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Major Issues Regarding Nuclear Power Generation Costs Assessment in Japan

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Summary

This paper reviewed and assessed major issues based on the existing assessments of nuclear and other power generation costs, a key matter for making energy policies. In Japan, many major issues on power generation costs have been comprehensively discussed at the Cost Review Committee created by the government in 2011. Most of these issues, with some exceptions, might have been discussed appropriately. The issue that has been left as the biggest challenge is the accident risk cost, as discussed in detail by a separate paper. Studies and model development must be conducted to enable more reliable assessments of accident damage and frequency.

The decommissioning cost and the backend cost, including geological disposal and reprocessing of nuclear spent fuel, do not account for any large share of nuclear power generation costs, in contrast to what is generally believed. What has the greatest impact on the economics of nuclear power generation is the financing issues, represented by the discount rate for estimating power generation costs, as has been widely perceived since before the Fukushima accident. Since electric utilities have so far been able to raise funds in a relatively favorable environment, nuclear power generation has actually been cheaper than other power generation methods in Japan. In the United Kingdom where electricity market deregulation has made progress since the 1990s, however, an increase in electric utilities' financial costs has been expected to affect the economics of nuclear power generation, becoming one of the major factors behind the stagnation of new nuclear plant construction projects. If Japan's introduction of a more competitive electricity market affects the credit ratings of electric utilities, it may become difficult for them to raise funds at lower interest rates, bringing about a large change in the economics of nuclear power generation. Given that business conditions for electric utilities in Japan are far different from those in Europe and the United States, however, future developments in Japan are uncertain. Given that the economics of nuclear power generation has a great impact on the future energy mix, we must pay special attention to this point in discussing Japan's energy policy.

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1. Introduction

The assessment of nuclear and other power generation costs is important for making national energy policies. Therefore, many countries have continuously assessed costs for each electric source. Internationally, the Organization for Economic Cooperation and Development (OECD) has regularly assessed costs for each electric source based on data collected from member countries. In 2010, the OECD published the seventh and latest electric cost assessment report1). Governments and research organizations in major industrial countries have been estimating power generation costs on their own, allowing their estimates to be used for making national energy policies. Among them is Japan where government and research organizations have estimated power generation costs for model plants2)3)4) and assessed objective data available through financial statements of corporations5)6)7)8). Through such efforts, methods for assessing nuclear, thermal and hydro power generation costs have been fairly established in Japan, providing useful information.

Since the March 2011 Fukushima Daiichi Nuclear Power Plant accident, however, Japan has been greatly revising its energy policies, leading to methods for assessing nuclear power generation costs being questioned. First, some people questioned if there were problems regarding the methodology for estimating power generation costs. Second, other people asked whether some costs left out from traditional estimations might have to be covered by nuclear power generation costs. In order to address these questions, the government created the Cost Review Committee in the autumn of 2011. The committee later compiled a report giving power generation costs estimates based on open data and methods9). The committee based its estimation on the traditional model plant method similar to the OECD method for estimating the levelized cost of electricity, or LCOE. The committee made no major innovation regarding the methodology. Rather, the report was valuable in that it updated assumptions to reflect the latest conditions, and that it quantified and added costs that had not been assessed in earlier estimations in Japan, such as the policy costs including costs for siting and research and development, and the accident risk costs.

The Cost Review Committee attempted to comprehensively collect data on electric sources such as nuclear, fossil and renewable energy. The attempt was roughly successful. As described later, however, estimation methods have had some problems. In addition, the methodology and the assumptions for some aspects (including the accident risk cost for nuclear power generation) were specified as tentative and some costs (including grid stabilization costs for renewable energy) were explicitly excluded from the cost estimation. These points were subjected to continuous discussion. Due to these problems, the committee’s estimation results have been subjected to various arguments including both significant opinions and mere misunderstandings.

