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# Latest Trends in and Prospects for Coal Utilization and Clean Coal Technologies

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## 1 Introduction

Coal, a fuel used in the production of iron and steel, has played a major role in driving industrial development ever since the industrial revolution in the 18th century. Although oil took the place of coal following the energy revolution in the 1960s, the two oil crises in the next decade made the world rediscover the value of coal. Coal is abundant and hence is cost-effective; its widespread distribution (primarily in industrialized countries) ensures the security of supply. In Japan, which needs to reduce its energy supply vulnerability, coal is a primary alternative energy source to oil. Indeed, its consumption is on the rise, with low-cost imports increasing.

Japan consumes about 150 million tons of coal a year, which accounts for some 17.9% of Japan's primary energy supply (as of 2000)[1]. This proportion is estimated at 18.0% for 2010 and 17.0% for 2030, according to a long-term energy outlook released in October 2004. Coal, therefore, continues to be an essential energy source[2].

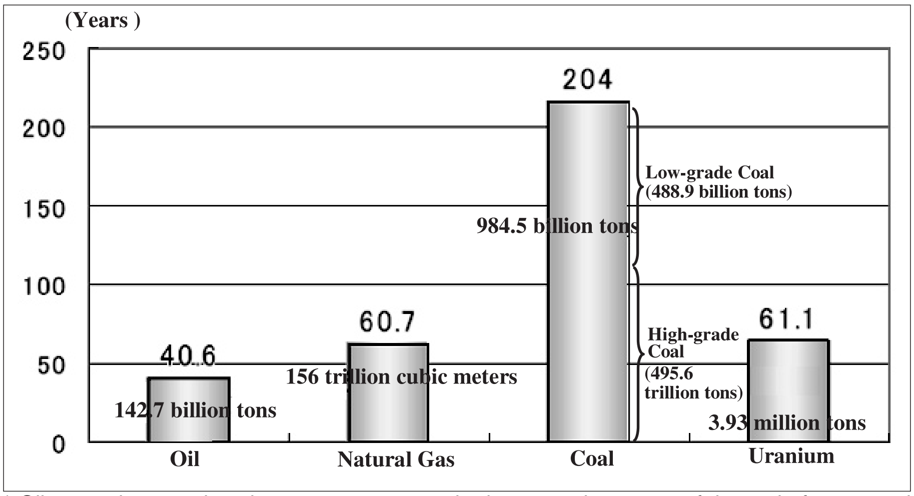
When combusted, however, coal produces a relatively large amount of $CO_2$ per unit calorific value, compared to other fossil fuels. In response to growing public awareness of global environmental problems such as global warming and acid rain, there is an increasing need to consume coal in an eco-friendly manner (i.e., reduction of SOx and $CO_2$ emissions) and to improve its utilization efficiency at power plants, etc. In Japan, meanwhile, coal is not being produced on a commercial basis, except for production for the sake of technology transfer - which makes Japan almost fully dependent on imported coal. With demand for coal rising in the Asia Pacific region, it is becoming increasingly critical that the security of coal supply be ensured for Japan.

Such recent trends translate into the growing need to develop eco-friendly clean coal technology (hereinafter referred to as "CCT") and take proactive measures to ensure the security of the coal supply. The Agency of Natural Resources and Energy organized the "Clean Coal Cycle" (C3) this January, which came up with an interim report this June. The monthly report of Science & Technology Trends (July 2004) refers to CCT as one of the key technologies that can be transferred to China to solve energy and environmental problems between the two countries[3]. Bearing these in mind, this article addresses: coal supply and demand trends; CCT overview; CCT development trends in Japan, the U.S. and Europe; and challenges in promoting CCT in Japan. It also provides an overview of policies to be adopted in the future. Specifically, Chapter 2 features the status of coal; Chapter 3, the outline and details of CCT; Chapter 4, technological development trends in Japan, the U.S. and Europe; and Chapter 5, challenges lying ahead and recommended policies.

## 2 Status of coal

This chapter summarizes the characteristics of coal, its supply and demand trends, and its position in Japan's energy policy.

**Figure 1** : Proven reserves and reserve-production-ratio (RPR) of major energy sources




* Oil, natural gas and coal reserves represent the known estimates as of the end of 2002, and those of uranium, as of January 1, 2001. Proven reserves of high-grade coal (bituminous and anthracite coal) and low-grade coal (brown and sub-bituminous coal) are estimates based on References[13].
Source: Author's compilation based on BP Statistics 2003, OECD/NEA and Uranium 2001 (IEA).

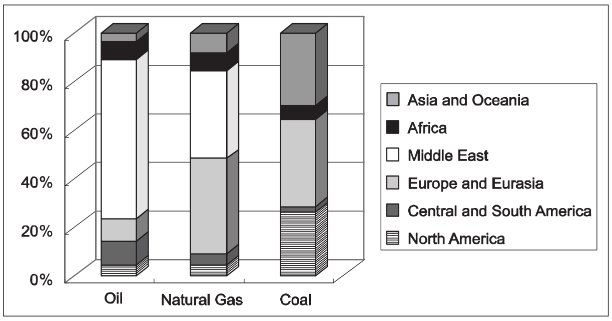
## *2-1 Characteristics of coal*

Coal has clear advantages over other energy sources in terms of the amount of reserves and cost effectiveness. Figure 1 shows proven reserve-production-ratio (RPR) of major energy sources. Coal dwarfs other energy sources in the amount of reserves. BP Statistics 2003 estimates that coal reserves represent more than 200 years of production at current levels, which ensures a long-lasting, stable supply. By contrast, oil, natural gas and uranium are expected to last for only 41 years, 61 years and 61 years, respectively.

Energy prices have been fluctuating, with oil and natural gas prices swinging widely; they are increasing in the long term. Coal prices, meanwhile, have been relatively stable over the last three decades, though they showed a marginal upward trend before and after the oil shocks. Coal costs less than half the price of oil per unit calorific value. Coal's economic advantages, therefore, lie in its cheap price and long-lasting, stable supply.

Figure 2 shows the distribution of proven fossil-energy-source reserves. Oil reserves are concentrated in the Middle East, while natural gas is produced primarily in the Middle East and the former Soviet bloc. The supply of these energy sources, therefore, involves political and social uncertainties. By contrast, coal is widely distributed across the globe (North America, the former Soviet bloc, Europe, etc.), with some 30% found in the Asia Pacific region - a situation that ensures coal supply against political and social destabilization.

**Figure 2** : Distribution of proven fossil-energy-source reserves




Source: Author's compilation based on BP Statistics 2003.

Although being abundant and cost-effective, coal has a major drawback: its high carbon content, compared to other fossil fuels, results in a large amount of $CO_2$ emissions when combusted. Specifically, oil and coal produce 1.2 and 1.5 times more $CO_2$ emissions (per unit calorific value), respectively, than natural gas. Of all the fossil fuels, coal places the largest burden on the environment. $CO_2$ emissions from coal combustion should thus be recovered and disposed of. It is also necessary to treat the combustion gas that contains SOx and NOx (the causes of air pollution and acid rain), and to make use of coal ash.

