MITSUBISHI HITACHI POWER SYSTEMS, LTD.
JOBAN JOINT POWER CO., LTD.

Achieving Higher Efficiency by Gasifying Coal –
"Integrated Coal Gasification Combined Cycle (IGCC)"

Power generation efficiency is 48 to 50%
Aim for reduction of coal consumption by 20% (the most advanced thermal power generation ratio of the past)

Coal is an inexpensive fuel, and the amount of its minable reserve is larger than the amount of minable reserve of any other fossil fuel. In addition, coal is present in many countries around the world unlike oil, natural gas, etc., which are present only in certain countries. On the other hand, coal emits more CO2 than any other fossil fuel when burned and contains large amounts of environmentally hazardous substances such as sulfur and ash.

Because of these facts, efforts to develop and put into practical use a next-generation coal-fired thermal power generation system with smaller coal consumption and higher power generation efficiency than existing coal-fired thermal power generation systems (which is called the "Integrated Coal Gasification Combined Cycle (IGCC)") have been pursued using technologies of MITSUBISHI HITACHI POWER SYSTEMS, LTD. (MHPS; the company name at the time was Mitsubishi Heavy Industries, Ltd.) and making use of the NEDO project and other projects, with electric power companies leading the research and development.

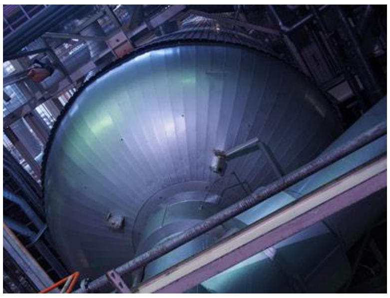
The development of the IGCC technology started in 1983 with experiments conducted at the Central Research Institute of Electric Power Industry using 2-ton/day basic experiment equipment. In 1986, a 200-ton/day pilot plant was constructed on the premises of the Nakoso Power Station (located in Iwaki City of Fukushima Prefecture) of JOBAN JOINT POWER CO., LTD. Within the project of NEDO. In 1991, research on the operation of the pilot plant using the plant was started. The research encountered many problems in the beginning, but ultimately 789-hour continuous operation was achieved in 1996, the year in which the project was completed.

After completion of the project, various tests for realizing a demonstration plant were conducted at the Comprehensive IGCC Test Facility in the Nagasaki Research Institute of Mitsubishi Heavy Industries, Ltd. As a result, a 250,000kW-class demonstration plant (owned by Clean Coal Power R&D Co., LTD.) was constructed on the premises of the above-mentioned Nakoso Power Station. The demonstration plant achieved power generation efficiency on par with that of state-of-the-art coal-fired thermal power stations. Thereafter the plant was taken over by JOBAN JOINT POWER CO., LTD., and, started operation as a commercial plant on June 30, 2013. In December 2013, the plant demonstrated its high reliability by achieving 3917-hour continuous operation, which set the world record for IGCC.

This success showed that it was possible to achieve coal-fired thermal power plants whose coal consumption is about 20% less than that of traditional coal-fired thermal power plants and whose power generation efficiency is 48 to 50% (in terms of LHV at the upstream end of power transmission). Currently, a plan to construct two 500,000kW-class high-efficiency demonstration plants is being made as part of the project for establishing power sources for helping Fukushima recover from the effects of the earthquake (The two demonstration plants will be put into operation in the early 2020s).

Gas cleanup facility

Photo shows the gas cooling and cleaning towers.



View from the bottom of gasifier

Piping to transport air to gasifier

Nakoso Power Plant No. 10 unit of Joban Joint Power Company achieved a new world record for IGCC continuous operation.

Column: Project for the Development of an Entrained Bed Coal Gasification Power Generation Plant

Q. Why did this project start?

Japan relies on other countries for about 90% of the energy resources it uses, and changes in trends in the international demand and supply of energy resources can seriously affect social and economic activities in Japan. Among these energy resources, coal is an economical energy resource and the stability of supply of coal is higher than the stability of supply of any other fossil fuel because coal occurs in many countries around the world and it estimated to be minable for at least the next 109 years. For these reasons, coal is regarded in Japan as an important energy resource for the nation in the future as well. However, there are environmental challenges that must be addressed including the fact that coal emits more CO2 than any other fossil fuel when burned (per unit heat generated). After the two oil crises the nation experienced, Japan has pursued the development of technologies for effective utilization of coal along with the development of energy-saving technologies and new energy sources.

Today, not only diversifying energy resources but also reducing environmental impacts by developing "clean coal technologies" including measures to alleviate global warming has become an important task.

Q. What was the aim of the project?

IGCC is a combined power generation system that transforms coal into flammable gas in a high-temperature, high-pressure gasification furnace, introduces the obtained flammable gas into gas turbines to generate electricity, and collects the waste heat from the gas-based power generation in the form of steam and uses the collected steam to generate electricity with steam turbines. This project aimed at increasing types of coals that can be used for coal-fired thermal power generation and reducing the environmental impacts of coal-fired thermal power generation by putting IGCC into practical use, to achieve more effective utilization of coal, which is more economical than other fossil fuels and whose supply is more stable than other fossil fuels, because the problem of increasing international demands for energy resources against the limited supplies and with ongoing sharp rises in the prices of energy resources. In particular, the air-blown IGCC technology adopted by this project as a candidate technology is a revolutionary technology that is attracting attention not only from Japanese companies but also from overseas companies for its high efficiency and reliability. Air-blown IGCC requires the establishment of new technologies such as the two-stage, two-chamber entrained bed technology that efficiently gasifies pulverized coal by using air. In this project, a demonstration plant (of the same type as commercial units) whose output (250,000kW) was one-half the output of commercial units (500,000 to 600,000kW) was constructed and operation tests were conducted using the demonstration plant, to verify that the reliability, durability, efficiency and economic efficiency required for the introduction of commercial IGCC systems can be achieved.

Q. What is the role of NEDO?

The development of IGCC was initiated after the first oil crisis with the aim of enabling Japan to cope with further oil crises. In response to the increasing demand for the development of coal-based high-efficiency and environmentally-friendly power generation technologies, NEDO conducted IGCC feasibility studies during the period from 1983 to 1985. A research plan for IGCC was developed in 1985 based on the results of the feasibility studies, and it was decided to develop a pilot IGCC plant.

Because it was expected that putting the technology into practical use would involve high technological risks and require a long development period and huge development investments, the involvement of the national government was essential. So, the Ministry of Economy, Trade and Industry and NEDO have actively supported the development and demonstration tests of IGCC during the period from 1986 to 2009.

IGCC in full scale operation after thirty years of development

Japan experienced two oil shocks in the 1970s. This led to recognition of the importance of energy security, and seeking diversification of energy sources to reduce oil dependence became a national concern. Accordingly, coal was once again highlighted due to its more even distributions throughout the world as well as the high quantities of extractable resources. But coal has certain disadvantages: it contains many elements causing air pollution such as sulfur and ash, and, when used as fuel, produces a larger amount of carbon dioxide than any other fossil fuels. As such, the environmental burden from using coal is considerable.

In this context, in 1983, NEDO embarked on research and development of Integrated Coal Gasification Combined Cycle (IGCC), a next-generation coal-fired power plant with higher efficiency than conventional coal-fired power plants.

Efforts to put IGCC into commercial use continued even after the NEDO project had ended. These were taken over by Clean Coal Power R&D Company founded jointly among the government and major power companies. A research company successfully converted it into a demonstration plant and operated the plant on a demonstration basis. After continuous development over some 30 years, on June 30, 2013, an IGCC plant capable of producing critical electricity of 250 MW began commercial operations on the premises of Nakoso Power Plant of Joban Joint Power Company.

