invention of various types of high-strength ferritic steel enabled the production of main pipes and headers for 600°C class steam condition, which had been difficult before. The

*1 Deputy General Manager, Boiler Products Headquarters, Mitsubishi Hitachi Power Systems, Ltd.
*2 Manager, Boiler Business Strategy Planning Department, Boiler Products Headquarters, Mitsubishi Hitachi Power Systems, Ltd.
*3 Chief Staff Manager, Boiler Business Strategy Planning Department, Boiler Products Headquarters, Mitsubishi Hitachi Power Systems, Ltd.
*4 Manager, Boiler Engineering Department, Boiler Products Headquarters, Mitsubishi Hitachi Power Systems, Ltd.
*5 Manager, Kure Boiler Engineering Department, Boiler Products Headquarters, Mitsubishi Hitachi Power Systems, Ltd.

steam temperature was then increased to improve the plant efficiency, with a goal of materializing more environmentally-sustainable plants. In 1995, we supplied a USC coal-fired boiler with a reheat steam temperature of 593°C to Unit 1 of the Nanao-ohta Thermal Power Station of Hokuriku Electric Power Company (500 MW, 24.1 MPag and 566/593°C). The main and reheat steam temperatures were then increased gradually. Our boiler products later on include Unit 2 of the Matsuura Thermal Power Station of J-POWER with an increased main steam temperature of 593°C (1,000 MW, 24.1 MPag and 593/593°C) in 1997, Unit 1 of the Misumi Thermal Power Station of Chugoku Electric Power Co., Inc., in which both the main and reheat steam temperatures reach 600°C (1,000 MW, 24.5 MPag and 600/600°C) in 1998, and Unit 2 of the Tachibanawan Thermal Power Station of J-POWER with an applicable reheat steam temperature of 610°C (1,050 MW, 25.0 MPag and 600/610°C) in 2000.

Figure 2 gives a quick look of our USC/SC coal-fired boilers installed worldwide. As mentioned before, USC/SC boilers are commonly used in other countries, as well as in Japan. MHPS has constructed and provided a total of 153 boilers around the world.

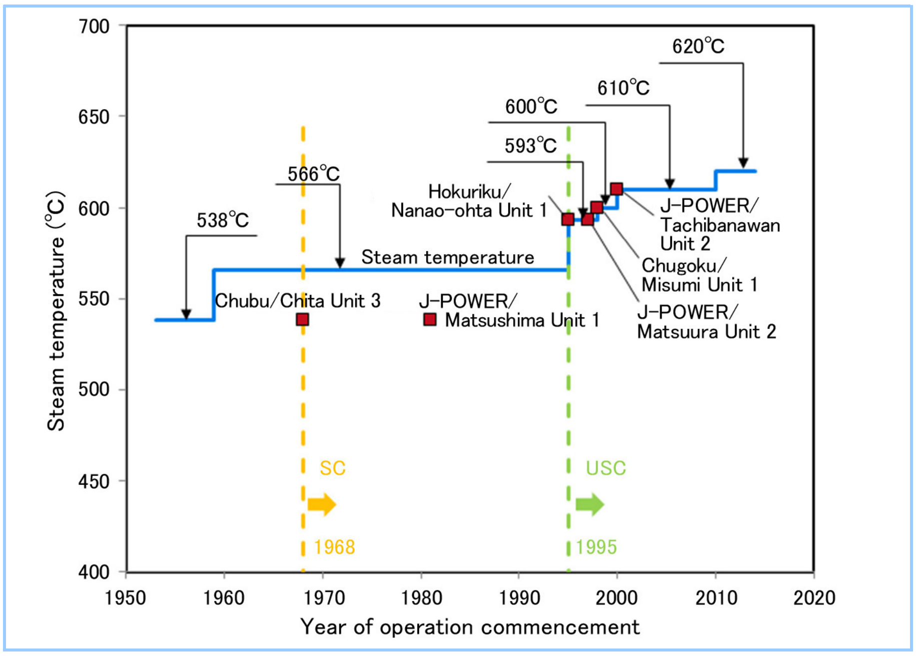


Figure 1 Steam conditions of thermal power generation facilities and their operation commencement years

