The Economic Aspects and Policy Options of Clean Coal Technologies

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Clean coal technologies (CCT), such as a pressurized fluidized-bed combustion (PFBC), an integrated coal gasification combined cycle (IGCC), and an integrated coal gasification fuel cell combined system (IGFC), are recognized as efficient and environmentally sound technologies. Although CCT has a possibility to enhance energy security, the cost, such as the specific capital cost and ancillary operating cost of CCT is higher than those of other power plants, such as gas combined cycle power and advanced coal-fired power plants. Therefore, in this study, after we analyzed the introduction of CCT into the electricity market in Japan, we assumed the introduction of both an energy tax and a carbon tax as policy options to promote the introduction of CCT into the electricity market. Moreover, we have assumed that the tax revenue which is gained by the carbon tax and energy tax is returned to the specific capital cost of CCT as a subsidy. From the result of our study, it is seen that an energy tax has an impact on the promotion of CCT. In particular, the subsidy for the specific capital cost of CCT has a large impact on the electricity market.

Introduction

Coal has some advantages, for example, coal has the largest reserves/production (R/P) ratio of any of the fossil fuels such as natural gas and crude oil, and has a regionally uniform distribution of producing countries (British Petroleum, 2002). On the other hand, there are some disadvantages, namely that the carbon content of coal is larger than that of any of the other fossil fuels, and is not environmentally friendly. Thus, it is important for strengthening energy security, to develop and promote the technologies which can use coal efficiently and in an environmentally friendly way.

The research and development of CCT, such as PFBC, IGCC, and IGFC, are widely recognized. The PFBC and the IGCC have been commercialized already in Europe and the United States. In Japan, PFBC is already commercialized, but the IGCC is still in the demonstration stage. In Europe, the development of CCT is promoted as a way to reduce dependence on natural gas which is expected to increase in demand. In the United States, in response to severe environmental regulations, the development of CCT has been promoted by the government (U.S. Department of Energy, 1987). For Japan, which depends on imported resources for its energy supply, clean coal technologies become important from the view point of energy security. Thus, for the development of CCT, it is necessary to examine the introduction characteristics of CCT from a long-term technical and economic view.

Several studies have been conducted on the technical and economic specifications of CCT. Campbell studied the energy efficiency and the electricity price of an IGCC plant in Puertollano, Spain, by using the ECLIPSE process simulator (Campbell, 2000). McMullan studied the techno-economic aspects of PFBC and IGCC and whether they are competitive with existing power plants in the electricity market by using the process simulator (McMullan, 2001). Moreover, introduction of a carbon tax in energy systems has been examined by many researchers. Williams analyzed optimal policy introducing carbon taxation by using a global warming model (Williams, 1995).

However, very few attempts have been made to research both energy conversion efficiencies and economic aspects, such as specific capital cost and competitive power, in the long-term electricity market. Moreover, there has been no study that analyzed the return of tax revenue from carbon taxation as the subsidy for CCT. In this paper, we develop an energy-economic model to consider both the economic aspects and energy conversion efficiencies of CCT. By analyzing this model, we examine the introduction of CCT into the electricity market. And then, we analyze the impact of taxation on the introduction of CCT and explore effective options to accelerate the introduction of CCT.

An Energy-economic Model

Japan Model

We have developed the detailed model in the electricity sector based on the Japan model which has been designed by Nakata et al. (Nakata, 2000; 2001. The Japan model has eighty-two processes; includes eight demand nodes in the industrial, commercial, residential and transportation sectors; and contains thirteen resource nodes modeling purchases of coal, natural gas, petroleum and nuclear fuel in the world markets. Additional processes model the electricity sector, transportation services, and the conversion of fuel to heat. Nakata, et al. analyzed the impact of carbon taxes on energy systems in Japan using this model. The Japan model runs from the year 1999 to 2044 in increments of 5 years.