In December 2013, the IGCC plant achieved the world's longest continuous operation of 3,917 hours as an IGCC facility. The plant also recorded a net thermal efficiency of 42.9%, having proved to be of sufficient quality for commercial use in terms of essential elements necessary for a power plant, such as high reliability, energy-saving performance, and CO2 emissions effects.

Currently, a project is in progress at Nakoso Power Plant to construct a demonstration plant (two 500 MW class facilities) capable of producing twice the power of No.10 unit and having much higher efficiency. The demonstration plant is scheduled to start operations in the early 2020s to provide power sources for reconstruction of areas of Fukushima prefecture impacted by the 2011 Great East Japan earthquake and tsunami. To date, No.10 unit at Nakoso Power Plant has hosted more than 3,000 visitors from organizations with concerns in the energy sector from more than 24 countries. Japan's IGCC technology is attracting a great deal of attention from the industry throughout the world, and there are expectations on expansion worldwide in future.

The Nakoso Power Plant's No. 10 unit is located in Iwaki city, Fukushima prefecture.
This 250 MW IGCC power plant (formerly demonstration plant) is currently connected to the grid of the Tokyo Electric Power Company (TEPCO), serving as an indispensable power source to support reconstruction efforts after the Great East Japan earthquake and tsunami disaster.

IGCC in full scale operation after thirty years of development

Japan experienced two oil shocks in the 1970s. This led to recognition of the importance of energy security, and seeking diversification of energy sources to reduce oil dependence became a national concern. Accordingly, coal was once again highlighted due to its more even distributions throughout the world as well as the high quantities of extractable resources. But coal has certain disadvantages: it contains many elements causing air pollution such as sulfur and ash, and, when used as fuel, produces a larger amount of carbon dioxide than any other fossil fuels. As such, the environmental burden from using coal is considerable.

First, let us take a brief look at the power generating mechanism of the IGCC power generation plant in operation at Nakoso Power Plant.

A conventional coal-fired power plant produces electricity by burning coal and generating steam with a boiler to drive a steam turbine (Figure 1-left).

Meanwhile, an IGCC system adopts a "combined power generation system" consisting of two power generation processes. First, the system gasifies coal and uses the gas produced to propel the gas turbine generating electricity. Then, it uses waste heat from the gas turbine to generate steam, which drives the steam turbine to generate electricity (Figure 1-right).

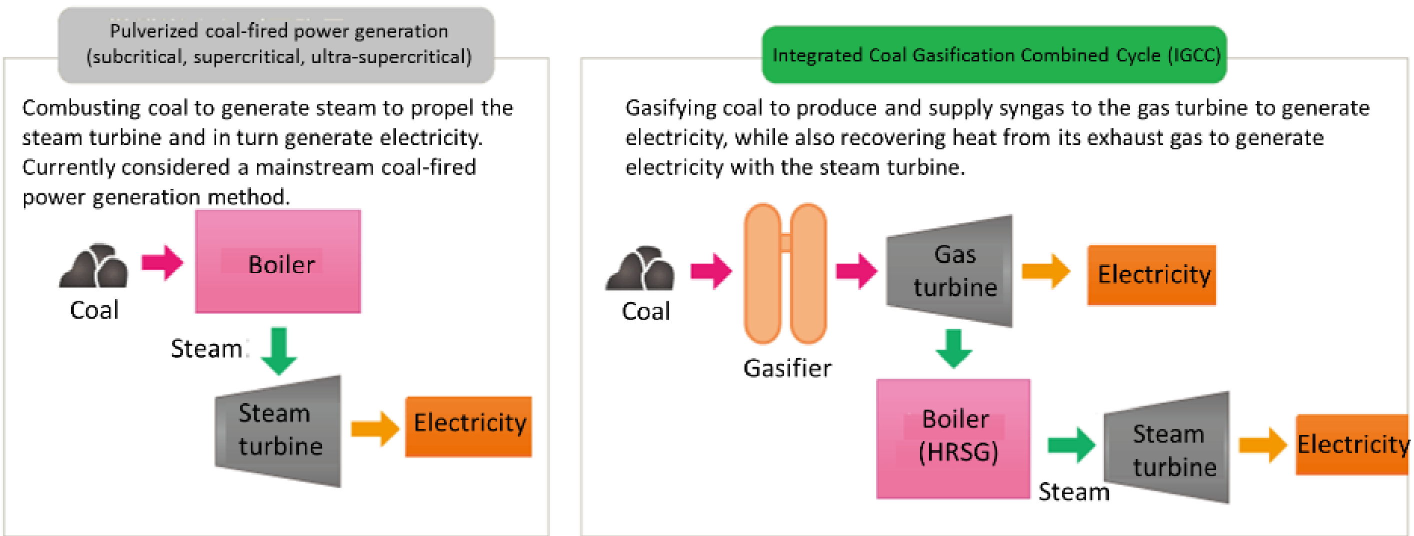


Figure 1　Differences between Conventional Coal-Fired Power Generation and IGCC

Next, let us have a closer look at the IGCC power generation system. IGCC consists chiefly of three main facilities: a gasifier to convert coal into syngas, a gas purifying process to remove air pollutants from coal gas generated in the gasifier, and a combined cycle facility to use clean coal gas and steam to generate electricity (Figure 2).

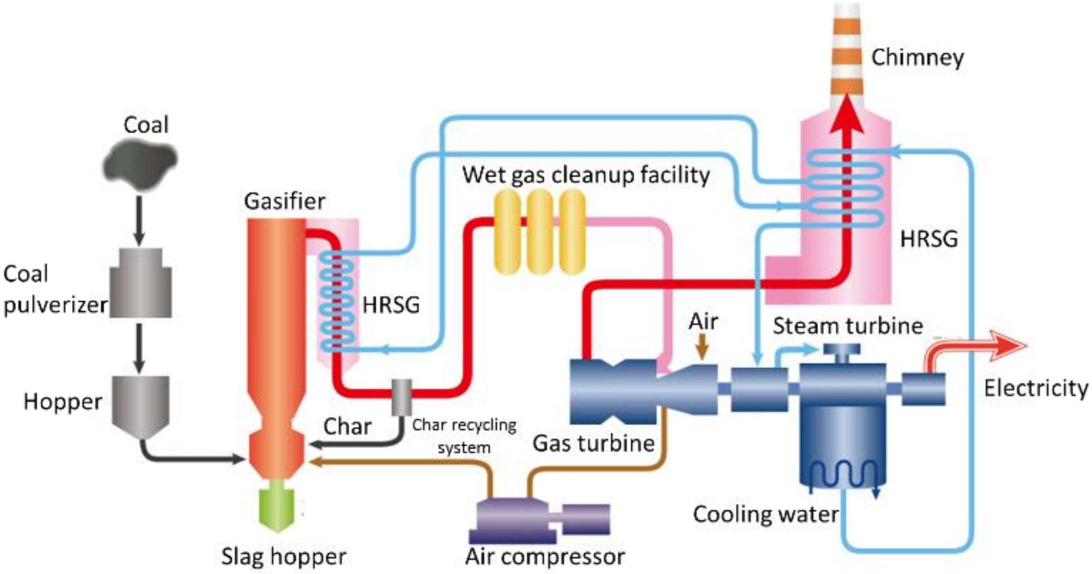


Figure 2　Schematic Diagram of IGCC

The IGCC system uses pulverized coal as fuel. Coal is crushed finely into a powder form; dispatched to the feeding hopper; pressurized with nitrogen gas for safety reasons, namely to prevent explosions; and transferred to the burner installed at the bottom of the gasifier.