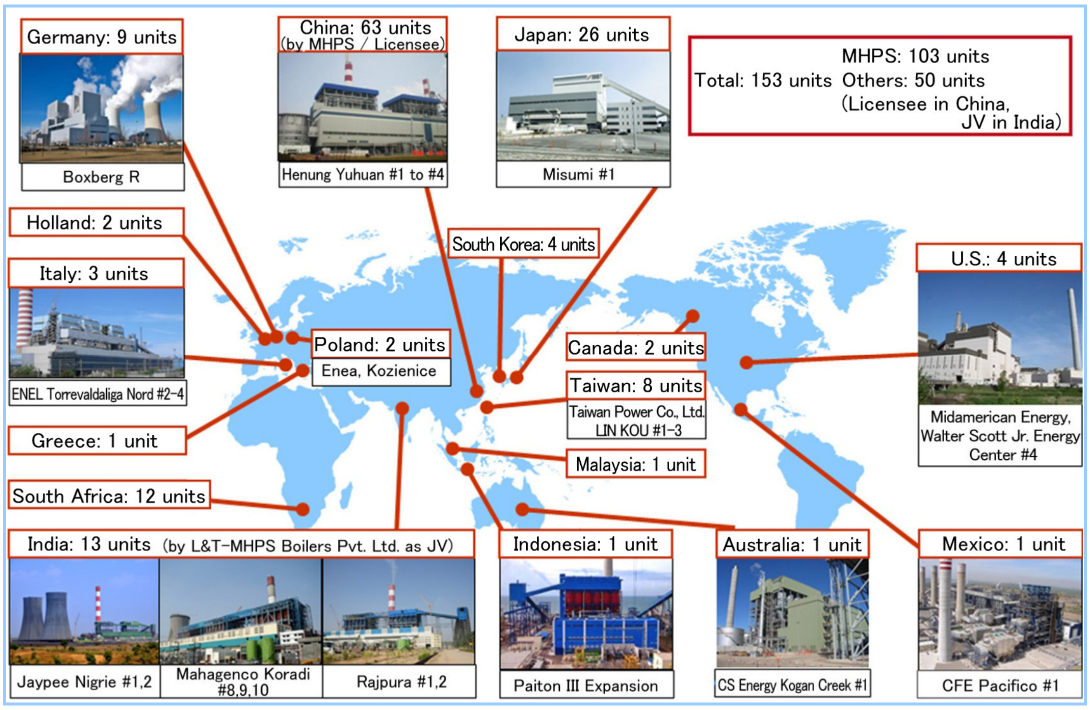


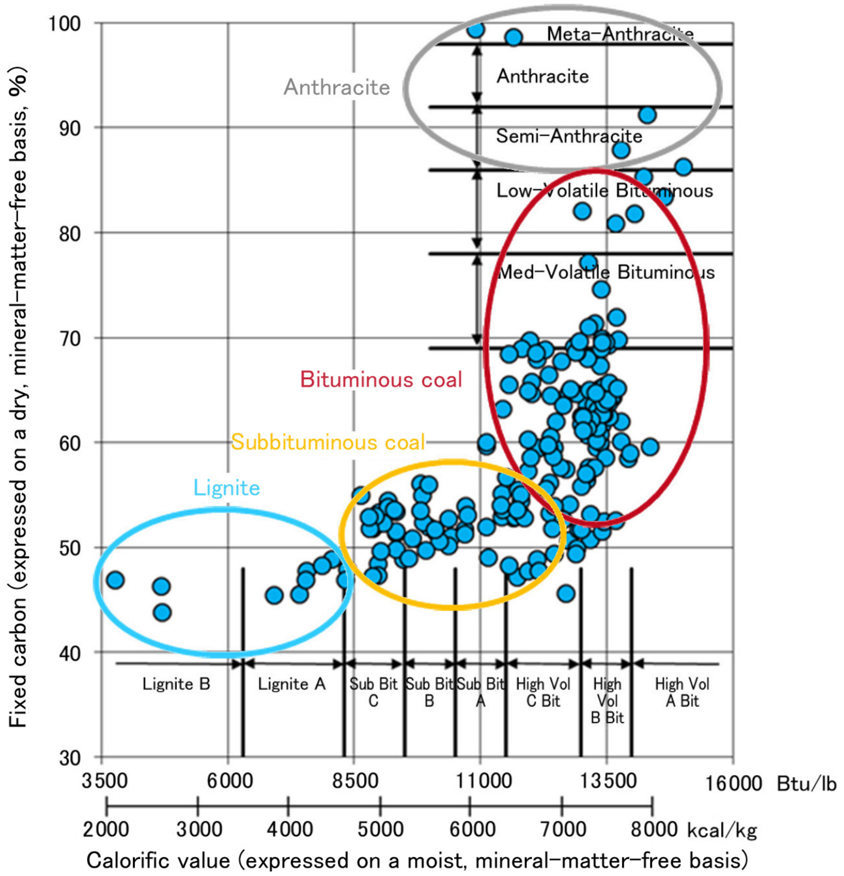
Figure 2 Our USC/SC coal-fired boilers installed worldwide