Electricity Sector Model

The Japanese electricity model consists of oil-fired power, gas-fired power, coal-fired power, hydro power, renewable energy, such as photovoltaics and wind power, and nuclear power. Gas-fired power consists of gas combined cycle power plant, gas turbine power plant, and gas boiler power plant. Coal-fired power consists of additional conventional coal boiler power plant and advanced coal boiler power plant. In this study, we have assumed that conventional coal boiler power plants and oil boiler power plants will not be constructed, and the amount of electricity power generation by them will decrease.

We have designed three nodes of clean coal technologies such as PFBC, IGCC and IGFC in the electricity market. Then, in terms of the introduction of clean coal technologies into the electricity market, we have defined the following

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three scenarios:

a) Most likely case
The cost and the share of CCT in Japan are derived from the actual performances of CCT's commercialization in the United States and Europe.

b) High cost case
This case assumes that the cost of CCT in Japan becomes higher than that of the actual performance of CCT's commercialization in the U.S.A. and Europe. Therefore, the cost in this case becomes higher than that of the *Most likely case*.

c) Advance case
As compared with the *Most likely case*, this case assumes that the technological innovations in CCT arise in around five years. Therefore, the cost of CCT becomes lower than that of the *Most likely case*.

Moreover, we have assumed another case as follows: Commercialization of CCT will not be done on a large scale. This is the business as usual (BAU) case.

In this case, in terms of coal-fueled power plants, both conventional coal boiler and advanced coal boiler power plants exist in the electricity market.

The technical parameters of CCT such as the specific capital cost, the ancillary operating cost, and the energy conversion efficiency are summarized in Table 1. These parameters are carefully examined from current references (Longwell, 1995; Takahashi, 2001; U.S. Department of Energy, Energy Information Administration, 2002).

Table 1
Technical and Cost Parameters of CCT

	Case	Specific capital cost($/(mmBtu/ year))	Ancillary operating cost ($/mmBtu)	Efficiency %	Available Year
Conv. Coal		75.3	3.45	39	
Adv. Coal		66.9	3.25	41.5	
	High cost	80.3	6.25	40.5	
PFBC	Most likely	73.9	5.75	41	1998
	Advance	68.8	5.75	42	
	High cost	86.9	6.86	42	
IGCC	Most likely	80.0	6.32	43	2004
	Advance	74.5	6.32	44	
	High cost	91.7	7.08	48	
IGFC	Most likely	84.4	6.52	50	2009
	Advance	78.6	6.52	52	

Policy Options for the Promotion of Clean Coal Technologies

As the specific capital cost and the ancillary operating cost of CCT are higher than those of other power plants such as advanced coal boiler power and gas combined power plants, the electricity price of CCT becomes higher than that of other power plants. Since price differences obstruct the introduction of CCT, it is important for the introduction of CCT to reduce the electricity price.

A carbon tax and an energy tax are expected to be an efficient approach to reduce carbon dioxide emissions. It has been implemented already in both Sweden and Denmark in 1990s. In Japan, the introduction of these taxes has been discussed extensively. These taxes will promote the shift from lower energy efficiency technologies to higher energy efficiency technologies. In particular, the carbon tax will raise the price of high-carbon fuels such as coal and petroleum, and promote the energy shift from high-carbon fuels to low-carbon fuels such as natural gas.

In this study, it is assumed that a carbon tax and an energy tax are imposed as the method of reducing the price difference of electricity between the CCT and other power plants. In terms of the amount of tax, it is assumed to reduce 10% of CO_2 emissions in the year 2044 in the BAU case. In the case of carbon taxation, the tax reaches $80/tonC. In the case of energy taxation, the tax reaches $3/mmBtu. To mitigate the impact of taxation on energy systems, the taxes were introduced gradually over time, increasing the tax rate in uniform steps each period until the maximum rate was reached in 2044 .

A large amount of tax revenue is gained by the imposition of taxes. In Northern European countries, this tax revenue is used for general finances. In this study, it is assumed that the tax revenue is used as the subsidy for the introduction of CCT. It is assumed that 10% of the specific capital cost of CCT is subsidized by the tax revenue.