The better part of coal used for power generation, iron manufacturing and other industrial processes is high-grade coal (bituminous and anthracite coal)[4], which accounts for only half of the proven coal reserves, as shown in Figure 1. For that matter, low-grade coal (sub-bituminous and brown coal) should be exploited further.

### 2-2 Coal supply and demand trends

The world's coal production, which has been relatively stable since the 1980s, is estimated at 5 billion tons for 2002. Specifically, production in the Asia Pacific region, which is highly dependent on coal for its energy supply, is on the rise; it began to surge in and after 2000 in response to increasing coal consumption in the region[5]. Production in other regions is relatively stable or increasing gradually except for Europe and Eurasia, where production is declining.

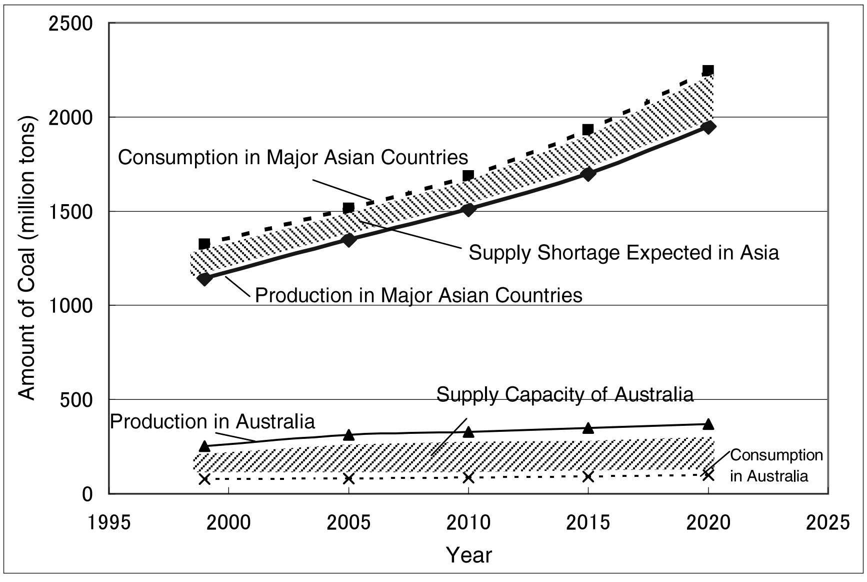
As shown in Figure 3, coal consumption in major Asian countries including Japan is expected to increase steadily, while Australia and Asian coal-producing countries are likely to cater for the regional demand. That said, the security of the coal supply as well as its efficient use remains a major concern for all Asian countries.

Figure 4 shows the recent trends in Japan's coal consumption by sector[6]. The consumption of steam coal by the power generation sector increased by an average annual rate of 7% from 1991 to 2002, reaching 38 million tons a year, whereas that of coking coal by the steel industry has been relatively stable at about 65 million tons a year since 1980. Other industries including the cement industry consume an average of 23 million tons a year.

Imported coal accounted for over 80% of Japan's coal supply throughout the 1980s; the proportion reached 99.2% in 2002 due to an increase in imports and a decrease in domestic production[6]. As shown in Figure 5, Australia commands a 56.5% share of the total imports in 2002, followed by China (19.1%), Indonesia (12.0%), Canada (5.8%) and Russia (4.3%). Imports from the top three countries together account for more than 85% of the total.

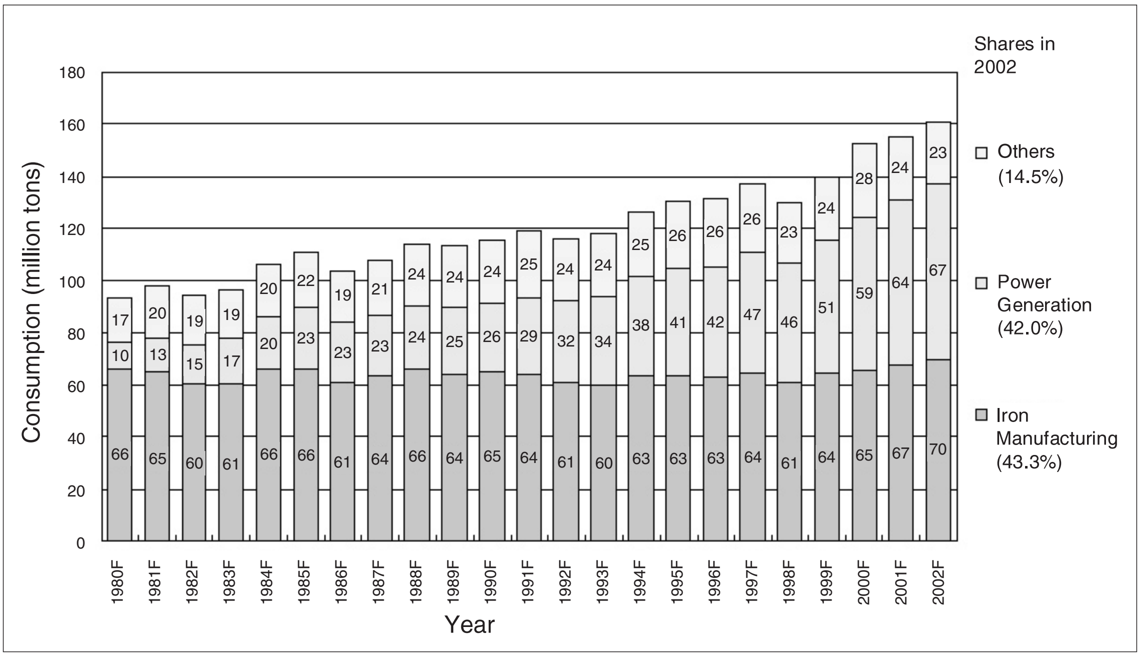
One of the challenges in ensuring the security of the coal supply is the need to improve the coal transportation infrastructure (including railroad and harbor facilities) in Australia, China and Indonesia. In Australia, for instance, more than 50 ships remained queued off the port of Newcastle in March 2004 due to a bottleneck in railroad transportation[5]. In view of growing coal imports, drastic measures should be taken to shore up and improve the infrastructure.