2.2 Application of low-rank coals

In recent years, in addition to bituminous coal of good quality as a fuel, there is growing demand for less costly low-rank coals such as subbituminous coal and lignite to be applied as a fuel in coal-fired power plants. In low-rank coal-fired mine-mouth power generation, which is often the case with overseas projects, USC/SC steam conditions are frequently employed for environmental reasons. The number of USC/SC power plants with the design of low-rank coal application is increasing.

Among such trends, MHPS allows itself to be actively involved in low-rank coal-fired USC/SC boiler projects, applying its abundant low-rank coal-firing technologies accumulated over the years to USC/SC boilers. **Figure 3** shows the designed range of applicable coals[Note] for power plants that MHPS was in charge of, according to the classification by the American Society for Testing and Materials (ASTM). We supplied boilers with a wide variety of applicable coals including lignite and anthracite, which proves our rich expertise in the field. Utilizing such advantages, MHPS has designed optimal low-rank coal-fired boilers, the demand for which has been increasing in recent years, and offers highly reliable USC/SC boilers of high efficiency for low-rank coals.

(Note) Determined range of applicable coal properties at the time of coal-fired power plant design



・Equilibrium moisture: moisture content of a coal sample when being placed and in equilibrium with a relative humidity of 96-97% at 30°C
・Mineral-matter-free basis: an analytical value obtained based on the assumption that no mineral matter is contained
・Fixed carbon: an industrial analytical value, determined by subtracting the percentages of moisture, volatile matter, and ash from 100
・Dry, mineral-matter-free basis: an analytical value obtained based on the assumption that neither moisture nor mineral matter is contained
・Btu/lb: British thermal unit/lb : Btu/lb: British thermal unit/lb

Figure 3 MHPS' designed range of applicable coals

Figure 4 gives the exterior view and major specifications of Paiton III, which is Indonesia's first SC boiler. The fuel fired is Indonesian subbituminous coal with a moisture content of 30%. **Figure 5** is the exterior view and major specifications of Boxberg R, which is a lignite-fired USC boiler in Germany. German lignite is known by its very high moisture content and that of the coal fired in this boiler is approximately 60%. **Figure 6** shows the exterior view and major specifications of Rajpura Unit 1, which was constructed by LMB, a joint venture of MHPS and local Indian company Larsen & Toubro. The applied fuel is bituminous coal with a high ash content of 30%.

These projects are all related to the firing of low-rank coals under SC or USC steam conditions. The designs of these boilers are based on MHPS's extensive experience and expertise in coal, ensuring very high reliability.

Output :	866MW
Main Steam Flow :	2,695 t/h
Main Steam :	538 °C / 24.9 MPag
Reheat Steam :	566 °C
Commercial Operation :	April 2012
Fuel :	Sub-bituminous coal
Thermal efficiency :	Approx. 2 ~ 3% better*1

*1: Relative value as compared with Sub-critical plant (16.7MPag, 538/538°C)

Figure 4 Subbituminous coal-fired SC boiler, Paiton II (Indonesia)

Output :	1 x 670MW
Main Steam Flow :	1,760 t/h
Main Steam :	600 °C/ 29.4 MPag
Reheat Steam :	610 °C
Commercial Operation :	October 2012
Fuel :	German Lignite coal
Thermal efficiency :	Approx. 5 ~ 6% better*1

*1: Relative value as compared with Sub-critical plant (16.7MPag, 538/538°C)

Figure 5 Lignite-fired USC boiler, Boxberg R (Germany)

Output :	700MW
Main Steam Flow :	2,322 t/h
Main Steam :	565 °C / 24.1 MPag
Reheat Steam :	593 °C
Commercial Operation :	February 2014
Fuel :	Bituminous coal
NOx (ppm) :	116 (actual) / 365 (limits)
Thermal efficiency :	Approx. 4 ~ 5% better*1

*1: Relative value as compared with Sub-critical plant (16.7MPag, 538/538°C)

Figure 6 High ash content coal-fired SC boiler, Rajpura Unit 1 (India)

2.3 Low-NOx combustion system

To contribute to environmental conservation from the aspect of combustion, we also develop coal combustion technologies in addition to USC/SC technologies with improved steam conditions. As shown in **Figure 7**, we have continuously worked on the development of better low-NOx combustion technologies since the 1980s. As the current latest models, there are the M-PM burner (i.e., multiple pollution minimum burner) for circular firing systems and the NR3 burner (NOx reduction burner for small-to-medium capacity facilities), as well as the NR4 burner (for large capacity facilities) for opposed firing systems. These models have been developed for further NOx reduction in a flame by the enhancement of rapid ignition. The enhancement of rapid ignition can also achieve higher combustibility and reduce unburned carbon in fly ash, which usually have inverse relation to low NOx combustion.