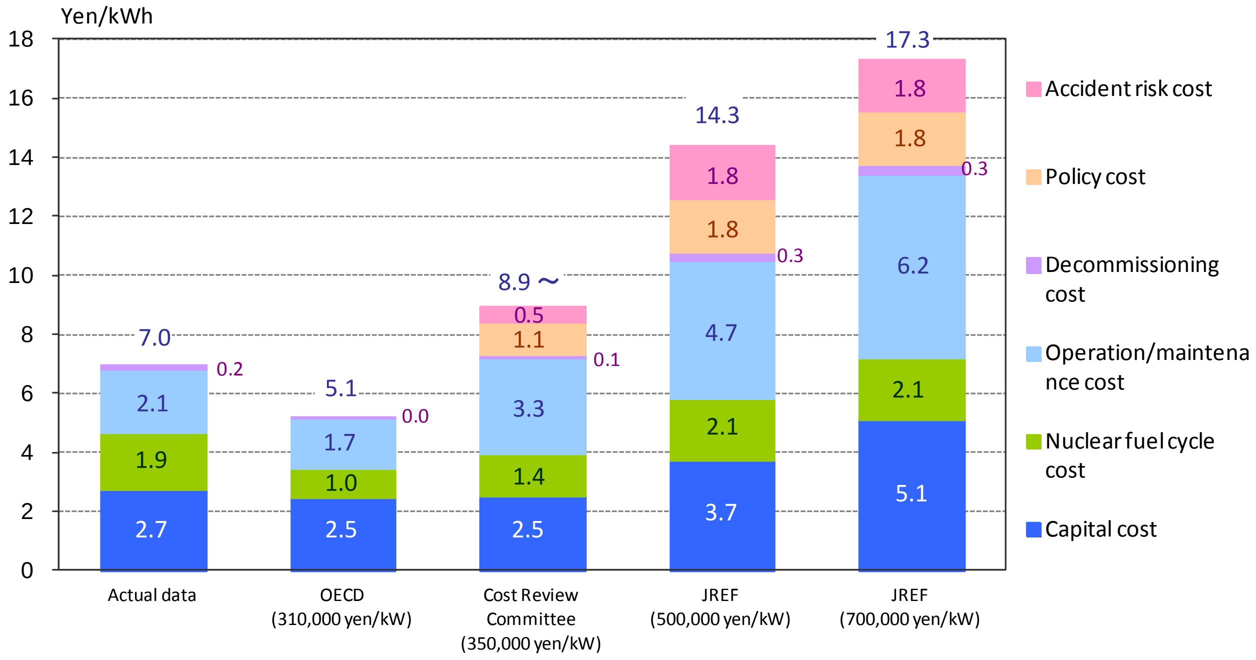
Based on the situation, this paper overviews what are the issues that would greatly affect future cost changes, after the estimation by the Cost Review Committee, focusing especially on nuclear power generation costs. Chapter 2 compares some estimation results to extract unresolved issues. Chapters 3 and 4 attempt to consider details about these points.

2. Nuclear Power Generation Cost Assessments and Relevant Issues

2-1 Nuclear Power Generation Cost Assessments

There are multiple assessments of Japanese nuclear unit power generation costs, including those by Matsuo et al.10), the OECD1), the Cost Review Committee9) and the Japan Renewable Energy Foundation11)12), as shown in Fig. 2-1. Of them, Matsuo et al. assessed unit power generation costs as actual data based on financial statements of electric utilities, as given as “actual data” in the figure. The other estimates represent unit cost assessments using the “model plant” method, calculating the LCOE of a typical nuclear power plant that would be constructed in the future. Fig. 2-1 indicates OECD estimates at the discount rate of 5% and Cost Review Committee estimates at 3%. The discount rate for estimates by the Japan Renewable Energy Foundation is assumed at 3%.

Fig. 2-1 Nuclear Power Generation Cost Estimates for Japan



(Sources) Prepared from relevant papers

The Cost Review Committee estimate is remarkably higher than the OECD estimate. On an equal basis excluding policy and accident risk costs, the estimate using financial statements stands at 7.0 yen/kWh against the OECD estimate at 5.1 yen/kWh and the Cost Review Committee estimate at 7.3 yen/kWh. The Cost Review Committee is thus closer than the OECD estimate to the actual data-based estimate. (But the breakdown of the costs of the actual data-based estimate are different from those of the Cost Review Committee estimate. See Reference 10) for more detail.) Particularly, the operation and maintenance (O&M) cost is 1.7 yen/kWh for the OECD estimate against 3.3 yen/kWh for the Cost Review Committee Estimate.