**Figure 3** : Coal supply and demand outlook in major Asian countries



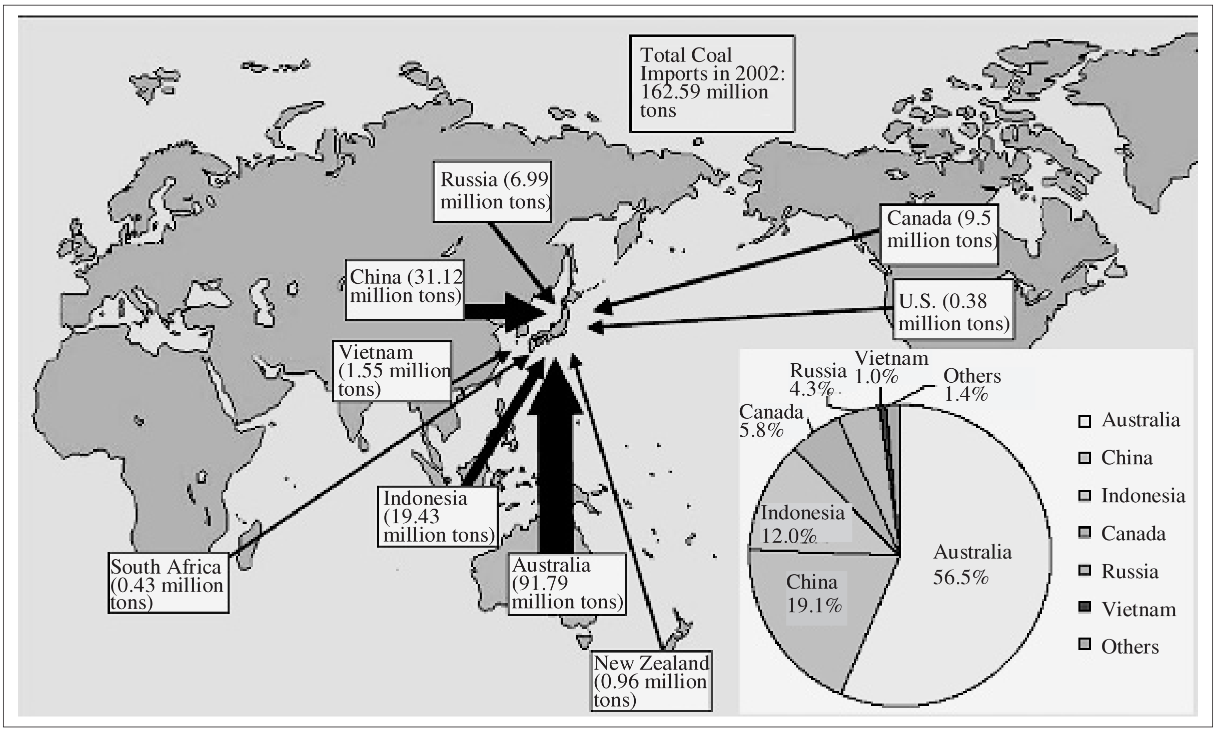

* Calculated based on the assumption that 1 kg of coal produces 6,000 kcal and 1 ton of oil represents 1.645 tons of coal. Major Asian countries include Japan, China, Korea, Taiwan, Indonesia, Malaysia, the Philippines, Thailand and Vietnam (not including India).
Source: Author's compilation based on APEC Energy Demand and Supply Outlook 2002 (APERC).

**Figure 4** : Trends in coal consumption in Japan




Source: References[6]

**Figure 5** : Japan's coal imports by country of origin




Source: References[6]

## 2-3 Position of coal

The position of coal in Japan's policy on natural resources and energy depends on its advantage over other energy sources and the magnitude of the challenges it faces. Although increasingly serious global environmental problems translate into an emphasis on the environmental disadvantages of coal, it is and will be an essential energy source because of its abundance and cost effectiveness, as mentioned in Chapter 2-1. Taken all together, coal is an eco-friendly energy source in the medium and long terms, and hence is expected to be a promising option in a well-balanced energy supply system, to which CCT development holds the key.

## 3 Clean coal technology (CCT)

This chapter refers to the elements of eco-friendly CCT and its technical specifications.

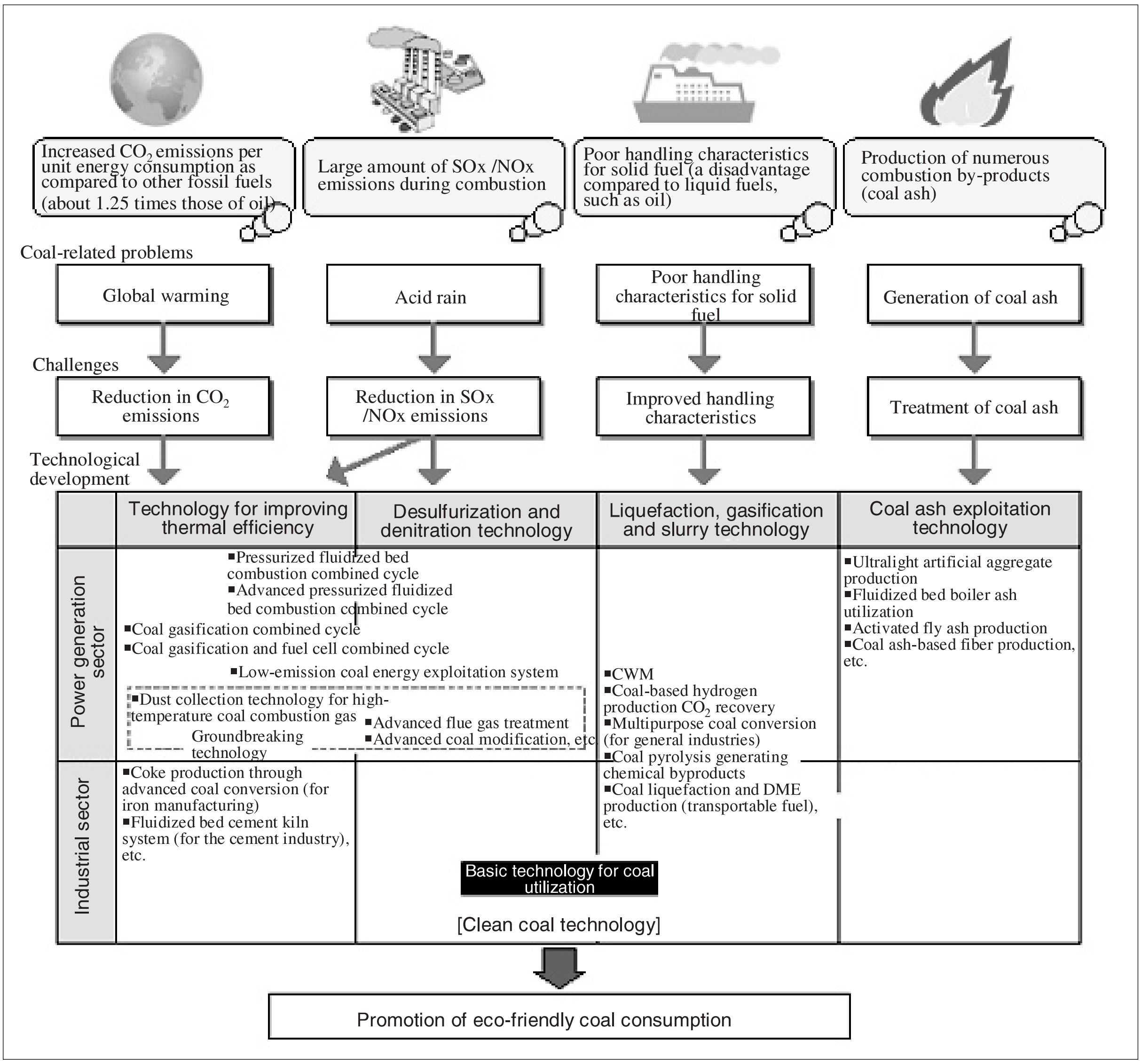
### 3-1 Overview

The two major coal consumers in Japan are the power and steel industries, each of which accounts for some 40% of the total domestic consumption and is capable of adopting CCT. The total installed capacity of coal-fired power plants stands at 33.77 million kW as of the end of 2002, with 78 units operating. A total of 9.8 million kW will be added, according to a power supply plan laid out in 2003. Moreover, 11-million-kW worth of power facilities (about 30% of the current capacity) will be replaced by 2030 on the assumption that their service life is 40 years. There is thus scope to introduce improved coal-fired power plants adopting CCT[2]. As for the steel industry, the total installed capacity of coke ovens stands at some 32 million kW as of the end of 2002, with 44 ovens in operation. Likewise, about 31-million-kW worth of ovens (more than 95% of the current capacity) will be replaced by 2030, assuming that their service life is 50 years. There is also scope to introduce next-generation, energy-efficient coke ovens adopting CCT[2].