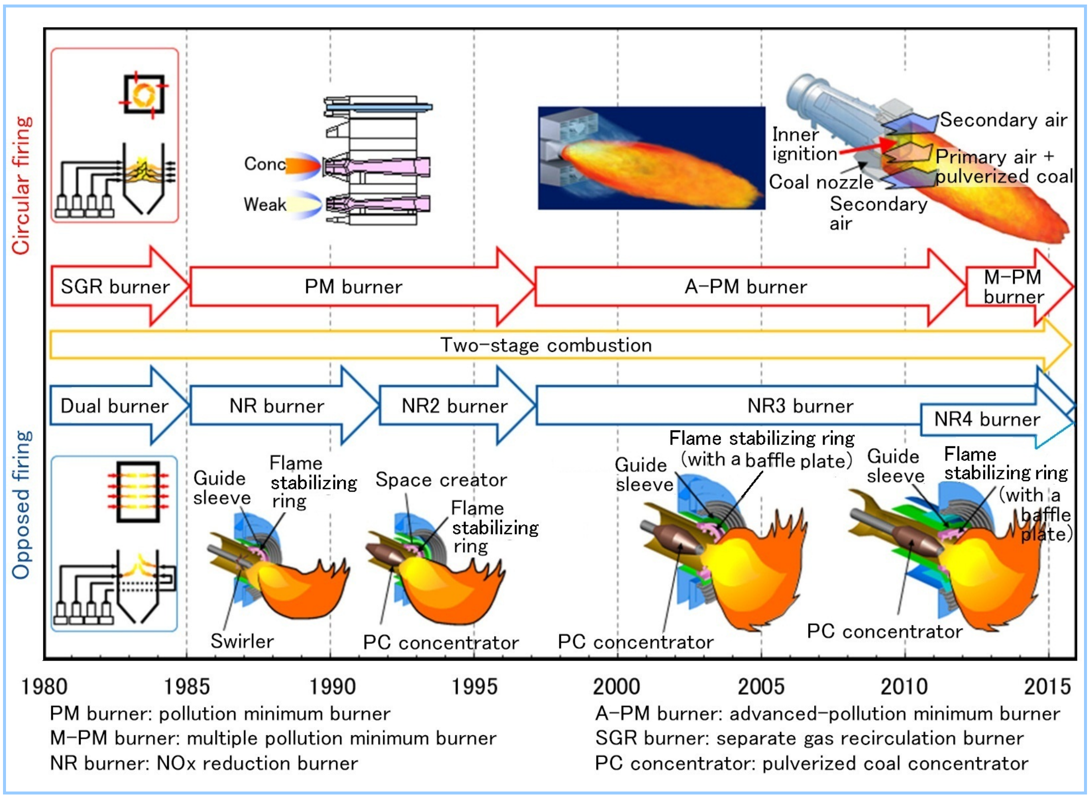


Figure 7 History of development of low-NOx combustion technologies

3. Latest trends of clean coal technologies

3.1 Advanced ultra-supercritical (A-USC) plants

To improve the efficiency of coal-fired power plants, MHPS is engaged in the development of A-USC technologies to achieve even higher steam temperatures, which can be a continuation of conventional pulverized coal-fired power generation systems. Development targeting the steam temperature of ≥700°C and the net thermal efficiency of 46-48% (on the basis of higher calorific value) is currently under way as a national project with a subsidy from the Ministry of Economy, Trade and Industry (METI).

The major domains requiring technological development to realize the steam temperature of ≥700°C include materials, manufacturing technique and lifetime assessment methodology. As shown by the project timetable in **Figure 8**, our main activities between 2008 and 2012 are basic tests on the candidate materials including the one we have developed for this purpose. From 2013 onward, field tests at the steam temperature of 700°C have been conducted using the candidate materials.

