The Economics of Nuclear Energy

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1. Introduction

The economics of the civilian uses of nuclear energy, --- that is to say the economics of nuclear power generation in which its civilian uses has been virtually limited to power generation--- has been the focus of much public discussion both internationally and domestically here in Japan. The reasons are that there are many underlying factors which determine the economics of power generation methods and that various assumptions can be made concerning these factors. In addition, the value of these factors will change over time and thus entail considerable uncertainties.

Although there are many aspects to the economics of nuclear power generation, in its narrowest sense, it refers to the power generation costs of nuclear power plants and other arguments from other aspects can be summarized in terms of power generation costs. Therefore, this paper will focus on power generation costs at nuclear power plants.

In this paper, I will introduce an outline of the economic evaluation of nuclear power generation by the Japanese Government, and describe its features by comparing this evaluation with an evaluation by the United States Government, and then point out what policy implications these economic evaluations have on nuclear power generation.

2. Economic Evaluation of Nuclear Power Generation by the Japanese Government

The profitability of nuclear power generation overall was analyzed and evaluated by the Cost Examination Subcommittee of the Electric Utilities Subcommittee which is part of the Advisory Committee for Natural Resources and Energy, an advisory body to the Ministry of Economy, Trade and Industry (METI) in Japan. Even though the analysis and evaluation of their report on January 23, 2004 has become a little out-dated, I will cover the content as it is the latest analysis by the Japanese Government.

In this analysis and evaluation, the power generation costs are calculated not as the costs of the power plants that are actually in operation, but as the costs of model plants assumed to starting operations during the same period as in other similar analyses and evaluations. The costs that it uses have been calculated upon set preconditions. The analysis was carried out as a way to verify the cost calculations by Japanese electric utilities.

The following is a detailed outline of the electric utilities' cost calculations.

(1) Model plant

In principle, the power plants which satisfied the following conditions were selected and their average values were used.

a) Year of commencement of operations: Power plants that stared operations between fiscal 1999 and fiscal 2003
b) Capacity: Hydroelectric power 10,000~20,000kW, Coal thermal power 0.6~1.05 million kW, Liquefied Natural Gas (LNG) thermal power 1.44~1.52 million kW, Oil thermal power 350.000~500,000kW, Nuclear power 1.18~1.36 million kW

However, when the number of plants meeting these conditions was too small, those plants which had commenced operations recently out of those targeted at the time of the previous government analysis in 1999 were also included. Moreover, the power plants selection was designed in such a way as to avoid partiality to specific electrical power suppliers.

(2) Economic indicators

a) Exchange rate: 121.98 yen/US$ (average rate in fiscal 2002)
b) Price of fuel: Average price in fiscal 2002 for the first year.

Oil: US$27.41/b, LNG: 28,090 yen, Coal: US$35.5/t

The rate of increase in the fuel prices for oil, LNG and coal was calculated based on the latest values from the IEA's "World Energy Outlook".

(3) Operational period

Calculated on 40 years of operations to see its long-term economy, it also calculated its statutory useful life (16 years for nuclear power, 15 years for thermal power, 40 years for hydroelectric power) to see actual costs from the viewpoint of private company management.

(4) Capacity factor

Cost calculations were made using assumed capacity factors of 70% and 80% for thermal power based on its comparison with nuclear power. In addition, capacity factors for various power sources (45% for hydroelectric power, 30% for oil thermal, 60% for LNG thermal power and 85% for nuclear power) were also assumed based upon their past performance for capacity factor.

(5) Discount rate

The "Discount rate" is an interest rate used in which the future value is discounted from the present value in order to evaluate long-term investment efficiency. This rate is calculated in five stages (0%, 1%, 2%, 3%, and 4%).

(6) Nuclear fuel costs

A conversion is made from the costs and the amounts of fuel processed concurrently each fiscal year from which the unit price per ton of nuclear fuel is calculated. The acquisition unit price of uranium fuel is calculated total purchases between fiscal 2000~2002. As for the reprocessing of spent fuel, it is assumed that it will be reprocessed after eight years have passed since the nuclear reactor loadings and that it will be reprocessed after 50 years in interim storage. The regeneration rate of next-generation nuclear fuel by reprocessing the spent fuel is assumed to be 15%. Both the equalized unit price of a 40 year operational period and the equalized unit price at the operational period of statutory useful life (16 years) are calculated for the reprocessing and mixed oxide (MOX) fuel fabrication just like with nuclear reactors.