CCT is comprised primarily of the following four elementary technologies (see Figure 6):

(1) Efficiency improvement technologies
(2) Desulfurization and denitration technologies contributing to environmental improvement

**Figure 6** : Typical clean coal technologies




CWM : Coal Water Mixture DME : Dimethyl Ether

Source: Author's compilation based on References[12]

(including technologies for separating, recovering and sequestrating $CO_2$)

(3) Technologies for converting coal into liquid fuel, gas and slurry

(4) Coal ash utilization technologies

These technologies are designed to reduce the environmental load caused by coal combustion (through reduction of $CO_2$, SOx and NOx), develop new ways of using coal (through improvement of its handling characteristics) and dispose of coal ash. CCT also includes technologies for making use of low-grade coal.

## 3-2 Technical specifications

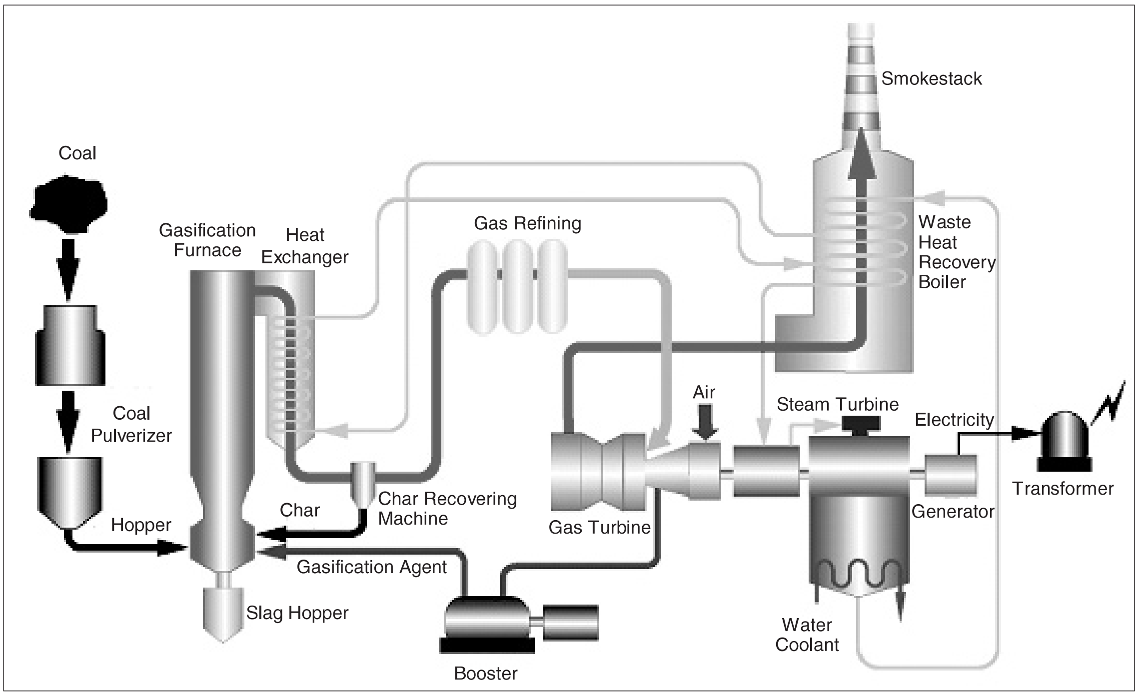
### (1) Technologies for thermal efficiency improvement

With respect to technologies for thermal efficiency improvement for power generation purposes, (i) super critical pulverized coal-fired power generation (main steam with a temperature of about 540˚C at a pressure of 238 atmospheres) has been commercialized, while (ii) ultra super critical pulverized coal-fired power generation (main steam with a temperature of about 600˚C at a pressure of 241 atmospheres) and (iii) pressurized fluidized bed combustion combined cycle (PFBC) are nearing commercialization. PFBC involves combustion of coarsely pulverized coal in a fluidized bed at a pressure of about 10 atmospheres.

On the other hand, (iv) integrated gasification combined cycle (IGCC), which is shown in Figure 7, is scheduled for commercialization in around 2010. This technology utilizes both coal gas (composed primarily of carbon monoxide and hydrogen) and steam (produced by a gasification furnace) to drive a gas and a steam turbine, thereby achieving high power generation efficiency. There is also an advanced type of PFBC (A-PFBC), where PFBC is combined with partial coal gasification to further improve efficiency. In around 2020, (v) integrated gasification fuel cell combined cycle (IGFC), which incorporates a fuel cell fueled by coal gas, is expected to enter commercial operation[7].

The average net power generation efficiency of coal-fired power plants in Japan stands at 38% as of 1997, whereas those of the technologies outlined above are estimated at 40% for (i), 41% for (ii), 42% for (iii), 46% for (iv) and 54% for (v). Efficiency improves in the order (i), (ii), (iii), (iv) and (v). Figure 8 shows $CO_2$ emissions of IGCC per unit power generated as well as those of conventional coal-fired, oil-fired and LNG-fired power generation[8]. CCT contributes to reducing the $CO_2$ emissions of coal-fired power generation by some 24%, a level lower than that of oil-fired

**Figure 7** : Integrated gasification combined cycle system (IGCC)



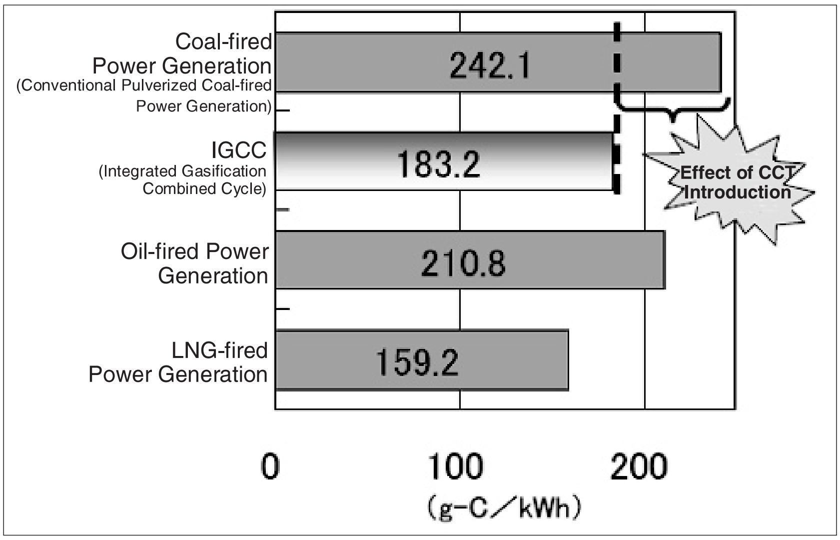
power generation.