Pulverized coal hopper at IGCC plant of Nakoso Power Plant (left) and use of pulverized coal as fuel (right)

Pulverized coal, when combusted with air at the bottom of the gasifier, generates high-temperature heat, which causes the gasification reaction of pulverized coal to generate high-temperature coal gas (chiefly CO and H2) (Figure 2).

Next, this high-temperature syngas is cooled down in the SGC heat exchanger (syngas cooler), and recovered heat is used to generate steam, which is transmitted to the steam turbine together with steam generated in HRSG.

Syngas in the SGC heat exchanger contains char, and unburnt carbon, which is collected using the char recycling system to be recycled back to the gasifier until it is completely combusted.

Following removal of char and fly ash, syngas is transmitted to the gas cleanup facility, where impurities causing air pollution such as sulfur compounds are removed. Then, syngas is transferred to the gas turbine to propel the generator in order to generate electricity.

Exhaust gas generated in the course of combustion for the gas turbine has a high calorific value. For this reason it is transferred to HRSG for the heat to be recovered to generate steam. This steam, together with steam from the SGC heat exchanger, is transferred to the steam turbine to generate electricity.

The component facilities of IGCC mutually exchange materials and energy to generate electricity at two stages through the gas and steam turbines. This enables highly efficient power generation with 48-50% net thermal efficiency.

Gas cleanup facility

Photo shows the gas cooling and cleaning towers.

High-efficiency gas turbine combined cycle

The gasifier is the central, crucial facility of IGCC, and consists of a "two-stage entrained flow coal gasification system".

Let us now turn our attention to look at cutting-edge technologies utilized in component facilities of IGCC.

The gasifier is the central facility of IGCC, chiefly composed of a pulverized coal feeding facility, gasifier and char recycling system.

The pulverized coal feeding facility is employed to feed pulverized coal to the high-pressure gasifier. To keep the atmospheric pressure of the gasifier at about 3-4 MPa, the facility uses three hoppers in alternation to continuously and efficiently pressurize and feed pulverized coal to the gasifier.

The gasifier itself is contained within a pressure container, with a water wall circulating for cooling purposes.

The gasifier has two stages: a combustor (for combustion) below and a reductor (for gasification) above, each of which is equipped with a burner to feed pulverized coal. Because of this structure, the gasifier is called a two-stage entrained flow coal gasification system (Figure 3).

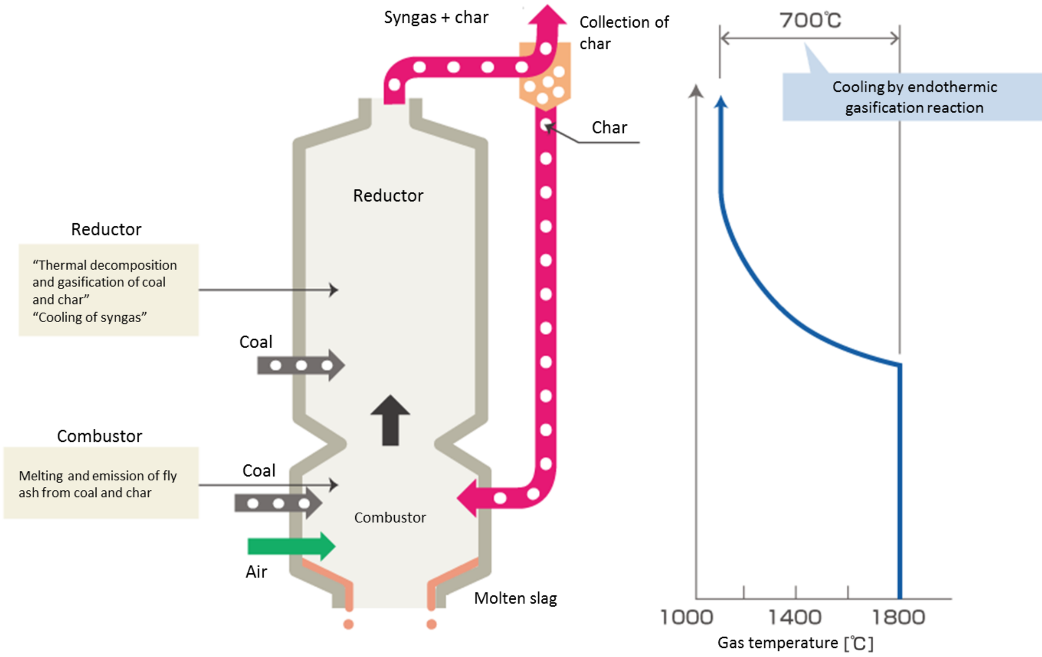


Figure 3 Principle of Air-Blown Two-Stage Entrained Flow Coal Gasification System

The combustor is equipped with a burner to burn char, which does not react sufficiently in the gasifier and thus is collected by the char recycling system. The burner burns pulverized coal and char to generate heat of some 1,800°C to supply it to the reductor for coal gasification.

View from the bottom of gasifier (left), side view of gasifier (filled with COS catalyst) (right)

Inside the combustor, pulverized coal and char is burnt to generate an ascending and swirling flow to the reductor. Ash contained in pulverized coal and char is melted through high temperature heat, centrifugally attached to the cooling water wall, and converted into molten slag before draining down to the bottom of the gasifier.

Molten slag, drained from the slag hole at the bottom of the combustor, falls into a water-filled slag hopper, is rapidly cooled, and then discharged to the outside the gasifier.

High temperature gas generated by the combustor rises to the reductor. When pulverized coal is injected from the burner of the reductor, a portion of the coal is gasified in reaction to the high temperatures. The remaining portion is converted into char, which is also gasified in reaction with CO2 and H2O generated in the combustor.

As described so far, the gasifier plays the two crucial roles of gasifying coal, and melting and discharging ash as slag. IGCC is equipped with the two functions of high efficiency gasification and simultaneous smooth discharge of slag. This is due to IGCC by employing the two-stage entrained flow coal gasification system.

The adoption of this system has also made it possible to use coal of various properties. It has traditionally been difficult to use such coal in conventional coal-fired power generation plants. If coal with ash having a low melting point is used in a conventional coal-fired power plant, molten ash adheres to the wall (heating surface) of the boiler and causes problems. One of the major features of IGCC is of the capacity to use coal of various ranks to their best advantage (Figure 4).

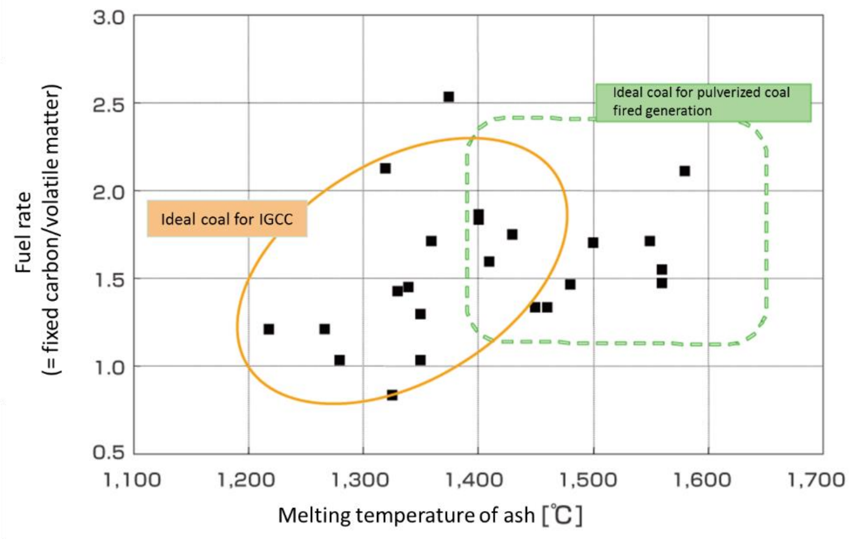


Figure 4 IGCC Utilizing Coal of Various Types

In addition, while coal-fired power generation plants generate a large amount of ash, gasifiers discharge slag in a glass form. This, together with the higher efficiency, reduces the volume of slag to be discharged to almost half. Glassy slag emits few trace components while serving as an eco-friendly byproduct. Recent studies have scrutinized the effective application of glassy slag as material for asphalt pavements and cement aggregates.