(7) Calculation results

Though the numerical results of all cases are shown in the official report, the calculation results for the 3% discount rate are shown here for the sake of simplification.

The nuclear fuel cycle cost was provisionally calculated as 1.47 yen/kWh for 40 years operation, and 1.66 yen/kWh for 16 years operation.

Power generation costs are calculated as 11.9 yen/kWh for hydroelectric power, 5.3 yen/kWh for nuclear power, 5.7 yen/kWh for coal thermal power, 6.2 yen/kWh for LNG thermal power and 10.7 yen/kWh for oil thermal power (capacity factor is 80% for both nuclear and thermal powers)

Table 2 Nuclear Cycle Cost Calculation Results (unit: yen/kWh)

	40 years operation	16 years operation
Uranium fuel	0.59	0.59
MOX fuel	0.07	0.08
(Front-end subtotal)	0.66	0.67
Reprocessing (including transportation)	0.50	0.65
HLW storage/transportation/disposal	0.15	0.15
TRU processing/storage/disposal	0.09	0.09
Decommissioning of reprocessing plant	0.03	0.07
Interim storage (including transportation)	0.04	0.04
(Back-end subtotal)	0.81	0.99
(Fuel cycle total)	1.47	1.66

Table 2 Power Generation Cost Calculation Results (unit: yen/kWh)

Generation type	Capacity factor	40 years operation	Statutory useful life operation
Hydro power	45%	11.9	11.9
Coal thermal power	30%	16.5	21.1
〃	70%	11.2	13.2
〃	80%	10.7	12.4
LNG thermal power	60%	6.8	8.1
〃	70%	6.5	7.6
〃	80%	6.2	7.2
Coal thermal power	70%	6.2	8.1
〃	80%	5.7	7.4
Nuclear power	70%	5.9	8.2
〃	80%	5.3	7.4
〃	85%	5.1	7.0

The Cost Examination Subcommittee analyzed the calculation results by changing various set preconditions such as the period of operation, capacity factor, exchange rate, the rate of increase of fuel prices, discount rate and comparing them with the previous government cost calculations in 1999.

The subcommittee said that the generation cost of nuclear power has remained the cheapest when the period of operation is 40 years, capacity factor is 80% and the discount rate is equal to or more than 1%.

The subcommittee also said that coal thermal power is on par with nuclear power at the discount rate of 3% and is cheaper than nuclear power at the discount rate equal to or less than 2% when the period of operation is the statutory useful life. However, the subcommittee stated that this represents a minimal difference in cost between coal power and nuclear power in this case.

As for LNG thermal power, the subcommittee referred to the previous calculation in 1999 which showed that LNG thermal power was cheaper than nuclear power at any discount rates when the period of operation is the statutory useful life, capacity factor is 80%. Then the subcommittee added that, though the calculation this time shows the same results, the difference in cost between LNG thermal power and nuclear power is narrowed.

The subcommittee concluded that there is no need to change the previous evaluation that nuclear power is by no means inferior to other methods of power generation according to the analysis and evaluation results of the profitability of nuclear power generation as a whole.

3. Economic Evaluation of Nuclear Power Generation by the U.S. Government: Importance of Discount Rate

As mentioned above, the cost of nuclear power generation is calculated to be a little lower than other power generation methods in Japan when the period of operation is 40 years. However, a different result is given by the cost calculation in the United States.

The Congressional Budget Office (CBO) in the U.S. Congress publicized the cost calculation in May 2008 as the latest analysis by a U.S. governmental organization. In a reference scenario of CBO's calculation which excludes any policy support to power generation, the power generation costs of conventional coal and natural gas thermal power are US$55/MWh and US$57/MWh respectively, while that of nuclear power is US$72/MWh and about 30% higher than those of thermal energies (CBO also calculated the cost of innovative coal and natural gas powers with "carbon capture and storage" (CCS). Here those results have been omitted).