Coke production through advanced coal conversion (SCOPE21: Super Coke Oven for Productivity and Environment Enhancement Toward the 21st Century) is a technology that improves the thermal efficiency of the iron-making process. Specifically, coal pretreatment processes contribute to reducing the energy consumption of coke production by as much as 20%.

### (2) Technologies contributing to environmental improvement

Technologies contributing to environmental improvement include the treatment of SOx and NOx in coal combustion gas[9], and $CO_2$ disposal, where $CO_2$ emissions from large-scale sources such as power plants are separated and recovered efficiently for sequestration in the soil or oceans (see Figure 9)[9,10]. These technologies

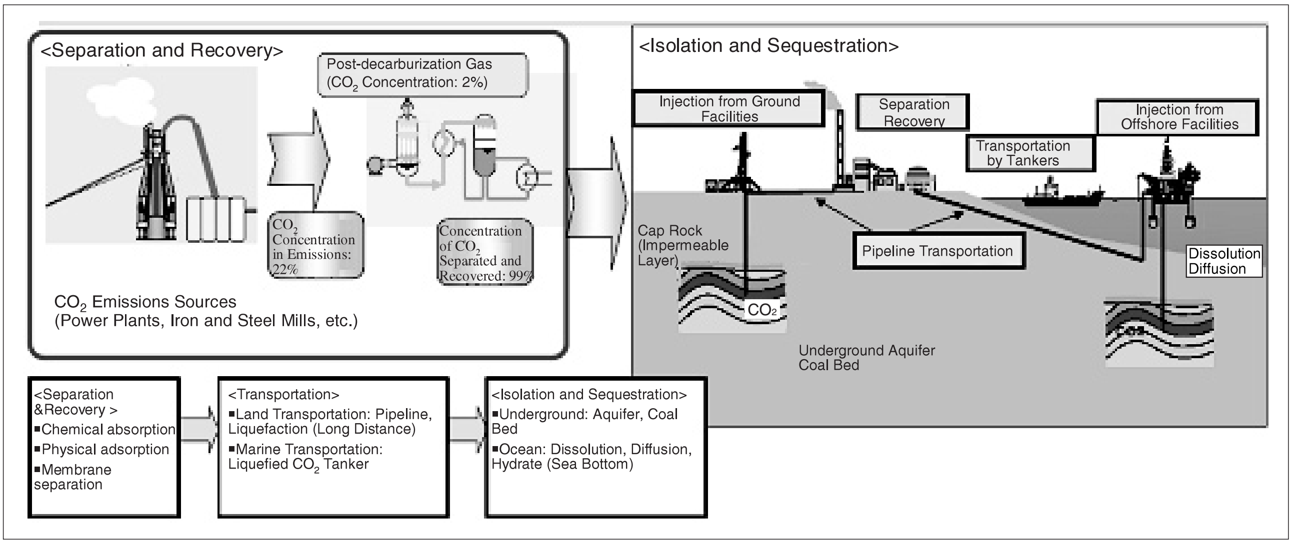
**Figure 8** : $CO_2$ emissions per unit power generated




* The above figures are based on $CO_2$ emissions per unit energy produced (taking into account the combustion, production and transportation of fuels, according to a report released by the Institute of Energy Economics, Japan in May 1999) and the following respective net power generation efficiencies: Coal-fired, 40.1%; Oil-fired, 36.7%; LNG-fired, 41.9% (actual results in 2001 and power demand outlook in 2002, by METI). The power generation efficiency of IGCC is set at 53.0%, a target level.

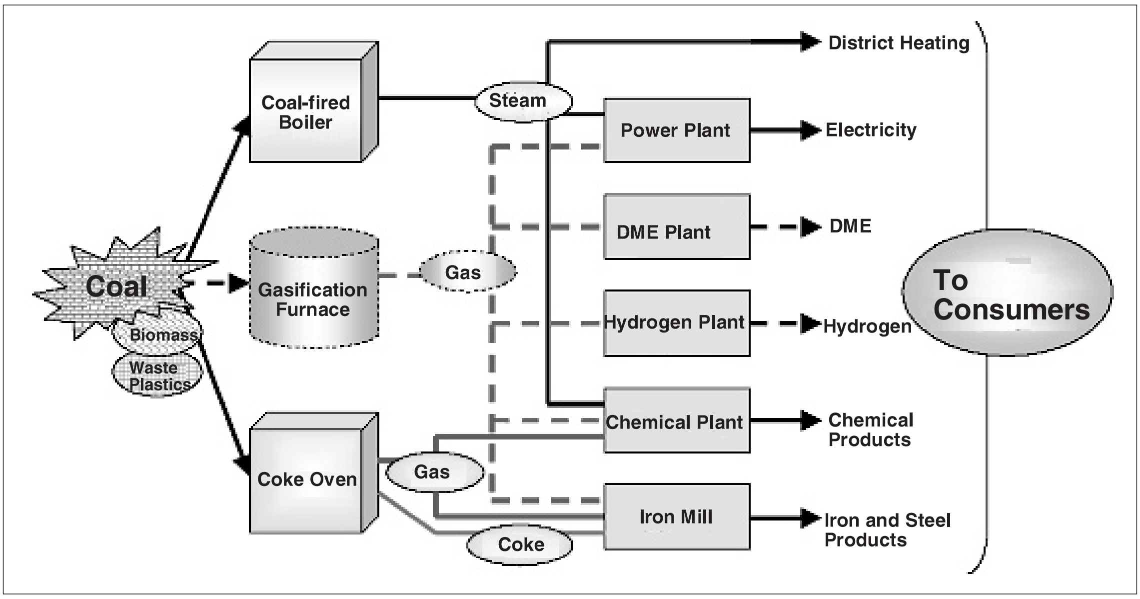
Source: References[8]

**Figure 9** : Separation, recovery, isolation and sequestration of $CO_2$




Source: References[13]

**Figure 10** : New energy and material production system based on coal gasification technology




Source: References[10]

are essential in curbing global warming over the medium and long term. Recovered $CO_2$ can be injected into oil wells to boost oil production (EOR: Enhanced Oil Recovery)[11].

At the same time, basic research is underway to inject recovered $CO_2$ into coal beds for carbon sequestration and recovery of a clean energy source: methane gas.

### (3) Coal conversion technologies

Synthesis gas produced from coal is converted into high value-added materials and fuels such as chemical raw materials (methanol, ammonia, activated carbon, etc.), liquid fuels for automobiles, household fuels (dimethyl ether, etc. as substitutes for light oil, kerosene and LPG) and hydrogen. New energy and material production systems are expected to emerge from cooperation between various industries primarily in the field of coal gasification (see Figure 10). As for coal handling, development efforts are underway for CWM ("coal water mixture," where finely pulverized coal and water are mixed at a ratio of 7:3 to produce fluidized coal) and CCS (a "coal cartridge system," where finely pulverized coal is packed in cartridges for transportation purposes and coal ash is disposed of en masse). Both of these technologies are in the demonstration phase.