Since the electricity sector accounted for 33% of total CO_2 emissions in the year 1999, the total amount of subsidy took 33% of the amount of carbon tax revenue.

Tools for the Analysis

In this study, we have used the META•Net economic modeling system which was developed at the Lawrence Livermore National Laboratory. The META•Net is a partial equilibrium modeling system that allows for explicit price competition between technologies, and can constrain or tax emissions. It allows a user to build and solve complex economic models. Although the changes in the economy are largely driven by consumers' behavior and the costs of technologies and resources, they are also affected by various government policies. These can include constraints on prices and quantities, and various taxes and constraints on environmental emissions. The META•Net can incorporate many of these mechanisms and evaluate their potential impact on the development of the economic system (Lamont, 1994).

Initial Conditions for the Analysis

Several key assumptions are required to drive any analysis of this type. These include growth rates and demand response to changes in price. In this study, we assumed a moderate rate of growth over the time horizon. Table 2 shows the assumptions for the growth and demand elasticities in each sector. As for IGCC and IGFC, these have not yet been commercialized in the Japanese electricity sector. Therefore, it is assumed that the introduction of IGCC begins from the year 2004, and the introduction of IGFC begins from the year 2009 in this model.

Table 2
Growth Rate and Elasticity Assumptions for End-use Sector

Sector	Annual rate of demand growth[a)]	Demand elasticity[b)]
Industrial heat demand	0.001	-0.340
Industrial electricity demand	0.005	-0.340
Commercial heat demand	0.009	-0.230
Commercial electricity demand	0.021	-0.230
Residential heat demand	0.003	-0.380
Residential electricity demand	0.006	-0.380
Truck transportation demand	0.003	-0.170
Personal transportation demand	0.003	-0.230

a) Energy Data and Modeling Center. (2002) *EDMC Handbook of Energy & Economic Statistic in Japan*, Tokyo.

b) Nagata, Y. (2000) Personal communication. June 21, 2000.

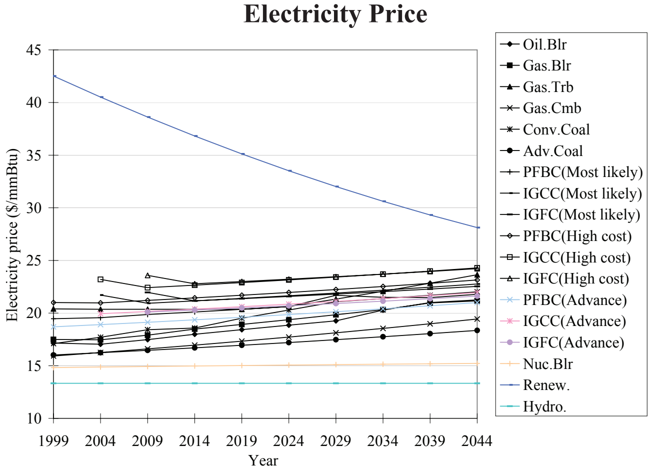
Results of the Analysis

Electricity Price and Electricity Power Generation of CCT

The discussion in this section highlights the analytical results of the electricity price and the electricity power generation of CCT.