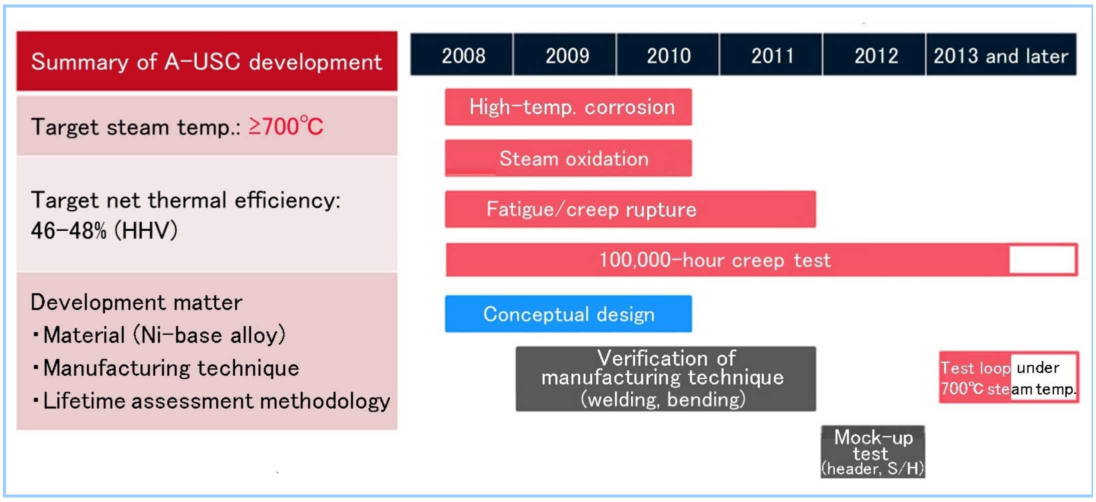


Figure 8 Schedule for the development of A-USC boiler

The basic tests of the candidate materials include the steam oxidation test, high-temperature corrosion test, welding test, bending test, material long-term durability assessment, and mock-up fabrication test of the real-scale pressure parts. The results are given below. **Figure 9** shows the photographs taken during the welding test, bending test and mock-up fabrication test.

- Steam oxidation test: The test was conducted with a maximum test duration of 10,000 hours, examining the scale property. The oxidation resistance of test materials were as good as or superior to the existing materials under the same test conditions.
- High-temperature corrosion test: The test was conducted on the candidate materials to examine the corrosion behavior. The corrosion resistance of test materials were as good as or superior to the existing materials under the same test conditions.
- Welding test: The welding techniques for the plates and small/large-bore pipings of each candidate material were established.
- Bending test: The test was conducted using small/large-bore pipings of each candidate material. The techniques for flawless bending in designed dimensions were established using the existing facilities.
- Material long-term durability assessment: A long-term creep test on welded joints and bent parts of each candidate material is under way. At this point, the obtained data on rupture characteristics indicate their strength being equivalent to the base metal.
- Mock-up fabrication test of the real-scale pressure parts: The mock-ups of the superheater outlet header, the reheater outlet header, and the superheater tube coil, all of which were supposed to be subjected to a steam temperature of ≥700°C, were manufactured. Their productivity as real-scale structural components was verified.