### (4) Coal ash utilization technologies

It is also essential that coal ash produced by thermal power plants be utilized. Coal ash, for instance, is used for cement materials, roadbed materials and soil conditioners. Technologies that are expected to be in practical use include those for ultralight artificial aggregate production, fluidized bed boiler ash utilization, and activated fly ash production[13].

## 4 Research and development trends

Research and development trends in CCT in Japan, the U.S. and Europe can be summarized as follows:

### *4-1 Status in Japan*

Table 1 shows an overview of the achievements of national coal utilization projects implemented so far[14], with reference to their categories, themes, development periods, outline, evaluation results and commercialization status. A total of some ¥360 billion has been invested in these projects.

In the field of thermal efficiency improvement, a number of technologies such as pressurized fluidized bed combustion combined cycle (PFBC) and ultra super critical pulverized coal-fired power generation have been commercialized. In particular, Japan is far ahead of the U.S. and Europe in expanding the capacity of power plants. Coal partial combustion technology was also established through a series of pilot projects, though the declining needs for this technology resulted in a shift to pressurized pulverized coal partial combustion technology that can be combined with IGCC.

Based on the iron-making technologies introduced from the U.S., an advanced process unique to Japan was developed, where a large quantity of powdered coal is blown into a blast furnace through the tuyere. This particular process is in use at all the blast furnaces in Japan. Currently, 130-140kg of coal is used to produce one ton of pig iron, one of the highest levels in the world.

Flue gas treatment technologies contributing to environmental improvement - (i) desulfurization and denitration systems for coal-fired boilers, (ii) a dry-type simultaneous desulfurization and denitration system using activated coke and (iii) a high-performance dust removal system - have all been commercialized in Japan, which leads the world in commercial applications of these systems. In 1991, for instance, SOx, NOx and particle emissions in Japan were reduced to only one-tenth the levels required by the standards in the U.S. and Europe. The most stringent emission standards in place are the ones adopted by the Hekinan thermal power plant of Chubu Electric Power: 25ppm for SOx, 15ppm for NOx and 5mg/Nm$^3$ for particles.

As for coal conversion, particularly coal gasification, the fluidized bed gasification process was originally being developed to produce low Btu gas for IGCC - which later gave way to the entrained bed gasification process to accommodate a variety of coal. In 1995, a trial project using a 200-ton/day pilot plant was completed for the latter process, while a new project for the construction and operation of a 250MW IGCC demonstration plant is underway. Although Japan lags behind the U.S and Europe in the field of coal gasification power generation, with little accumulated technology available, a project is in progress to test-run a 150-ton/day pilot plant for two-stage entrained bed gasification with the aim of commercializing a triple-cycle power generation system using a fuel cell, gas turbine and steam turbine. High-Btu gas production technologies such as hybrid gasification and hydrogasification have yet to be commercialized because of their poor cost effectiveness. With respect to coal liquefaction, pilot plants were set up for bituminous and brown coal in the framework of the Sunshine Project. Japan's level of technology in this area is on par with international standards, but coal liquefaction is nowhere near commercialization.

On the other hand, coal ash utilization technologies are in practice in the fields of civil engineering, construction and agriculture, being used for hardening agents, earthwork materials, Pozotech, artificial lightweight aggregates, etc.

An IGCC demonstration project (slated to launch test operations in 2008 and be adopted by the Misumi power plant of the Chugoku Electric Power in 2014 or later) and IGFC technological development are expected to boost Japan's CCT development. Also promising are hydrogen production from coal involving $CO_2$ recovery and a high-efficiency power generation system using hyper coal.

### *4-2 Status in the U.S.*

Originally, CCT demonstration projects in the U.S. were designed to address the acid rain problem between the U.S. and Canada back in 1985. In an effort to commercialize CCT as early as in 2005 through test runs of demonstration plants, development efforts are underway in the following areas (Of 38 demonstration projects, 29 projects were completed before 2001, while a total of US$5.7 billion had been invested as of 1998):

- Advanced power generation technologies: PFBC, IGCC, A-PFBC, etc.
- Environmental improvement technologies: SOx/NOx reduction technologies
- Coal processing: coal conversion, liquid fuel production, etc.
- Industrial technologies: iron manufacturing, etc.

Early-stage programs in the 1980s focused on

**Table 1** : Achievements of national coal utilization projects

| Category | | Theme | Development Period | Outline | Evaluation | Commercialization |
|---|---|---|---|---|---|---|
| (1) Improvement of Thermal Efficiency | Combustion | Pressurized Fluidized Bed Combustion Combined Cycle (PFBC) | 1988s-1999 | 71MW-electricity demonstration project (Wakamatsu) | Commercial plants are operating in Tomatoh-atsuma (Hokkaido Electric Power), Karia (Kyushu Electric Power) and Osaki (Chubu Electric Power), producing a total of 670MW and with another plant in the pipeline. Suitable for medium-scale power plants. | ○ |
| | | Ultra Super Critical Pulverized Coal-fired Power Generation (USC) | | Steam conditions of steam turbines: 600/610°C, 25Mpa | Commercial plants are operating at eight power plants, producing a total of 7,100MW. Two more plants are in the pipeline (2,000MW in total). A net power generation efficiency of 41% has been achieved. Development efforts are underway in Europe, targeting 700°C or higher. | ○ |
| | | Pressurized Circulating Fluidized Bed Boiler | 1992-1994 | A technical survey and trial design | On hold in the trial-design phase. | × |
| | | Coal Partial Combustion Furnace | 1984-1999 | Shift from constant pressure to pressurization; introduction of a pressurized IGCC system (25 t/day at a pilot plant) | The technology has been developed through a pressurized pilot plant for applications for medium- to small-scale direct coal-fired combined cycle plants-which are on hold in a trial phase. | × |
| | Iron Manufacturing | Pulverized Coal Injection for Blast Furnace | -1976 | Developed by each iron-manufacturing company | Already commercialized. | ○ |
| | | Direct Iron Ore Smelting Reduction (DIOS) | 1988-1995 | 500 t/day at a pilot plant | The technology has been developed for pilot plants, while a commercialization plan is underway to reduce $CO_2$ emissions. | × |
| | Industrial Furnace | Coal-based Metal Smelting System | 1993-1997 | 1-5 t/day at a basic plant | The technology has been developed for basic plants, though a commercialization plan has been abandoned due to changes in the economic situation. | × |
| (2) Improvement of the Environment | Desulfurization | Activated Carbon Method | 1975-1982 | Desulfurization efficiency: 95% | Already commercialized. | ○ |
| | Denitration | Selective Catalytic Reduction Process | 1979-1980 | Denitration efficiency: 80% | Already commercialized. | ○ |
| | Desulfurization and Denitration | Activated Coke Method | 1979-1981 | Desulfurization efficiency: 97%, Denitration efficiency: 80% | Already commercialized. | ○ |
| | Dust Removal | High-temperature Dust Removal | 1989-1995 | Ceramic filter (less than 1 mg/Nm³) | Adopted by Unit 3 of the Tomatoh-atsuma plant of Hokkaido Electric Power. | ○ |
| (2) Improvement of the Environment | Gasification | Entrained Flow Gasification | 1991-1996 | Production of low-Btu gas for IGCC (200 t/day at a pilot plant in Nakoso) | The technology has been developed for pilot plants, with a 250MW demonstration unit for IGCC scheduled to start operating in 2007. | ○ |
| | | Hybrid Gasification | 1974-1986 | Production of high-Btu gas using coal and heavy oil (7,000 m³/day at a pilot plant in Tokiwa) | The technology has been developed for pilot plants, but demonstration plants are not economically viable. | × |
| | | Coal Gasification with Hydrogen Injection | 1996-2000 | Production of high-Btu gas with hydrogen injection | Elementary technologies have been developed, but the construction of pilot plants depends on future economic conditions. | × |
| | Liquefaction | Bituminous Coal Liquefaction | 1974-1999 | NEDOL method (150 t/day at a pilot plant) | The technology has been developed for pilot plants, but a plan for demonstration plants is on hold for economic reasons. | × |
| | | Brown Coal Liquefaction | 1981-1993 | Joint development with Australia (50 t/day at a pilot plant) | The technology has been developed for pilot plants, while brown coal was replaced by bituminous coal for economic reasons. | × |
| | Fluidization | Coal Water Mixture (CWM) | 1980-1995 | Decalcified CWM for power generation and other industrial processes, distribution transit (from China to Japan) | The technology has been commercialized for both power and other industrial plants, though a fuel shift is currently tabled due to changes in the economic situation (at the Tokiwa joint thermal power plant). | ○ |
| | | Low-grade Coal Water Mixture | 1991-1995 | Production of CWM from brown coal, based on the hot dewatering method | A feasibility study conducted in Indonesia suggested poor cost efficiency; commercialization depends on future economic conditions. | × |
| | Handling | Coal Cartridge System (CCS) | 1982-1987<br>1990-1995 | 5 t/h,<br>25 t/h | A CCS center is operating in Chita City (200,000 t/y) for Nisshinbo Industries and Nichiha. | ○ |
| | | Low-grade Coal Utilization | 1977-1997 | Dehydration and modification of brown coal | The technology has been developed for pilot plants; commercialization depends on future economic conditions. | × |
| (4) Coal Ash | Utilization Technology | Applications for Engineering and Construction Works | 1980- | Hardened materials, earthwork materials, civil engineering materials (Pozotech), Artificial aggregate, etc. | Pozotech is already on the market, while full-scale demonstration projects are underway for artificial aggregates, fluidized bed ash solidification, etc. | ○ |