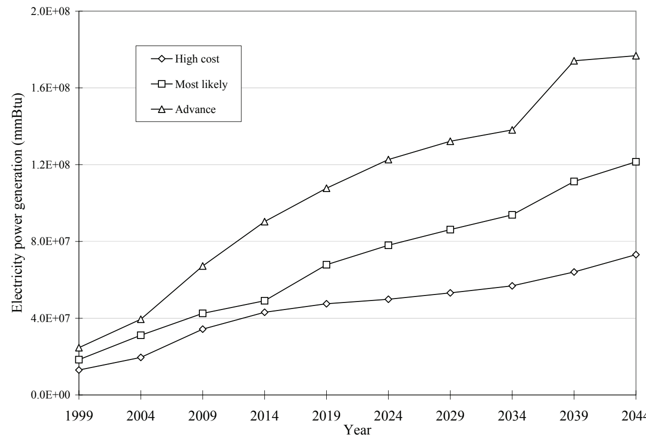
First, the electricity prices are shown in Figure 1. In each case, the electricity prices of CCT became higher than those of other power plants such as gas combined power plant and advanced coal boiler power plant. The electricity price of IGFC became lower than that of IGCC. Although the specific capital cost and ancillary operating cost of IGFC are higher than those of IGCC, since the energy efficiency of IGFC is much higher than that of IGCC, the electricity price of IGFC becomes lower than that of IGCC.

Figure 1
Electricity Price



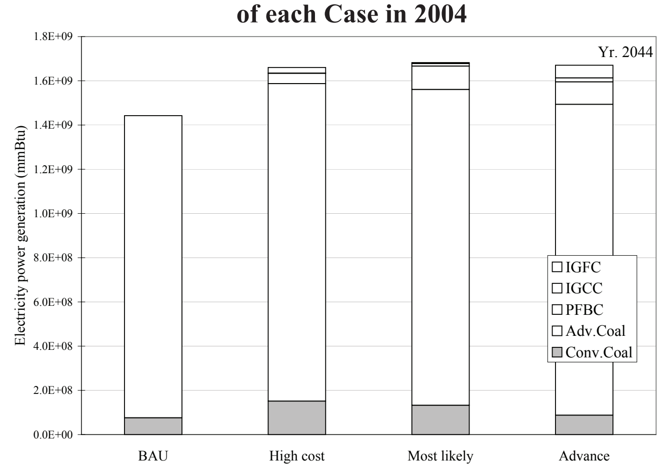
Second, the electricity power generation of CCT is shown in Figure 2. The growth rate of electricity power generation of CCT depends on the electricity cost. For the advanced and high cost cases, the electricity power generation of CCT in the advanced case becomes 2.4 times larger than that of CCT in high cost case in the year 2044.

Figure 2
Electricity Power Generation of CCT in Each Case



The component of coal-fueled power generation is shown in Figure 3.The electricity power generation of conventional coal boiler power plants decreases, so that the electricity power generation of CCT increases. In the advanced case, which increased the introduction of CCT into the electricity market, electricity power generation of CCT reached 11% of coal-fueled power generation. Moreover, since the electricity price of IGFC is lower than that of IGCC, the electricity power generation of IGFC becomes larger than that of IGCC.

Figure 3
Electricity Power Generation of Coal-fueled Power Plant of each Case in 2004

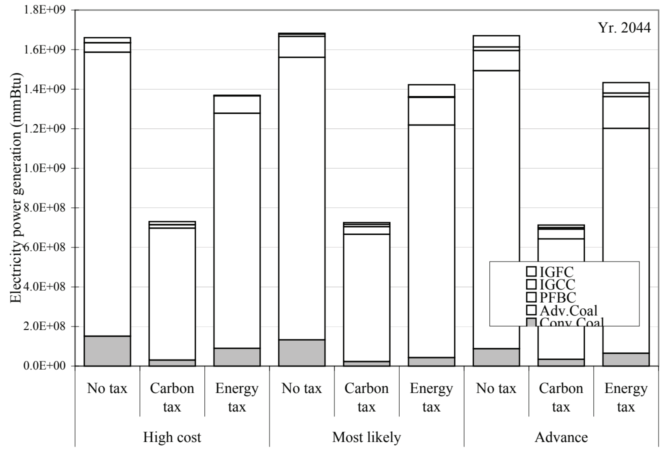


Electricity Power Generation of CCT When Carbon and Energy Tax are Imposed

The discussion in this section highlights the analytical results of electricity power generation of CCT when a carbon tax and an energy tax are imposed.