It will be worthwhile to ascertain where this difference in nuclear power generation cost calculation in each country originates because it will lead us to the factor which determines the economics of nuclear power generation. Mr. Yuji Matsuo and colleagues at the Institute of Energy Economics, Japan, analyzed the difference between the Japanese Government's calculation and that of U.S. CBO. In order to compare with Japan's 2004 analysis, Matsuo et al. adjusted the cost calculation of CBO to the 2002 year price level by using the gross domestic product (GDP) deflator and converting it into Japanese yen at the exchange rate of 122 yen/US$. They obtained comparable numerical values as follows: in the CBO's Reference scenario, 7.8 yen/kWh for nuclear power, 6.0 yen/kWh for coal thermal, and 6.2 yen/kWh for natural gas thermal. The differences between Japan and U.S. are small in coal and natural gas thermal power, but large in nuclear power. Nuclear power is still expensive according to the U.S. calculations.

Table 3 Comparison of calculation results by Japan and the U.S. (2002 yen price)

(unit: yen/kWh)

	Nuclear power	Coal thermal power	Natural gas thermal power
Japan's Cost Exam. Subcom. (Discount rate 3%, Capacity factor 80%)	5.3	5.7	6.2
U.S. CBO Reference scenario	7.8	6.0	6.2

Matsuo et al. searched for the factor which can explain the difference between Japan and the U.S. and found that there were no great differences in the unit construction cost of the nuclear plant which is slightly more expensive in Japan than in the U.S. They also found that front-end costs and back-end costs in the nuclear fuel cycle are a little higher in Japan because spent fuels are reprocessed in Japan. The difference in the discount rate is thought to be a major factor generating a cost difference between Japan and the U.S.; investor's expected rate of return is assumed to be 14% for stocks and 8% for debts in the U.S. while the discount rate is assumed to be only 3% in Japan. If the discount rate is reduced to 3%, the costs of power generation will be 3.5 yen/kWh for nuclear, 3.6 yen/kWh for coal thermal and 5.2 yen/kWh for natural gas thermal, according to U.S. CBO calculations. If we assume a discount rate of 3%, power generation costs in the U.S. will be lower than in Japan and nuclear power will be cheaper than other types even in the U.S. It can be said that the deference in interest rate levels largely controls the economics of nuclear power generation.

Table 4 Comparison of calculation results by Japan and the U.S. (2002 yen price)

(unit: yen/kWh)

	Nuclear power	Coal thermal power	Natural gas thermal power
Japan's Cost Exam. Subcom. (Discount rate 3%, Capacity factor 80%)	5.3	5.7	6.2
U.S. CBO Reference scenario	7.8	6.0	6.2
U.S. CBO Reference scenario adjusted by the discount rate of 3%	3.5	3.6	5.2

In the 2005 international comparative survey by NEA and IEA of OECD, it was also brought to light that the impact the discount rate has on power generation costs greatly varies among each power generation method. In all OECD member countries and three non-member countries (Bulgaria, Romania and South Africa), power generation costs were within the range of roughly US$21~31/MWh for nuclear, roughly US$25~50/MWh for coal thermal and roughly US$37~60/MWh for natural gas thermal, under an assumed discount rate of 5%. Under an assumed discount rate of 10%, the cost will increase to roughly US$30~50/MWh for nuclear, US$35~60/MWh for coal thermal and US$40~63/MWh for natural gas thermal. The increase in cost for nuclear power generation will be most significant, since the weight of capital investment is high thus making power generation costs for nuclear power plants also high.

The bank interest rate has a dominating influence over the discount rate. Though there are various arguments among economists how the bank interest rate level will be decided in each country, a general observation is that when an economy is undergoing rapid growth, its investment demand is vigorous and its interest rate tends to be high while when an economy is stagnant, its investment demand is sluggish and its interest rate tends to be low. If this is true, nuclear power generation might be uneconomical and at a disadvantage in newly emerging economies such as China, India and Brazil. Nuclear power might also be at a disadvantage in advanced countries whose economy is in the expanding phase.

4. The Uncertainty of Fossil Fuel Prices

If the interest rate level is high and nuclear power generation becomes disadvantageous to the newly emerging countries undergoing rapid economic growth and the advanced countries experiencing an economic boom, other forms of large-scale power generation, that is to say, coal-fired thermal power and gas thermal power will inevitably expand to meet the power demand that increases along with economic growth and the economic boom.

However, the expansion of such fossil fuel thermal power generation will bring about a rise in fossil fuel prices sooner or later. The change in the fuel prices will cause power generation costs to fluctuate. The aforementioned CBO report demonstrated that the sensitivity of cost to fuel prices greatly differs depending on the power generation method. When fuel costs double, an increase in the power generating costs of nuclear power remains at around 11% while the costs of coal thermal and natural gas thermal increase by about 27% and 70% respectively.