The Cost Review Committee estimate features the inclusion of policy and accident risk costs that the OECD estimate does not cover. The policy cost of 1.1 yen/kWh covers plant siting and R&D for nuclear power generation, including 0.4 yen/kWh for siting, 0.5 yen/kWh for future power generation technology development and 0.2 yen/kWh for others (including disaster prevention, various assessments and surveys, power generation technology development, etc.). The accident risk cost estimate is based on the assumed damage from the Fukushima Daiichi Nuclear Power Plant accident and the system for electric utilities to shoulder accident costs on a mutual aid basis. The assumed damage of 5.8 trillion yen was thus divided by nuclear power generation over 40 years into “more than” 0.5 yen/kWh. As the assumed damage increases by 1 trillion yen, the unit power generation cost is estimated to rise by 0.09 yen/kWh.

OECD estimates have been updated regularly since 1983, as explained at the outset. New estimates are expected to come out within 2015. In Japan, the Power Generation Cost Verification Working Group was created under the Advisory Committee for Natural Resources and Energy to reassess power generation costs based on up-to-date information.

2-2　Issues on Power Generation Cost Assessments

2-2-1　Concept of “power generation costs”

“Power generation costs” literally mean costs or expenses required for power generation. The costs required for power generation within a certain period are divided by power generation to determine unit power generation costs. If any confusion is avoided, the unit costs are frequently called the power generation costs. The problem here is what is included into the power generation costs. Generally, the power generation costs are computed under either of the following standards:

1. Costs required by power generators for generating electricity. Specifically, they include costs for constructing, operating and maintaining and decommissioning power plants and for disposing wastes. They amount to a combination of electricity business expenses and financial costs including interest payments as specified in corporate financial statements.
2. In addition to the above narrowly defined costs, this category covers the costs indispensable for power generation that are shouldered by others than power generators, including central and local governments and citizens.

Of the estimates given in Fig. 2-1, the OECD estimate excludes policy and accident risk costs, but the Cost Review Committee estimate includes them. The difference represents the gap between the above two definitions of power generation costs. The wall between the narrowly and broadly defined power generation costs indicates not only the coverage gap but also a change in the concept of costs. The former (narrowly defined) costs are booked as financial expenses by power generators, added to electricity rates paid by consumers generally and computed specifically from financial statements of electric utilities. In contrast, the latter (broadly defined) power generation costs are less specific. Generally, the broadly defined costs are viewed as shouldered by the entire nation rather than electric utilities. In a country with poor natural resources, even if an electric utility’s fossil power generation cost that mostly flows out of the country is nominally the same as its nuclear or renewable power generation cost that mostly stays in the country, the two costs for the nation may be viewed as different. It may also be argued that subsidies to nuclear power plant sites simply move between people within a country and cannot be considered costs for the entire nation[1]. In order to resolve the cost concept problem, we may have to comprehensively assess various costs' economic and social effects, including economic spillover effects. But this kind of assessment is usually considered out of the scope of power generation cost assessment.

In a more simplified way, the Cost Review Committee takes into account central and local government spending (including power plant location subsidies, and research and development costs) as well as electric utility spending on power generation. This may be close to aggregating electric utilities' financial costs for estimating the "narrowly defined" power generation costs. Therefore, the "widely defined" costs are interpreted (sometimes mistakenly) as representing an expansion of the "narrowly defined" costs. Even in this case, however, the "widely defined" costs are still theoretically recognized as the costs for the nation (or mankind). Therefore, the estimation of damage from an accident may cover the accident's macroeconomic effects and some other costs in addition to direct spending by central and local governments.

In addition to the conceptual ambiguity, there is a problem regarding the ambiguous scope of costs for assessment. In the case of Japan, some part of personnel and other costs for the Maritime Self-Defense Force defending sea lanes may have to be counted as part of power generation fuel procurement costs. But such costs have never been covered. So far, realistically available costs have been taken into account, with the other costs being left for future consideration. In this way, the concept of "widely defined" power generation costs have many problems, although many attempts have been made to capture the widely defined costs especially in Europe and the United States, and in Japan, the matter is in an early stage of discussion as explained later in this paper.

In addition to the narrowly and widely defined power generation costs, there is another standard for estimating power generation costs:

3. All the costs and contributions associated with a certain power generating technology, paid due to various social and institutional factors, are aggregated along with the costs necessary for power generation.

This standard is used by some people specifically for explaining nuclear power generation costs (e.g., Reference 13)). If the standard is used for estimating renewable energy power generation costs, however, electricity price surcharge under the feed-in-tariff system may have to be added to the costs. Therefore, this standard may not be appropriate for assessing and comparing power generation costs for multiple energy sources. See Addendum 1 for details.