Coal ash slag

IGCC satisfying strict environmental standards

We will now have a detailed look at the gas cleanup facility. Conventional coal-fired power generation plants remove air pollutants after gas combustion in a boiler. IGSS, on the other hand, removes sulfur compounds and other air pollutants via the gas cleanup facility while they are still in the form of high pressure gas, and before gas combustion in the gas turbine.

cleanup facility consists of a carbonyl sulfide (COS) exchanger, a gas cooling tower, a cleaning tower, a hydrogen sulfide (H2S) absorption tower and other components. The facility removes hazardous substances in coal gas, such as COS, HIS and other sulfur compounds, hydrogen chloride (HCl), and ammonia (NH3).

Syngas is first transferred from the gasifier to the COS exchanger, that uses chemical solvent to turn COS, which is present among other sulphur compounds in syngas, into H2S, to be easily absorbed in the H2S absorption tower.

Next, syngas is transferred from the COS exchanger to the gas cooling tower and cleaning tower. These towers wash syngas with water to remove HCl, NH3, and other impurities.

Syngas is then sent to the H2S absorption tower, which uses amine solution to absorb H2S in the gas. Amine solution that has absorbed H2S is heated in the recycling tower to emit H2S, which turns into sulfur dioxide (CO2) when burnt, and is collected in the form of gypsum at the SO2 absorption tower (Figure 5).

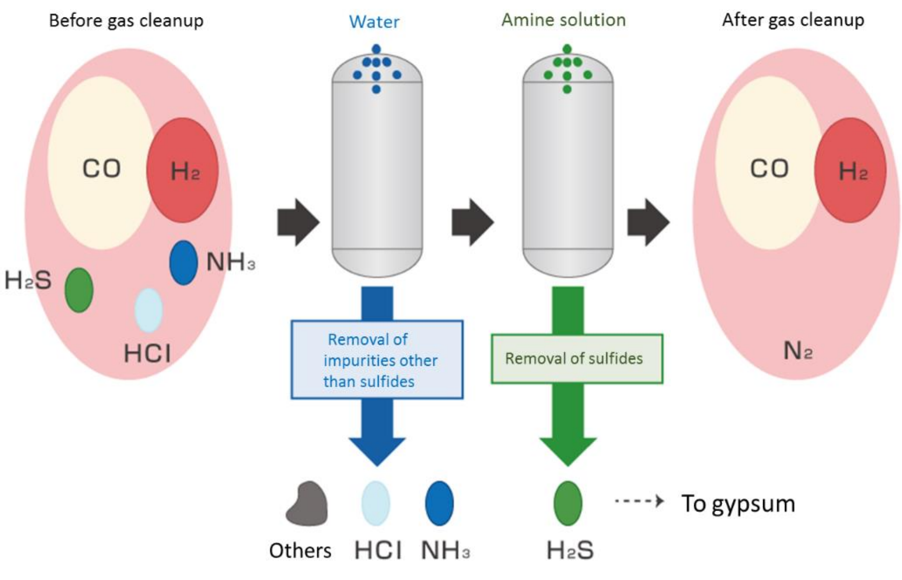


Figure 5 Schematic Diagram of Wet Gas Cleanup System

The gas cleanup facility currently in operation at Nakoso Power Plant is called a wet gas cleanup facility as it uses water and chemical solvent for cleaning. This gives it the capacity to comfortably conform with a range of rigorous environmental regulations.

Striving to develop the world's first "air-blown" IGCC

Japan is not the sole country to devote efforts to use IGCC in commercial applications. Rather, it was the U.S. and countries in Europe in which took the initiative in research and development of IGCC. The Netherlands, Spain and the U.S. already constructed, and began operations of, large-scale demonstration plants in the 1990s.

At that time, it was widely believed that IGCC should adopt oxygen-blown gasification. But the IGCC facility constructed by the Mitsubishi Hitachi Power Systems Company (MHPS) (then Mitsubishi Heavy Industries) at Nakoso Power Plant was unique in its adoption of an air-blown system. The two systems differ in terms of their use of, respectively, oxygen or air for coal gasification.

Mr. Koichi Sakamoto, who manages IGCC and gasification projects at the Engineering Headquarters of Mitsubishi Hitachi Power Systems, Ltd. (MHPS), says, "Coal gasification is easier with an oxygen-blown gasifier because oxygen contains no nitrogen and raises the combustion temperature. However, producing oxygen requires massive scale facilities and vast amounts of power, so it was clearly not possible to achieve high power generation efficiency. In other words, there was an extremely difficult hurdle to overcome with oxygen-blown gasification in order to realize the world's highest power generation efficiency. Accordingly we ventured to adopt an air-blown IGCC, which, although technologically sophisticated, does not require an oxygen manufacturing unit, in pursuit of the world's highest thermal efficiency" (Figure 6).

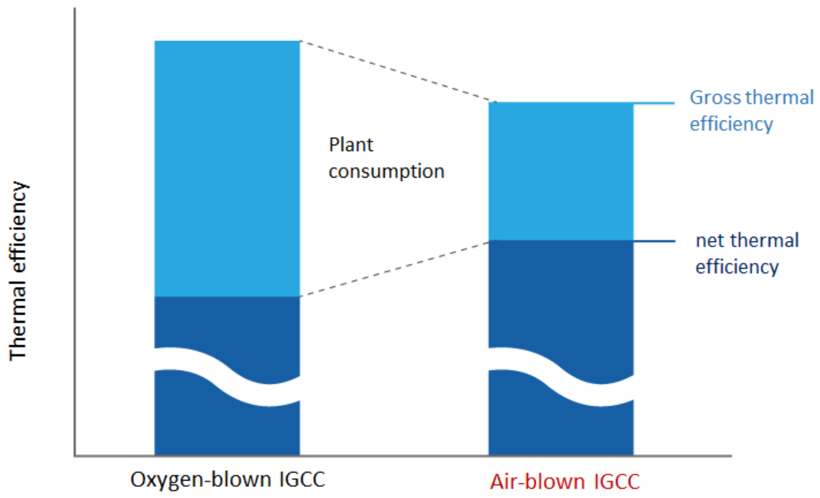


Figure 6 Thermal Efficiency of IGCC

Air-blown IGCC has a gross thermal efficiency equal to or even less than oxygen-blown IGCC, but its efficiency in applications for the commercial production of electricity, and net thermal efficiency, is greater than that of oxygen-blown IGCC, because the former consumes less electricity (light blue) for operation.

Researchers and engineers in the U.S. and Europe during this period considered that air-blown gasification as not being a viable technology, because it could not achieve sufficiently high temperatures required for combustion, despite its higher thermal efficiency.

Mr. Sakamoto recalls, “When presenting our plan to develop an air-blown IGCC system at international academic conferences, quite a few researchers from around the world repeatedly expressed strong reservations, saying that air-blown gasification would be absolutely impossible. This conversely prompted us to feel that it would be our mission to apply ourselves to realize the air-blown gasification by all means. I think perhaps that these negative opinions about our plan motivated us the most to successfully develop the world’s first air-blown IGCC.”