The components of a coal-fueled power plant when the taxes are imposed is shown in Figure 4. When a carbon tax or an energy tax is imposed, the electricity power generation of coal-fueled power plant decreased. However, in the case of energy taxation, the electricity power generation of CCT becomes larger. When a carbon tax is imposed, the electricity price of CCT rises more than that of other power plants because the CCT uses coal which has the highest carbon content of any other fossil fuels. Since the relative electricity price

Figure 4
Electricity Power Geneation of Coal-fueled Power Plant When the Taxes are Imposed

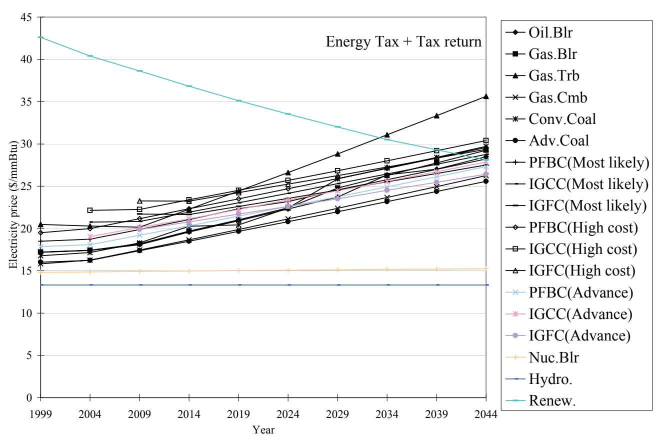


of CCT becomes higher in the electricity market, the electricity power generation of CCT decreases. However, when an energy tax is imposed, the electricity price of CCT rises less than that of other power plants because CCT has the higher energy efficiency. Therefore, the electricity power generation of CCT becomes larger than that of the zero taxation case.

Electricity Power Generation of CCT When Tax Revenue is Returned

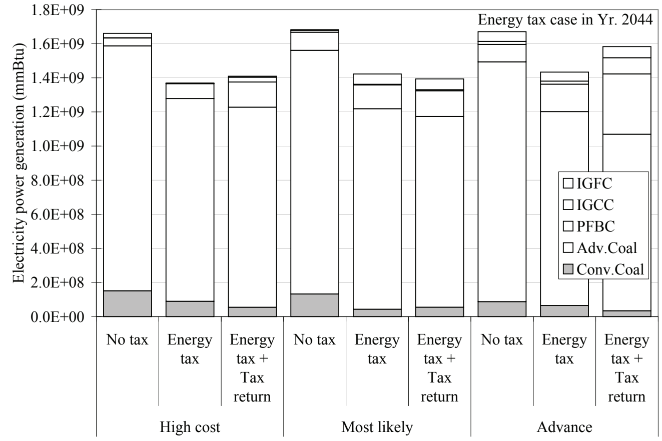
The discussion in this section highlights the analytical results of electricity power generation of CCT when the tax revenue is returned to the specific capital cost of CCT.

Figure 5
Electricity Price with Energy Tax and Tax Return



The electricity price, when the energy tax is imposed and the tax revenue is returned, is shown in Figure 5. The component of electricity power generation of coal-fueled power plants with energy tax and tax return is shown in Figure 6. By using the tax revenue as a subsidy, the specific capital cost of CCT became lower than that of the zero subsidy case.

Figure 6
CO_2 Emission from the Electricity Sector with Energy Tax and Tax Return