Source: Author's compilation based on Reference [14] demonstrating SOx/NOx reduction technologies, followed by research on IGCC and other high-efficiency power generation technologies. CCT demonstration programs in the U.S. are unique in that they are designed for similar technologies, which together contribute to improving US competitiveness in this particular area. In addition, there have been extensive efforts in transferring US proprietary CCT to developing countries. President Bush announced in 2002 that a total of US$2 billion would be appropriated to a 10-year program dubbed the "Clean Coal Initiative."

In 2000, meanwhile, "Vision 21" was mapped out to pursue high-efficiency power generation towards 2015, with elementary research launched for 27 themes, of which 12 themes are concerned with $CO_2$ sequestration. Typical themes are as follows:

- Zero emission facilities designed to coproduce electricity, fuel and chemicals
- Ultra-low SOx/NOx emissions
- Reduction or sequestration of $CO_2$
- Modules designed to coproduce hydrogen, clean transportable fuels and chemical fuels

DOE came up with the "Coal and Power Program"to meet domestic energy demand, presenting three major themes - i.e., power generation systems, carbon sequestration and advanced clean fuels. Six national initiatives including "Clean Coal Initiative" and "Vision 21" are in progress to put the program into practice.

### *4-3 Status in Europe*

In Europe, the EU laid out a framework program to strategically promote R&D efforts on an EC-wide basis, taking into account the common interest of the member countries. This program has been in place since 1984, with the fourth and the fifth phases implemented in 1994-1998 and 1999-2002, respectively; the sixth phase (2003-2006) is being implemented.

Development efforts related to CCT are in progress through the fifth-phase framework programs (energy-related programs such as "ENERGIE") as well as through the fourth-phase framework programs ("JOULE" and "THERMIE"). The former include the following activities:

- Demonstration of a 335MW IGCC plant of ELCOGAS (a continuous program in Puerto Llano, Spain): coal and petroleum coke are gasified in an entrained bed gasification furnace, into which limestone is charged to lower the melting point of ash.
- Demonstration of an advanced pulverized coal-fired power generation system (a continuous program in which 40 companies participate): a total of 40 companies including power companies and manufacturers will jointly develop metal materials to operate pulverized coal-fired boilers at temperatures above 700˚C.
- Demonstration of cogeneration through a 71MW PFBC power plant using brown coal (Cottbus, Germany): a PFBC boiler (12bar) produces both heat and electricity, using brown coal.
- Co-combustion of coal and biomass fuel (Austria): coal and biomass fuel are burned together in a pulverized coal-fired boiler to reduce $CO_2$ emissions (3-5% of coal is replaced with biomass fuel).

The sixth-phase program aims to develop (i) emission-free high-efficiency power generation systems, (ii) environmental measures such as $CO_2$ sequestration, and (iii) ecosystems, while emphasis is placed on measures to reduce $CO_2$ emissions, ensure energy security and promote renewable energy sources. At the same time, technologies for the use of biomass and other waste materials and for the co-combustion of coal and biomass fuel are being developed. Technology transfer to developing countries is also a priority issue. The EU has attached great importance to energy security ever since September 11, 2001, when the simultaneous terrorist attacks took place in the U.S. It is thus beginning to place a premium on the use of renewable energy sources and coal (including brown coal) produced in Europe to develop emission-free high-efficiency power generation systems.

### 4-4 Status in China

In its 10th Five-year Plan (2001-2005), the Chinese government is pushing ahead with science and technology research projects (“973 Plan,” “863 Plan” and “2010 Target”) in a bid to develop and promote energy-related technologies[15]. As for CCT, R&D is underway primarily in the fields of coal liquefaction, coal gasification, IGCC and eco-friendly coal utilization systems, all based on overseas technologies.

### 4-5 Comparison of competitiveness between Japan, the U.S. and Europe

Table 2 shows the competitiveness of CCT in Japan, the U.S. and Europe, based on the above-mentioned trends in CCT and Reference 11.

Although Japan is leading in combustion control, PFBC and the use of industrial coal for iron production - each of which contributes to improving thermal efficiency - it lags behind its Western counterparts in IGCC, with little accumulated technology available in this area.

In the field of environmental improvement, Japan has the world’s most advanced technologies for desulfurization and denitration, while the U.S. and Europe have a competitive edge in commercial technologies for the isolation, recovery and sequestration of $CO_2$, as well as in coal gasification, fluidization and synthetic fuel production. DME production, however, is one of Japan’s specialties. As for fuel production through indirect coal liquefaction, SASOL (South Africa) is a world leader - an advantage brought about by South Africa’s historical background, where oil was inaccessible. The basis of direct coal liquefaction technology has been established in Japan, the U.S. and Europe through a series of pilot projects, but it is far from commercialization because of its poor cost effectiveness.