Moreover, Mr. Yoshitaka Ishibashi, Executive General Manager (Associate Director) of IGCC Department of Nakoso Power Plant, Joban Joint Power Company, added:

“An oxygen-blown gasifier fundamentally differs in concept from an air-blown gasification gasifier. The former was originally developed in the field of the chemical industry for the purpose of producing highly purified coal gas, from which chemical products such as methanol and ammonia are manufactured. The air-blown gasification system built at Nakaso Power Plant, which represents the latter, was developed especially for a power plant, and gives priority to thermal efficiency over purity of the product gas. It was developed to build an integrated coal gasification combined cycle (IGCC) with the world’s highest thermal efficiency.”

Piping to transport air to gasifier (left), Air-booster compressor (right)

Two-Stage Entrained Flow Coal Gasification System as a Breakthrough in Development of Air-Blown IGCC

Development of air-blown IGCC in Japan dates back to 1983. At that time, the Central Research Institute of Electric Power Industry (CRIEPI) in Yokosuka city, Kanagawa prefecture, built a basic experimental plant, with a daily coal processing volume of a mere two tons.

This was followed by a five-year project, from 1991 to 1996, to construct a pilot plant on the premises of Nakoso Power Plant of Joban Joint Power Company. As part of the project it was planned, with the support of NEDO and in consideration of the outcomes obtained from the basic experimental plant, to construct a pilot plant with a coal processing volume of 200 tons per day and capacity of 250,000 kW. This constituted a capacity one hundred times greater than the experimental plant.

Joban Joint Power Company was founded in 1955 with the mission to stably supply electricity by taking advantage of low-quality coal resources in the Joban area. The Nakoso Power Plant was chosen as the location of the IGCC pilot plant due to its well-established infrastructure to conduct plant tests such as those involving coal storage and power transmission lines. An additional reason for the selection was the longstanding familiarity and knowledge of the local community with coal.

The IGCC pilot plant was constructed by Japan's major manufacturers and power companies led by MHPS (then Mitsubishi Heavy Industries), which was specifically responsible for development of the gasifier.

"A gasifier has two functions. One is to stably produce coal syngas, and the other is to melt and remove ash as slag from the gasifier. But the most difficult task for the gasifier is to satisfy the two functions simultaneously. A high temperature of 1,800°C is needed to completely melt the ash, and it was common knowledge among researchers that only oxygen-blown gasifier could achieve such high temperature. As an effective solution, we developed a two-stage two-chamber entrained flow coal gasification system (Figure 3)," says Mr. Sakamoto.

This was a breakthrough to realize air-blown IGCC. Specifically this involved the gasifier being divided into a combustor and reductor. The combustor was designed to melt ash at high temperatures of 1,800°C by intensive intake of large amounts of air.

The reductor was meanwhile designed to focus on gasifying coal efficiently and rationally by using only the heat generated in the combustor while not using any air, as air was unnecessary for coal gasification. The idea of two stages in a single gasifier was something only MHPS had envisioned, having devoted themselves to development of coal combustion and other technologies over many years.

Not only did MHPS, dedicated to developing technologies, successfully realize "air-blown IGCC", previously thought impossible by experts from throughout the world, but the company also achieved all of its most ambitious targets, including high thermal efficiency, increase in the types of coal usable for the system, and reduction in the environmental burden (Figure 7).

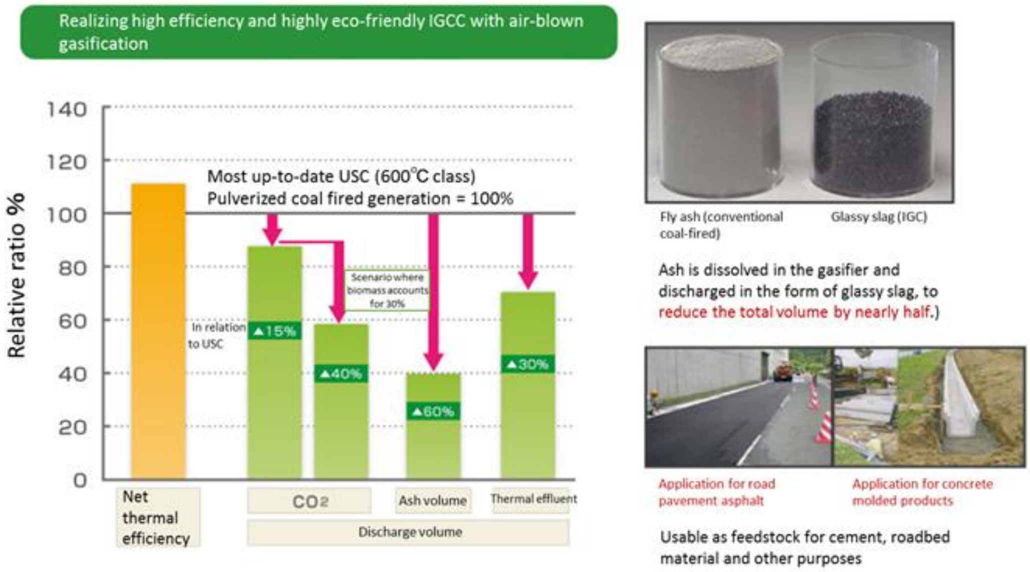


Figure 7 Comparison of Performance with Most Up-to-Date Ultra Super Critical Power Plant (USC, 600°C Class)
IGCC is not only highly efficient but also eco-friendly, with 100% recycling of discharged slag.

The road from troubled pilot plant to demonstration plant

"Even so, the pilot plant initially had many incidents. The biggest source of these incidents was that it was a hundred times as large as the size of a previously facilitated process development unit. This caused plugging of ash and slag melted in the gasifier. I was resigned to abandoning operations in this context," recalled Mr. Sakamoto.

MHPS (then Mitsubishi Heavy Industries (MHI)) investigated the cause of the plugging by taking advantage of cutting-edge technologies of the time such as computer simulation and model testing.

Mr. Sakamoto says, "We finally found that the cause lay in the shape of a part of the gasifier itself. So, although the surrounding facilities had already been completed, we repeatedly asked our stakeholders and partners to agree on a substantial makeover to the gasifier. Specifically, we took the bold decision to cut off the problematic part of the gasifier together with the pressure vessel to be replaced by a part of the right shape. This solved the issue of the plugging completely such that we were subsequently able to smoothly perform continuous operation and tests."

After revising and improving the gasifier further, the project members led by Mr. Sakamoto were firmly convinced that the air-blown IGCC could be used for commercial operations.

After the conclusion of the NEDO project, MHPS (then Mitsubishi Heavy Industries) and Japan's major power companies jointly constructed an integrated test plant for IGCC on the premises of the Research &

Innovation Center in Nagasaki, Mitsubishi Heavy Industries to continue research and development towards realizing a demonstration plant. The test plant took advantage of the experience and know-how acquired from various failures and the successful overcoming thereof, and comprised all the basic component facilities of IGCC, ranging from the gasifier to the gas cleanup facility and gas turbine. (Figure 8)

Figure 8 24t/day Integrated Test Plant (within Research & Innovation Center in Nagasaki, Mitsubishi Heavy industries)

Realizing the fruits of more than 30 years of research and development on coal gasification technologies

Meanwhile, despite the involvement of multiple manufacturers in the pilot plant project, by the demonstration plant stage the project team led by Mr. Ishibashi, then in charge of IGCC at a power company, found themselves in the position of presenting a proposal to the government to suggest that power companies carry out the project to construct the demonstration plant with MHPS (then Mitsubishi Heavy Industries) as the only participating manufacturer.