The CBO report assumed the fuel price for coal power plant to be US$1.74 /million Btu, which is equivalent to US$46.3/t in terms of Australian steam coal with 6,700 kcal. As Australian steam coal was around US$80/t in fiscal 2008, the actual coal price was 73% higher than the assumed value. If the abovementioned sensitivity analysis is applied, the power generation costs of coal thermal would increase by about 20% (27%×73/100) to US$66/MWh. Even if the cost of the nuclear fuel cycle increases by the same ratio as coal prices (73%), the cost of nuclear power generation would increase by only 8% (11%×73/100) and remain at US$78/MWh narrowing the cost gap between coal thermal and nuclear. If natural gas prices increase by the same ratio as coal prices, the cost of natural gas thermal would increase by 51% (70%×73/100) to US$86/MWh and become more expensive than nuclear power.

The survey by NEA and IEA also described sensitivity analyses. According to the survey, doubled fuel prices will bring about a hike in power generation costs with about a 40% increase for coal thermal and about a 75% increase for natural gas thermal, while doubled Uranium fuel prices will only cause a 4% increase in nuclear power generation costs. Of course, not only Uranium ore prices but also fuel processing costs should be doubled in order to establish a proper comparison with fossil fuels, as the period for processing for Uranium ore into nuclear fuel is long in the case of nuclear power generation. However, even if the total cost of the nuclear fuel cycle is doubled, the cost of nuclear power generation will increase by only 15%. In short, OECD member countries on average are more sensitive to fossil fuel price fluctuations than in the U.S.

The experiences of the past year have taught us how drastic fluctuations in oil and other fossil fuel prices are and how difficult it can be to forecast them. Not only an actual supply-demand situation but also the influence of speculation has been pointed out as a cause of price fluctuations.

It is understood though that the earth will someday run out of fossil fuels eventually. The price of fossil fuels will no doubt soar the closer they reach the point of total depletion. At what stage near total depletion shall price start to soar? Even if nuclear power generation has become economical at that stage, will it be possible to fill in the fossil fuel gap in time?

Saying "In the long run, we are all dead", John Maynard Keynes criticized classical economists and pointed out that, even if a macroeconomic equilibrium is reached in the long run, what matters to us are the problems which occur up until that point. Saying "In the long run, our fuels will all be exhausted" might prove meaningless with forecasting the actual price trends of fossil fuels. Nevertheless, it remains a mystery just how much of the future can be foreseen when the market achieves a supply-demand equilibrium.

In the process of thermal power generation, fossil fuel thermal power plants emit carbon dioxide, which is regarded as a cause of global warming. Therefore, there is an approach which curbs fossil fuel power generation through taxing or charging on carbon dioxide emissions. Furthermore, there is an idea to install facilities which capture carbon dioxide from these fossil fuel thermal power plants and stores it in deep underground or other spaces ("carbon capture and storage" (CCS)). These ideas share the same view regarding carbon dioxide emitted through the consumption of fossil fuels as "waste" and requiring consumers of fossil fuels to bear the costs of disposing of their "waste". In nuclear power generation, costs for processing and disposing spent fuels are often included under nuclear fuel costs in its broader sense. Similarly, carbon tax/charges and CCS costs can be included under fossil fuel costs in its broader sense.

If fossil fuel costs in its broader sense increases due to the introduction of carbon tax/charges or CCS, the relative economy of nuclear power generation will improve. The U.S. CBO analyzed the impact of carbon tax/charges on the economies of various power generation methods and concluded that "Carbon dioxide charges of about $45 per metric ton would probably make nuclear generation competitive with conventional fossil-fuel technologies". Even if there is uncertainty about fossil fuel cost fluctuations in its narrow sense, an increase in remaining fossil fuel costs in its broader sense will reduce its potential impact on the relative economy of nuclear power.

5. Regulatory Risk

Finally, regulatory risk must be cited as an inherent characteristic that greatly determines the economics of nuclear power generation

OECD/NEA pointed out in its recent publications on the economics of nuclear power that "the earlier experiences with constructing nuclear power plants has shown that there is a kind of inherent risk with nuclear power generation projects that is out of the control of the investors and is difficult or might even be impossible for pricing commercial funding", specifically mentioning "those risks include the licensing risks (essentially risks which include delay or discontinuance due to barriers in the licensing process) ".