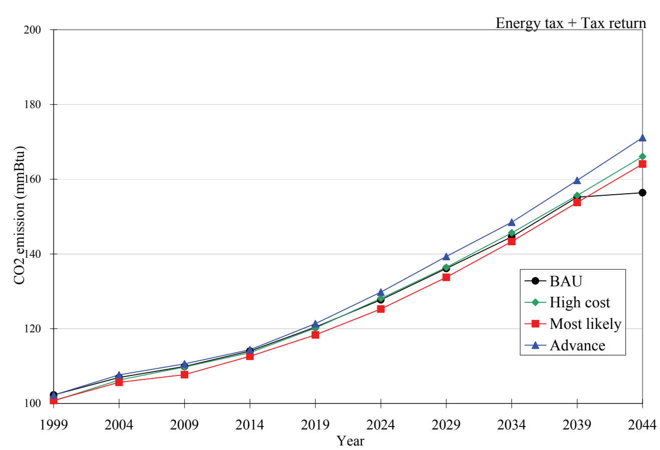
Therefore, the electricity price becomes lower than that of the zero subsidy case. Since the difference of electricity price among CCT and other power plants such as gas combined cycle power plant and advanced coal-fired power plants becomes small, the competitive power of CCT becomes strong in the electricity market. On condition that the energy tax is imposed, the electricity power generation of CCT became up to 2.9 times as large as that of zero subsidy case. In other words, by reducing specific capital costs ten percent, CCT becomes competitive in the electricity market. For the promotion of CCT, energy taxation has a larger impact than carbon taxation.

The CO_2 emissions from the electricity sector with energy tax and tax return is shown in Figure 7. In each case, CO_2 emission from the electricity sector increases. Although the energy efficiency of CCT is higher than that of existing power plants, CO_2 emissions increase because the consumption of coal rises by the increase in the demand of CCT.

Conclusion

In this study, we have developed an energy-economic model in which we can take both energy conversion efficien-

Figure 7
CO_2 Emission from the Electricity Sector with Energy Tax and Tax Return



cies and the economic aspects into consideration. Then we have evaluated the impact of CCT on energy systems in the electricity sector in Japan. The results of our analysis show that the introduction of CCT is not widely promoted largely because the electricity price of CCT becomes higher than that of other power plants.

Then, we have analyzed the effect of a carbon tax and an energy tax on the electricity price of CCT and other power plants in the electricity market. A carbon tax increases the difference in these electricity prices. In contrast, an energy tax can mitigate the price difference, and promote the introduction of CCT. Moreover, the results of our analysis shows that the tax return to the specific capital cost of CCT has a strong effect on the introduction of CCT. With respect to CO_2 emissions, the introduction of CCT has little impact on their reduction.

References

British Petroleum. (2002) BP statistical review of world energy June 2002.

Campbell, P.E., McMullan, J.T., Williams, B.C. (2000) Concept for a competitive coal fired integrated gasification combined cycle power plant. *Fuel* 79, 1031-1040.

Energy Data and Modeling Center. (2002) *EDMC Handbook of Energy & Economic Statistic in Japan*, Tokyo.

Lamont, A. (1994) User's Guide to the META•Net Economic Modeling System Version 1.2. UCRL-ID-122511. Lawrence Livermore National Laboratory, Livermore, California.

Longwell, J.P., Rubin, E.S., Wilson, J. (1995) Coal: energy for the future. *Progress in Energy and Combustion Science* 21, 269-360.

McMullan, J.T., Williams, B.C., McCahey, S. (2001) Strategic considerations for clean coal R&D. *Energy Policy* **29**, 441-452.

Nagata, Y. (2000) Personal communication. June 21, 2000.

Nakata, T. (2000) Analysis of the impact of hybrid vehicles on energy systems in Japan. *Transportation Research Part D* 5, 373-383.

Nakata, T. and Lamont, A. (2001) Analysis of the impacts of carbon taxes on energy systems in Japan. *Energy Policy* 29, 159-166.

Takahashi, M. (2001) Personal communication. Feb. 19, 2001.

U.S. Department of Energy. (1987) Comprehensive Report to Congress Clean Coal technology Program. DOE/FE-0077 CCT/87 PC797999.

U.S. Department of Energy, Energy Information Administration, (2002). Assumptions to the annual Energy Outlook 2002. DOE/EIA-0554.

Williams, M. (1995) Global warming and carbon taxation *Energy Economics* 17 (4), 319-327.