Mr. Ishibashi wished to engage in plant development with MHPS (then MHI). The reason he cites is: "MHPS (then MHI) is one of the few companies that have technologies of both gasifiers and gas turbines. IGCC is an integrated power generation system, in which various materials and energy move in and out between component facilities. High efficiency is only possible if these interactions occur without waste. I thought that it would be advantageous and essential to work for a company such as MHPS (then MHI) that covered the entirety of these fields."

In addition, he describes the reasons for promoting the project to construct a demonstration plant as follows:

"I joined the IGCC development project in 1998. At the time, no one knew how many customers would leave electric utility companies to opt for businesses from various other sectors which had started selling electricity following the liberalization of the electricity market in 1995. In such circumstances, quite a few directors were opposed to promotion of large projects such as the IGCC project. At first, even I was not sure if the development of IGCC should continue or not.”

“Nevertheless I felt that, if we abandoned our work on this excellent technology, to which we had devoted ourselves since 1983, it would be difficult to resume the project, as engineers of the team would disperse. This train of thought led to many discussions and eventually we managed to get all participating electric utility companies to agree to our implementing the demonstration plant project.” (Figure 9).

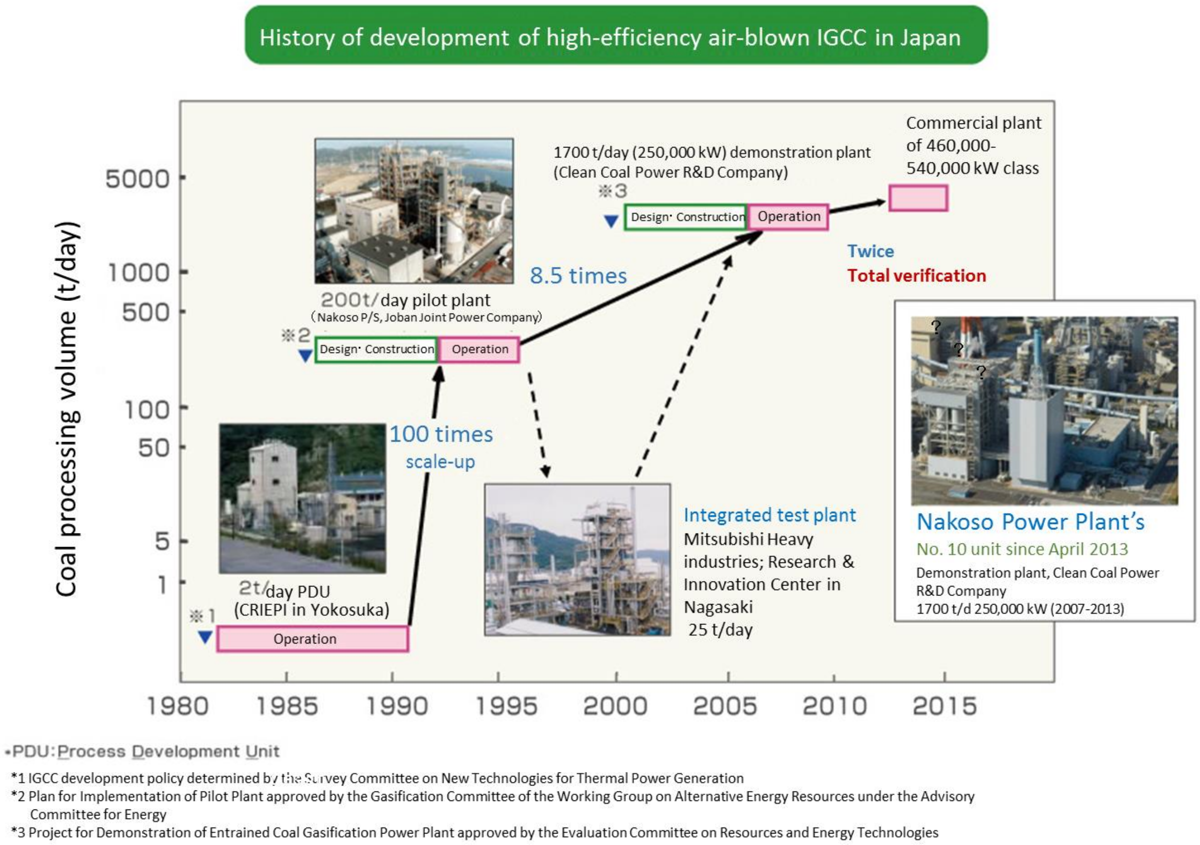


Figure 9 History of Development of Air-Blown IGCC in Japan

Power companies jointly worked to support construction and testing of a demonstration plant.
The plant now operates as a commercial facility supplying electricity to local communities, in the face of damage incurred as a result of the Great East Japan Earthquake.

In 2001, after the resolution on the project to construct the demonstration plant was adopted, nine power companies, together with the Electric Power Development Company, established the Clean Coal Power R&D Company. The project spent the first three years on design and environmental assessment and another three years on construction work before launching a five-year plan from FY2007 to FY2012 (Figure 10) with the daily coal processing volume of 1,700 tons and capacity of 250,000 kW.