The U.S. and Europe place a premium on high-efficiency IGCC and the isolation, recovery and sequestration of $CO_2$, in which they have a competitive edge. Japan also needs to commercialize coal gasification technology and IGCC as part of a total system in order to dramatically improve the efficiency of coal-fired

**Table 2** : Competitiveness of clean coal technologies in Japan, Europe and the U.S. (technological resources and operating cost)

| Category | | Japan | U.S. | Europe | Others |
|---|---|---|---|---|---|
| (1) Improvement of Thermal Efficiency | Ultra Super Critical Pulverized Coal-fired Power Generation | ○ | | | |
| | Pressurized Fluidized Bed Combustion Combined Cycle | ○ | | | |
| | Integrated Coal Gasification Combined Cycle | | ○ | ○ | |
| | Use of Industrial Coal | ○ | | | |
| (2) Improvement of the Environment | Desulfurization | ○ | | | |
| | Denitration | ○ | | | |
| | Dust Collection | ○ | ○ | ○ | |
| | $CO_2$ Sequestration | | ○ | ○ | |
| (3) Coal Modification | Gasification | | ○ Small Scale | ○ Large Scale | |
| | Liquefaction | Suspended | Suspended | Suspended | |
| | Fluidization | | ○ CWM, Coal Water Mine | | |
| | Synthetic Fuel | ○ (DME Production ) | ○ (Alcohol and DME Production) | | ○ (Coal Indirect Liquefaction by SASOL- Republic of South Africa) |
| (4) Coal Basic Technology | | ○ | | ○ | |

○ : Competitive, DME: Dimenthyl Ether

Soruce: Author’s compilation based on References[10, 14] power generation. In addition it is essential that a power generation process recovering $CO_2$ and technologies for $CO_2$ sequestration be developed domestically.

## 5 Future challenges and recommendations on policies

### 5-1 Future challenges

Coal continues to be an important source of primary energy in Japan as well as in the rest of the world. As mentioned in Chapter 3 and 4, the following issues should be addressed to promote the eco-friendly use of coal[16].

(i)Energy efficiency improvement and $CO_2$ reduction to curb global warming

- Coal-based power generation systems with higher efficiency, and low-cost $CO_2$ reduction measures
- Mergers between industries to dramatically improve energy efficiency (focusing on coproduction of energy and chemical raw materials from coal)
- High-efficiency hydrogen production from coal, and low-cost $CO_2$ recovery and sequestration
- $CO_2$ reduction through the use of coal with biomass and other waste materials

(ii) Measures to reduce the environmental load caused by coal combustion

- Disposal and utilization of coal ash - a product of coal combustion
- Advanced, cost-effective flue gas treatment technologies for removing NOx, SOx and particles

(iii) International cooperation

- Technology transfer to Asian countries to contribute to conserving the regional environment
- Application of the Kyoto Mechanism*1, particularly the Clean Development Mechanism (CDM)*2

(iv)Measures to ensure the security of the coal supply

- Coalmine development and transportation infrastructure improvement in coal-producing countries[5]
- Information sharing between coal producers and consumers regarding the prospects for supply and demand
- Conversion and utilization of low-grade coal

### 5-2 Recommendations on policies

In view of the challenges mentioned above, the following are recommended to promote the development of eco-friendly coal utilization technology:

**(1)Development, commercialization and cost-reduction of CCT, based on coal gasification**

Eco-friendly CCT contributes to reducing the environmental load caused by coal combustion - the major challenge faced by coal. An adequate budget should thus be provided for the following initiatives, in which the government is expected to play a leading role:

(i) Develop a cost-effective power generation system by 2010, based on coal gasification technology, while improving its reliability and power generation efficiency. Promote coal ash utilization technology.

(ii) Further improve the power generation efficiency by 2015 through combined cycle power generation technology comprised of coal gasification power generation and fuel cells.

(iii) Reduce greenhouse gas emissions by 2020 through the separation, recovery and sequestration of $CO_2$.

Initiative (i) and (ii) should be conducted as a national project, based on a partnership between industry, government and academia. In particular, Initiative (ii) should incorporate an evaluation program with specific targets for achievements (period, performance and cost), while introducing a project that involves strict interim assessments of technological development in accordance with a roadmap for commercialization - a means to fill the gap between state-of-the-art coal gasification technology and commercial technologies.

In addition, it is essential that the coal product ion/transportation infrastructure be improved in coal-producing countries to ensure the security of the coal supply. In this context, the following approaches are recommended:

**(2) Security of coal supply**

It is necessary to further develop coalmines and improve the production/transportation infrastructure in coal producing countries by conducting extensive surveys of their status and mobilizing financial resources so that the main advantage of coal - low and stable prices - can be exploited over the medium and long term. In addition, the trade and investment climate in coal-producing countries should be improved through bilateral dialogue to facilitate financing.

On the other hand, a national initiative should be set up and promoted to develop technologies for converting Asia's low-grade coal into high-grade coal - a means to ease the shortage of high-grade coal, which constitutes the majority of coal consumed in Japan.

Japan is expected to play a leading role in organizing and managing the "Asia Coal Forum" (provisional name) in cooperation with APEC and ASEAN+3 (Japan, China and Korea) to share and exchange information regarding the prospects for the Asian coal market and CCT promotional measures.

It is also essential that human resources specializing in CCT be developed if eco-friendly coal-based power generation is to supply some 20% of primary energy over the next few decades. To this end, the following approaches are recommended:

**(3) Medium- and long-term human resource development**

Medium- and long-term support measures should be in place at universities or graduate schools (e.g., designation of one university per nine regions) to develop human resources in CCT: interdisciplinary educational programs. With regard to such programs designed for graduate schools, internship training should be provided by future employers (companies engaged in CCT) so that students can learn expertise in commercializing technological achievements. Universities and graduate schools are expected to foster human resources specializing in advanced CCT and coal science, who can present new ideas and understand their technical viability. Companies, meanwhile, should develop better OJT programs to further strengthen the international competitiveness of Japan's CCT resources.

## 6 Conclusion

While energy consumption in the world, particularly in Asia, is expected to increase further, cost competitiveness, the security of supply and environmental measures are decisive factors for the international energy market in selecting energy sources.

The advantages of coal, as history shows, lie in its cost competitiveness and widespread distribution. With concerns growing over global warming, however, it is increasingly important to reduce the relatively high environmental load caused by coal combustion - which translates into the growing need to develop eco-friendly CCT and take proactive measures to ensure the security of the coal supply. This article summarizes the situation of coal supply and demand, CCT and its development trends (in Japan, the U.S. and Europe), and challenges in utilizing coal in Japan.

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**Notes**

*1 The Kyoto Mechanism is a flexible approach adopted in the Kyoto Protocol to help “Annex I countries” (industrialized countries obliged to reduce their greenhouse gas emissions in compliance with the protocol) achieve their reduction targets for greenhouse gas emissions. This international cooperative framework is comprised of (1) Joint Implementation, (2) Clean Development Mechanism, and (3) International Emission Trading.

*2 The Clean Development Mechanism is a system in which “Annex I countries” jointly implement greenhouse gas reduction projects in newly industrializing or developing countries, thereby earning emission credits arising from those projects. Project investments by “Annex I countries” are expected to benefit host countries through technological transfer and the promotion of environmental conservation measures.

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