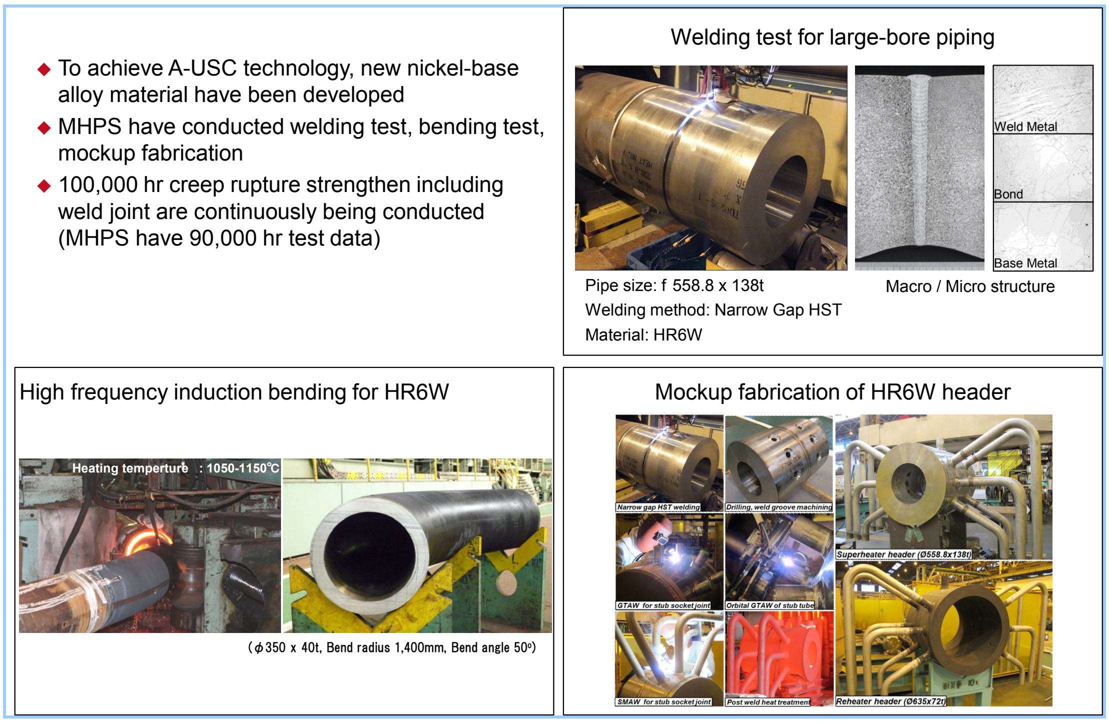


Figure 9 Candidate material development tests for A-USC boiler

3.2 Integrated coal gasification combined cycle (IGCC)

IGCC is a power generation system in which the coal fuel efficiency can be elevated by integrating a combined cycle system and a coal gasification process. **Figure 10** summarizes IGCC technology and its domestic projects (demonstration and commercial Plants). MHPS participates in all of the projects, dealing with both air-blown and oxygen-blown systems.

As the air-blown IGCC project, demonstration tests were conducted using a 250 MW output class demonstration unit of Clean Coal Power R&D Co., Ltd, which was jointly founded by the major power companies. In March 2013, all of the tests were completed and the construction of commercial units became technically possible. The ownership of the demonstration unit was then transferred to Joban Joint Power Co., Ltd., whereby it restarted operation as a commercial unit, Nakoso Unit 10. In 2013, the continuous operation time reached 3,917 hours, surpassing the previous world record by quite a large margin.

Following the demonstration by the aforementioned 250 MW demonstration unit (Nakoso), another air-blown IGCC project using a large unit of 500 MW output class is going to be started with a view to commencing operation in the beginning of 2020. This project involves the construction of large IGCC units at the Hirono Thermal Power Station of Tokyo Electric Power Co., Inc. (TEPCO) and at the Nakoso Power Station of Joban Joint Power Co., Ltd. (jointly founded by companies such as TEPCO). It is expected to facilitate the economic recovery of Fukushima by consolidating the industrial infrastructure and creating job opportunities.

Last year, a consortium led by MHPS received an order from TEPCO for design work in the "Project to Create World's Most Advanced Coal-fired Thermal Plant," and undertook the design work. In this project, a state-of-the-art gas turbine will be employed to improve efficiency, targeting CO_2 emissions lower than the latest USC power plants. Based on the demonstration test results by the 250 MW IGCC demonstration unit (Nakoso), this new IGCC system will be designed to have a wide range of applicable coals including low-rank coals with high moisture content.

On the other hand, for oxygen-blown gasification, MHPS participates in the large demonstration unit test project (subsidized by METI). The project is mainly undertaken by Osaki CoolGen Corporation, which was jointly established by Chugoku Electric Power Co., Inc. and J-POWER. It addresses "oxygen-blown IGCC technology," "IGCC with a CO_2 separation/capture facility" and "integrated coal gasification fuel cell combined cycle (IGFC) with a CO_2 separation/capture facility." According to the project plan, the first stage is dedicated to the demonstration of oxygen-blown IGCC, followed by the demonstration of IGCC with a CO_2 separation/capture facility as the second stage. At the third stage, IGFC with a CO_2 separation/capture facility will be demonstrated. In March 2013, the construction of the demonstration test facility started on the premises of the Osaki Power Station of Chugoku Electric Power Co., Inc. The operation of the first-stage demonstration test is to be commenced in 2016.