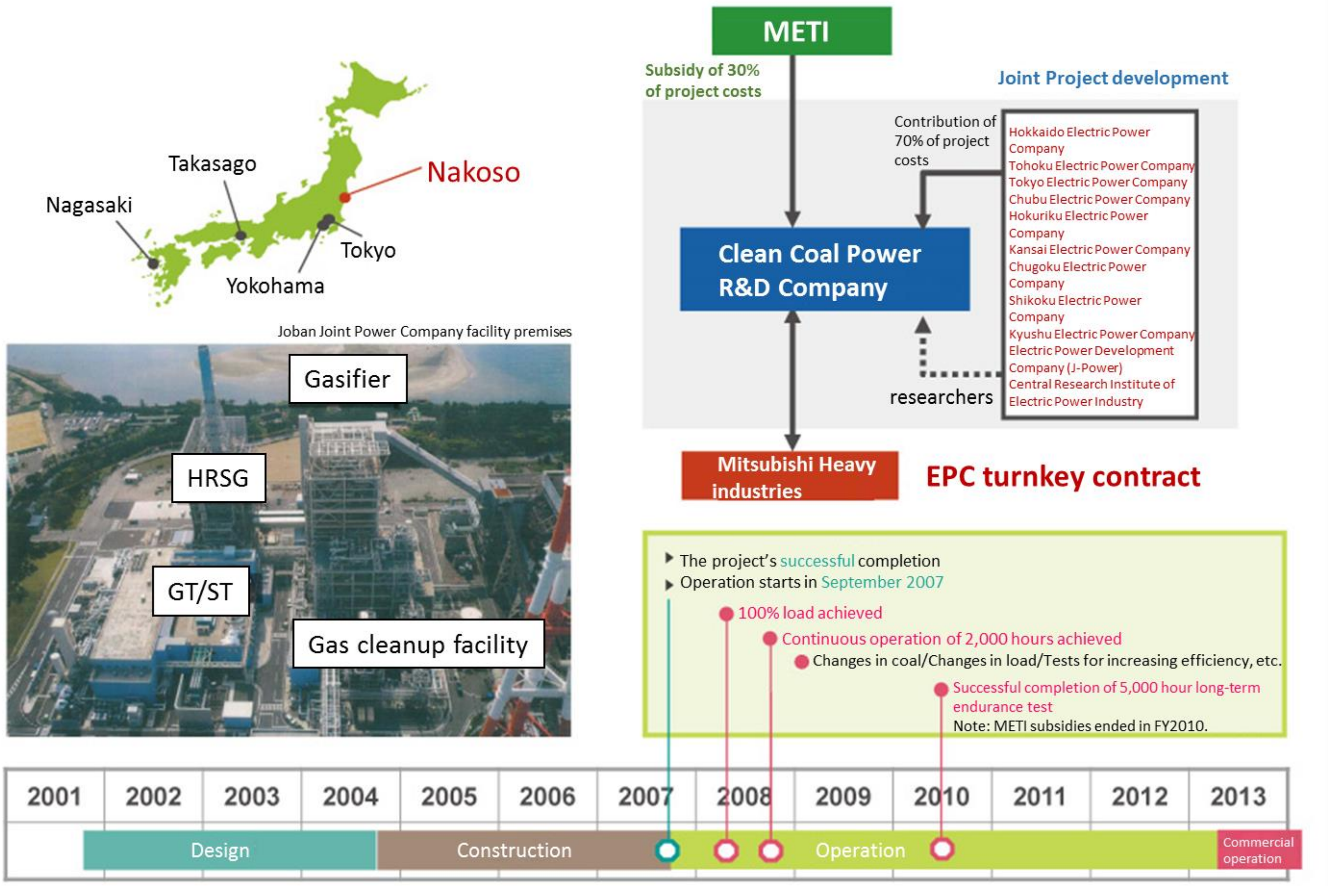


Figure 10　Construction/Test Operation Framework, Background and Performance of Demonstration Plant

“It was a public-private project: 30% was subsidized by the Ministry of Economy, Trade and Industry, and 70% was contributed by the power companies. The project scale was about 8.5 times as large as the pilot plant, but most issues involved in scaling-up had been solved by the time the pilot plant completed operation. So, we managed to start the demonstration operation fairly smoothly without any serious problems”, says Mr. Sakamoto.

Nakoso Power Plant No. 10 unit of Joban Joint Power Company achieved a new world record for IGCC continuous operation.

The project team actually completed the endurance test operation of 5,000 hours as scheduled in June 2010. The Great East Japan earthquake occurred in March 2011 as demonstration tests funded from the power companies were ongoing. The plant site was impacted by a tsunami of three meters height, but major components of the IGCC plant did not sustain serious damage, proving their durability and reliability. The plant was restored completely in by July 2011, within a mere four and a half months following the earthquake. Demonstration tests resumed and the plant contributed to ongoing supply of electricity in the midst of the shortages of the time.

On the basis of these remarkable achievements, the plant began its worlds-first commercial operations as an air-blown IGCC plant on June 30, 2013.

"In Japan, demonstration plants are normally dismantled when the demonstration tests are completed. But the plant has been taken over as a commercial plant by Joban Joint Power Company to continue its operations. This is because it can provide critical electricity of 250 MW, large enough to supply electricity to the entire local city of Iwaki, during the current electricity shortage in Japan as a result of the accident at Fukushima No.1 nuclear power plant, and also because it will enable us to obtain valuable experience and knowledge about the operations of the air-blown IGCC plant", says Mr. Ishibashi.

Currently, the IGCC facility is attracting a lot of attention as the world's first highly net efficient air-blown IGCC, with visitors from 24 countries having come to view the facility to date.

"Initially visitors from the U.S. and China made up the majority, but recently people from diverse countries, such as Singapore, Indonesia, Poland and Ukraine have come to view the facility," says Mr. Ishibashi.

"Constructing air-blown IGCC plants for commercial use has been a long-cherished desire of the company. We are now eager to continue to pursue endeavors to build commercial IGCC plants across the world into the future," adds Mr. Sakamoto

The project team had diligently committed itself to development over a long period of some thirty years, to ultimately realize Japan's original air-blown IGCC system. It is set to continue to attract increasing interest from all over the world and make momentous contributions to ensuring energy security; the effective use of energy resources; and even the mitigation of global warming.
(Interview in November 2013)

Column: Developers' profile

"I was glad to have engaged in the project as an engineer. It was truly fulfilling work."

Mr. Ishibashi, Joban Joint Power Company Ltd.

Currently, Mr. Yoshitaka Ishibashi works for Joban Joint Power Company as General Manager (Associate Director) of IGCC Department. He has participated in a number of coal-related development projects since he joined the Tokyo Electric Power Company (TEPCO).

"I have participated in multiple coal-related projects, but this project to construct an IGCC demonstration plant was the most successful. I am glad that I promoted it at the time. Thankfully, the plant has recorded the world's longest continuous operation of 3,917 hours, and has been acknowledged by people in this field around the world. I was glad to have been engaged in this truly fulfilling project. When Joban Joint Power Company took over the demonstration plant to continue its operation as a commercial plant, the Clean Coal Power R&D Company I worked for was merged to Joban Joint Power Company, and I myself was also transferred. However I intend to continue working hard so that IGCC will be used more widely."

"Researchers around me said that it would be impossible, which inspired me to rise to the challenge as an engineer."

Mr. Sakamoto, Mitsubishi Hitachi Power Systems, Ltd. (MHPS)

Mr. Koichi Sakamoto manages IGCC and gasification projects at the Engineering Headquarters of Mitsubishi Hitachi Power Systems, Ltd. (MHPS), in his capacity of Senior Manager / Chief engineer. He has long been engaged with the design and development of boilers.

"Since I joined the company, I have consistently worked in the field of development, designing, and after-sales services of small and large boilers. When I first got involved in IGCC, I simply regarded gasifiers of IGCC as a kind of variation on boilers. But at the same time, as the gasifier is the central, crucial facility of the IGCC system akin to the heart of the human body, I thought that the air-blown gasification was quite challenging, and hoped that we be the first in the worlds to realize it. Consequently, researchers from overseas asserting that it would impossible to realize the air-blown IGCC lent momentum to my motivations as an engineer on this project.

"Even so, we were obliged to make the demanding request that the gasifier and pressure vessel be cut off and replaced at the pilot plant test. This was accepted, owing to the understanding of the power companies and all other parties concerned, for which I would like to express my gratitude heartily. I am also deeply grateful for opportunity afforded to me to participate in the commercialization project. Currently, we receive many inquiries about the air-blown IGCC from all over the world, and are very excited about future prospects. I myself would like to continue working towards realization of as many commercial plants as possible."

General facts on coal

In this section the ranks and characteristics of coal are explained. Coal is broadly classified into five ranks by age scale, or in technical terms its metamorphic grade or carbon concentration.

Coal is referred to as “lignite”, “brown coal”, “subbituminous coal”, “bituminous coal” and “anthracite” in ascending order of carbon concentration. Although there are different opinions about the origin of petroleum, the origin of coal is clear: coal is fossilized vegetation. The higher the carbon concentration coal exhibits, the older it is; the lower the carbon concentration, the newer, i.e. the closer it is to vegetation (Table A).

Period			Ideal plant type	Around the world	Japan
Palaeozoic	Carboniferous	280 million years ago	Fern Horsetail Blackthorn	Anthracite	
	Permian	220 million years ago			
Mesozoic	Triassic	190 million years ago	Gymnosperm ・Cycad ・Ginkgo	Bituminous coal	Anthracite
	Jurassic	150 million years ago			
	Cretaceous	120 million years ago			
Cenozoic	Tertiary	7~20 million years ago	Present vegetation	Lignite	Bituminous coal

Table A　Metallogenic Epochs of Coal

Lignite, brown coal and subbituminous coal exhibit low carbon concentrations but contain large amounts of moisture. Their calorific values are low and they are generally brown in color. Bituminous coal is what people normally as associate with black coal, and has been used as fuel for conventional coal-fired power generation. Anthracite coal, the most highly carbonized coal, contains very little moisture and burns without producing smoke. Because of these qualities, anthracite coal is used as material for briquette coal and pea coal (Figure A and Table B).