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[1] For example, the Research Institute of Innovative Technology for the Earth (RITE)4) excludes the power plant location subsidies from the power generation costs for this reason. Given a view that a costless wealth transfer can adversely affect society (if all social wealth is collected for only a small number of people in a costless manner, it may create no social cost under this argument but adversely affect society by expanding social inequality), excluding the subsidies from the power generation costs may not necessarily be the best choice.

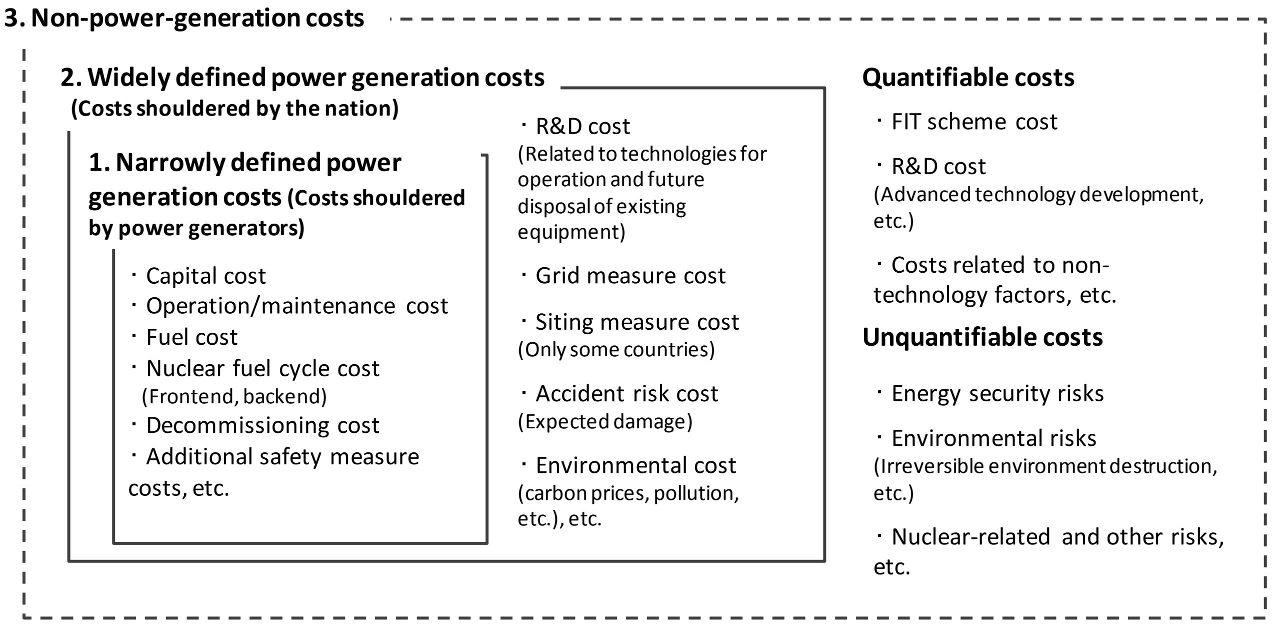
Another frequently asked question is how we should treat costs that are difficult to quantify. Here, it is important to separate “those that are unquantifiable into monetary values in principle” from “those that are quantifiable into monetary values in principle but are difficult to quantify in practice.” The former cannot be included into power generation costs as far as they are unquantifiable in principle. The latter may cover those that should be included into and excluded from power generation costs. We may have to continue efforts to appropriately quantify those that should be included into power generation costs. See Addendum 2 for details.

Given the above, various contributions and costs for power generation are classified as shown in Fig. 2-2. OECD and other estimates cover “narrowly defined power generation costs,” or electric utilities’ costs as described in Standard 1. This does not necessarily mean that nothing other than electric utilities’ costs is considered in the cost estimates. As explained later, in Europe and the United States other costs than electric utilities’ are assessed as “external costs.” At the same time, OECD estimates cover carbon prices that should be treated as external costs in nature, indicating a conceptual inconsistency.

Japan’s Cost Review Committee has attempted to assess “widely defined power generation costs.” But we must pay attention to the fact that its estimates do not strictly abide by the Standard 2 given above. In fact, the committee’s unit nuclear power generation cost estimate includes 0.5 yen/kWh for “future power generation technology development” including research and development costs for fast breeder reactors.