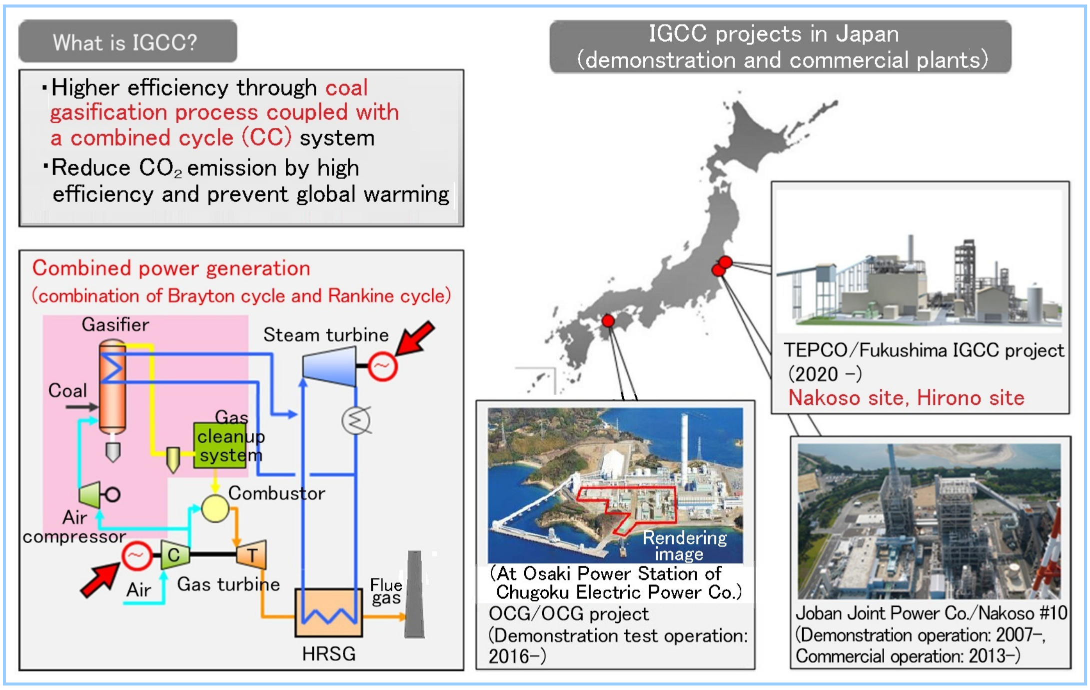


Figure 10 Summary of IGCC technology and its domestic projects

4. Technological development as MHPS

With the synergetic effects of the corporate merger, we are accelerating the development of new technologies to allow us to provide boiler plants with better efficiency and higher reliability. This section introduces a newly-built large combustion facility for the development of new combustion technologies and mutual benefits in non-destructive boiler inspection techniques.

In October 2014, the combustion test facility with a coal combustion capacity of 4 t/h (world's largest class) was completed (**Figure 11**). The purpose of this facility is to realize an advanced combustion technology, which is the foundation of boiler performance factors such as low NOx, low unburned carbon and low excess air ratio, by integrating the combustion technologies of MHI and HITACHI (including the former Babcock-Hitachi K.K.). The fuels usable in the facility cover a wide variety of types applied in the real units, such as bituminous coal, subbituminous coal, lignite, anthracite, biomass, petroleum coke and residual oil. By considerably improving the assessment ability regarding the combustion of inexpensive low-rank fuels, we will realize a fuel cost reduction and enhanced operability (both of which are most important for our customers), and eventually contribute to the realization of less environmental impact. This combustion test facility is equipped with the prominent functionality that backs up the development of pioneering technologies, including obtaining accurately the same fluid and combustion conditions as actual boilers and advanced combustion measurement devices to assess such conditions.

Figure 11 Exterior view of the 4 t/h combustion test facility

As shown in **Figure 12**, the accuracy of computational fluid dynamics (CFD) will be improved by reflecting the latest test data in simulations, consequently enabling us to simulate a combustion test for result prediction, effectively execute the test and obtain an accurate estimation of actual unit performance.