Figure A　Heterogenous Appearances of Coal of Different Ranks

Classification		Calorific value (Correction anhydrous ash-free basis) kJ/kg (kcal/kg)	Fuel rate	Coking	Main usage	Remarks
Coal quality	Category					
Authracite (A)	A_1	---	4.0 or more	Non-coking	Steam coal	
	A_2				Coking coal	Natural coke created in reaction to volcanic rock
Bituminous (B, C)	B_1	35,160 or more (8,400 or more)	1.5 or more	Heavy coking	Steam coal	
	B_2		less than 1.5		Coking coal	
	C	33,910 or more and less than 35,160 (8,100 or more less than 8,400)	—	Coking	Steam coal Coking coal	
Sub-Bituminous (D, E)	D	32,650 or more and less than 33,910 (7,800 or more less than 8,100)	—	Weak coking	Steam coal	
	E	30,560 or more and less than 32,650 (7,300 or more less than 7,800)	---	Non-coking	Steam coal	
Lignite (F)	F_1	29,470 or more and less than 30,560 (6,800 or more less than 7,300)	---	Non-coking	(Steam coal)	
	F_2	24,280 or more and less than 29,470 (5,800 or more less than 6,800)	---			

Table B JIS Classification of Coal

The ash melting point is lower for IGCC than that for conventional coal-fired power generation plants. As such, subbituminous coal and brown coal which have to date been applied in only limited capacities are suitable for IGCC (Figure B). In the present situations, while bituminous coal is mined chiefly in South Africa, India, China and Australia, subbituminous coal and brown coal are mined over wider areas which include Indonesia, Australia, Mongolia, Russia, Europe and America. This means that, introduction and dissemination of IGCC technology contributes to wider usage of different types of coal for coal-fired power generation as a whole. It is also effective from an energy security perspective, because coal can be imported from a wider range of source countries (Figure C).

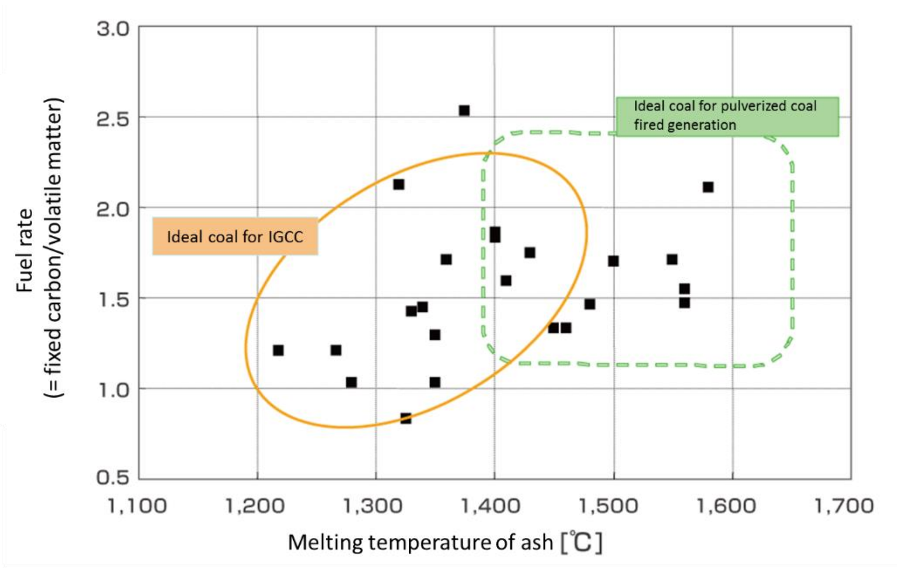


Figure B Differences between Coal for Conventional Pulverized Coal-Fired Power Generation and for IGCC

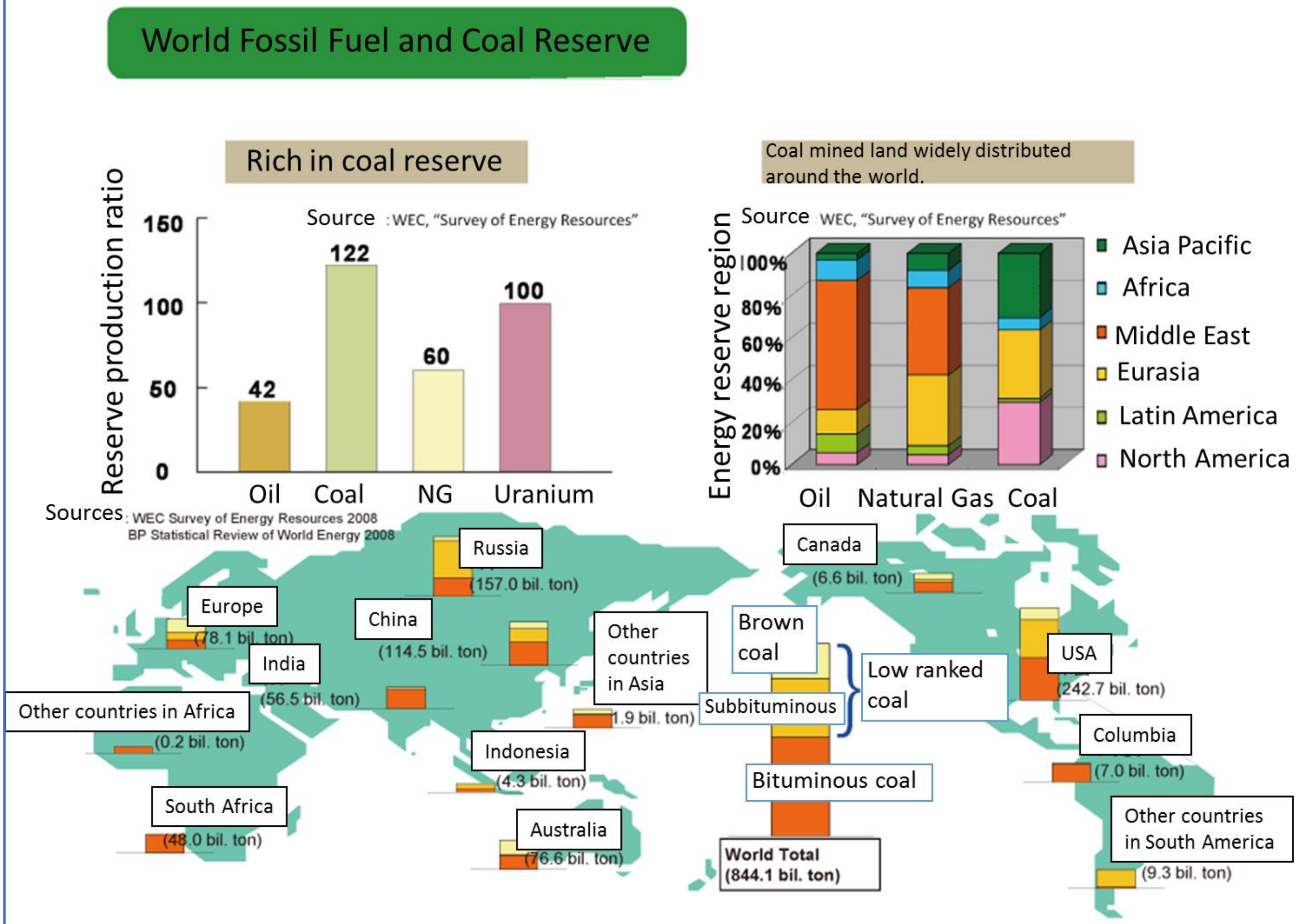


Figure C　World Fossil Fuel and Coal Reserve