Licensing risks can be called "Regulatory risk" under a slightly broader definition, when not only risks in the licensing process of construction phase but also risks in the regulatory processes of operation phase and decommissioning phase are included. Regulatory risk can exert a big influence on the costs of nuclear power generating through the period of operation and the capacity factor.

For instance, if the future operation period of new nuclear power generation plants is limited to a certain number of years, say 32 years by the government, the economics of new power plants will be considerably lowered. Strictly speaking, limiting the period of operation to virtually 32 years by the German Government as part of its nuclear phase-out policy was applied retroactively to existing power plants and therefore is not directly relevant to the cost calculations here.

Furthermore, the capacity factor of nuclear plants in Japan remained at 58.0% in 2008. One of the main contributing factors for low capacity factor is the prolonged forced outage of Tokyo Electric Power Company's Kashiwazaki Kariwa Nuclear Power Plant since the occurrence of the Niigata-ken Chuetsu-oki Earthquake in July, 2007. While the plant cannot operate safely, the outage is inevitable. However, if government regulation postpones restarting the plant even after the plant becomes safe to operate once again, an even lower capacity factor may result from regulatory risk. Because the capacity factor assumed under the cost calculation by the Japanese Government is 80%, the economics of nuclear power generation may already have suffered considerably at an actual capacity factor of 58%.

It is hoped that regulatory risk can be decreased by rational and scientific judgment, although nuclear power generation safety regulations should be carefully applied due to the enormous potential hazard that it can represent.

6. Concluding Remarks: Coping with Three Uncertainties

Electric utilities companies have to choose one of the power generation methods by both expecting that the regulatory risks of nuclear power will be decreased on the one hand and on the other hand comparing interest rate forecast and fuel price (especially, fossil fuel price) forecast. They are exposed to uncertainties both with the interest rate and fuel prices. The uncertainty which can be decreased is the uncertainty over the interest rate, as that uncertainty disappears if the utility can receive funding through long-term liabilities with fixed interest rates.

In Japan, nuclear power plants continued to be constructed before we entered the age of low interest rates since the middle of the 1990's. Therefore, the economy of nuclear power was secured. The Development Bank of Japan (DBJ), a government-affiliated financial institution, has played an important role in securing the economy of nuclear power. DBJ supplied long term finance with fixed interest rates to electric utilities for their nuclear power plant constructions as a part of the government's financial investment and loan programs.

As the unit construction cost for nuclear power plants is higher than other power generation methods and the size and scope of nuclear power plants has become larger and larger due to the falling unit construction costs which have arisen in tandem with facility size expansion, the size of nuclear power plant funding has become enormous. Although the significance of DBJ financing, government investment and bank loans are usually explained as its "quantitative side", (i.e. the enormous amount of loans), attention must also be paid to its “qualitative side”, (i.e. the ultralong-term fixed interest rates which have eliminated the uncertainty of interest rate levels).

It is often said that the ultralong-term fixed interest rates cannot be offered by private financial institutions and that the government-affiliated financial institutions have played a supplementary role by supplying ultralong-term fixed rates. However, even private financial institutions can offer ultralong-term fixed rates, if they can add enough risk premiums on to their interest rates. (Therefore, it might be possible to see that these risk premiums are provided as interest rate subsidies by the government's financial investment and loan programs).

In the newly emerging countries and advanced countries experiencing an economic boom, government financing or government guarantees which decrease the uncertainty of interest rate levels will be needed to realize the potential economy of nuclear power.

If such support by governments needs justification, the externality of nuclear power, which bypasses the market function, should be explained.

The positive externality for coping with uncertainties both in price and amount of fossil fuel supplies can be easily understood, but difficult to be quantified.

Another positive externality to restrain the emission of carbon dioxide by fossil fuel power generation can be also easily understood. However, it might be argued that internalizing the negative externality of fossil fuel power generation by taxation, by charging on carbon dioxide or by CCS is simpler and more appropriate than government subsidies to the positive externality of nuclear power. (It is the argument of increasing fossil fuel cost in its broader sense as mentioned above).

In any case, in order to realize the positive externalities of nuclear power generation, the governments should maintain the appropriate capacity of nuclear power both by minimizing regulatory risk and influencing the cost structure of power generation through government financing or guarantees, carbon dioxide taxation and/or other policy tools. Otherwise, it may become difficult to maintain an investment in nuclear power generation in many countries other than those with low discount rates such as Japan.

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