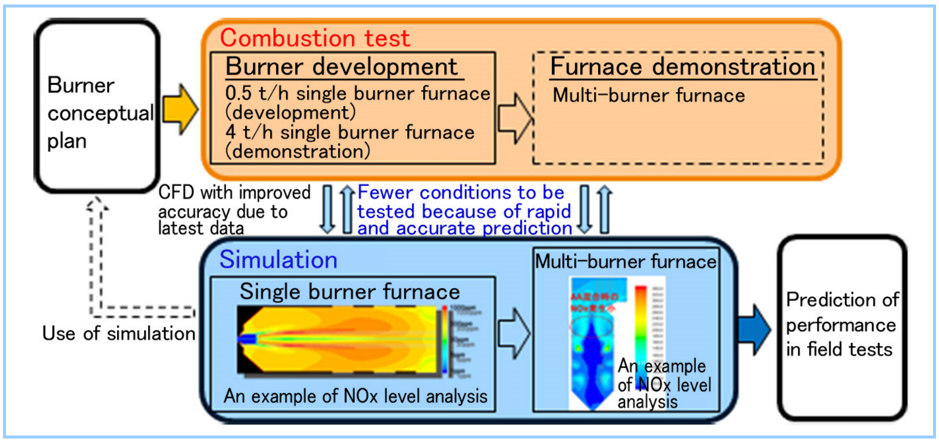


Figure 12 How to utilize the 4 t/h combustion test results

In after-sales service, inspection techniques can contribute to the yielding of better plant reliability, and those techniques developed and practically used in the two former companies are combined and utilized to the best effect. Especially regarding the phased array UT technique, which is effective in detecting early stage creep damage inside high-temperature piping welds, the unified procedure was established while developing a special ultrasonic sensor to make it more advanced and speedy. Application to the relevant units (inspections of which were carried out by the former companies) has already commenced. Special inspection techniques such as the inner UT system to effectively measure the thickness of heat transfer tubes (**Figure 13**) are also to be mutually exploited, whereby further synergetic effects will be expected to be result.

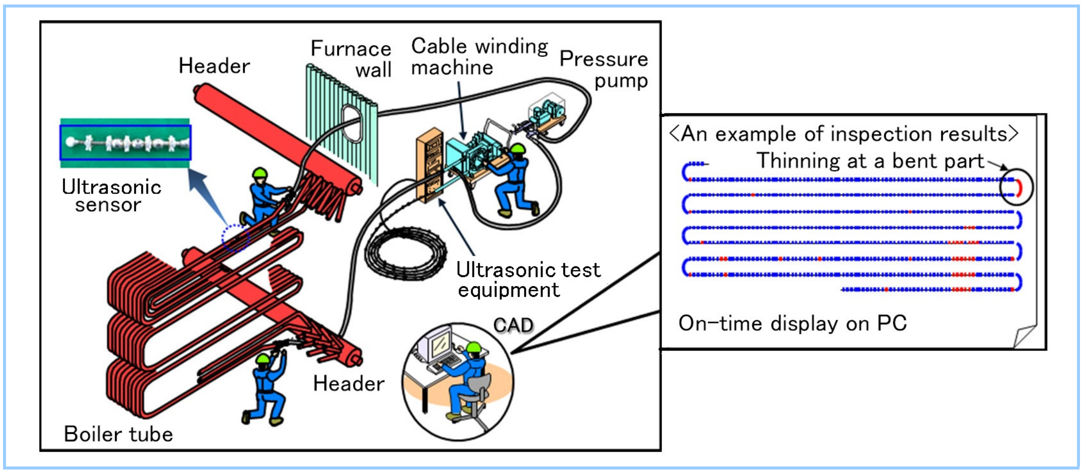


Figure 13 Outline of the inner UT inspection (thickness measurement from the tube inner surface)

5. Conclusion

With the synergetic effects brought about by the integration of the thermal power generation business sectors of MHI and HITACHI, MHPS will further widen the applicable fuel range and improve clean coal technologies. We supplied a total of 153 coal-fired USC/SC boilers as clean coal technology. Based on our experience with the use of various coals, we will provide state-of-the-art USC boilers in which not only high-rank bituminous coal, but also low-rank coals such as subbituminous coal, lignite and bituminous coal with high ash content, can be fired, thus continuously contributing to society in terms of environmental conservation.

We also develop the latest high-efficiency coal-fired power generation technologies such as A-USC and IGCC. The development of A-USC is currently under way as a national project subsidized by METI, and field tests at the steam temperature of 700°C are being conducted on the candidate materials. With regard to IGCC, the air-blown IGCC system has already been demonstrated and applied commercially to the Nakoso 250 MW unit, and the latest project deals with large IGCC of the 500 MW output class. For the oxygen-blown IGCC system, MHPS is participating in the large demonstration unit test project (subsidized by METI), mainly undertaken by Osaki CoolGen Corporation (which was jointly founded by Chugoku Electric Power Co., Inc. and J-POWER). The project addresses "oxygen-blown IGCC," "IGCC with a CO_2 separation/capture facility" and "IGFC with a CO_2 separation/capture facility."

The synergetic effects are ubiquitous. Examples include a new combustion test furnace enabling both firing systems (circular and opposed) which had been employed by the two former companies and the mutual exploitation of the latest inspection techniques in after-sales service. Not only in new construction projects, but also in after-sales service, we will offer our customers MHPS's products and technologies with the values maximized by our corporate consolidation.