Power generation costs are usually assessed for considering future energy mix options. The inclusion of 0.5 yen/kWh for “future power generation technology development” into the unit nuclear power generation costs means that 50 billion yen a year will be spent on research and development for 100 billion kWh in nuclear power generation in 2030, for example. Even if some

Fig. 2-2 Classification of Costs Accompanying Power Generation



nuclear power generation is expected in the future energy mix, the cost estimates may have to be separated from a decision on whether to continue FBR research and development. We doubt if it is reasonable to expect future research and development costs in proportion to the nuclear power generation output. Under Standard 2 shown above, future technology development costs may have to be excluded from power generation costs because they are not indispensable for power generation with light-water reactors.

Abovementioned Standard 2 is used for deciding what should be included into or excluded from the widely defined power generation costs. This means that decisions depend on whether a specific cost is characteristically required for a power generation technology or it is required for political or social reasons other than technology. For example, electricity grid measures required for the massive diffusion of renewable energy are related to the technologies so that their costs cannot be avoided for the massive diffusion irrespective of renewable energy diffusion scheme. Meanwhile, the FIT scheme cost depends on policy factors. If any other scheme, similar to the past renewable portfolio standard (RPS) system, for example, which requires electric utilities to secure a certain power generation share for renewable energy, is used for the massive diffusion of renewable energy, additional cost may change dramatically. Therefore, the grid measure cost may be included into the “widely defined power generation costs” while the FIT scheme cost may be excluded.

Costs in an intermediate territory may include a plant siting cost involving nuclear power generation in Japan, which is recognized as indispensable for nuclear while being required for social reasons rather than the technology. (In fact, such cost in foreign countries is far lower than in Japan.) Arguments may be divided over the inclusion of such cost into power generation costs. As far as Japan is concerned, the plant siting cost may be allowed in some cases to be deemed indispensable and included into power generation costs. An intermediate territory may emerge for anything. But arguments are confused even over a non-intermediate matter as shown above. Given such confusion, we may have to appropriately assess power generation costs.

(Addendum 1) Classification of power generation costs

Reference 13) states: “Power generation costs mean social costs required for power generation. Social costs here are costs for the entire society including those that fail to be paid or calculated by electric utilities.” This may amount to the definition of power generation costs in abovementioned Standard 3. The following two problems are conceivable regarding this definition.

First, the definition deviates from the impression of “power generation costs.” According to the above definition, FIT tariffs involving renewable energy may be called “power generation costs.” Specifically, the Cost Review Committee estimated the unit costs for onshore wind power generation at 9.9-17.3 yen/kWh (as of 2011). Under abovementioned Standard 3, the “power generation costs” turn out at 22 yen/kWh for a capacity of 20 kW or more and 55 yen/kWh for a capacity less than 20kW (for FY2014) as FIT tariffs. Generally, however, the FIT tariff is set to include appropriate profit along with power generation costs to promote the diffusion of renewable energy. Therefore, the description of the FIT tariff as “power generation costs” has a wording problem.

A more significant problem is that such definition of “power generation costs” may make it difficult to appropriately discuss costs for various power generation methods. For example, there may be a case in which Technology A that had been assumed to generate power at a very low cost has actually turned out to be economically inefficient. Whether the economic inefficiency is attributable to factors unique to Technology A itself or social or institutional factors is very important for making a policy decision. If it is attributable to the former, the Technology A choice itself may have to be revised. If it is attributable to the latter, social or institutional systems causing the economic inefficiency may have to be improved. FIT and other systems that are intended to bring about some deviations for policy purposes may have to be operated in a fine-tuned manner. If various costs in abovementioned Standard 3 are included into the “power generation costs,” estimated costs may not be useless for making policy decisions.

(Addendum 2) Costs quantifiable and unquantifiable into monetary values

“Costs that are quantifiable into monetary values in principle but are difficult to quantify” must be separated from “costs that are originally unquantifiable into monetary values.” Nevertheless, the two types of costs have actually failed to be separated from each other consistently and clearly. The former costs include environmental damage accompanying climate change. The damage (or benefits) ranges wide and is difficult to quantify. Nevertheless, attempts to quantify such damage are useful, required and actually made. It is reportedly difficult to quantify human lives and landscapes into monetary values. But human lives are quantifiable unless they are our own or our relatives’[2]. Costs that are considered unique to a specific technology in question under the abovementioned Standard 2 should be included into the “widely defined power generation costs” even if they are relatively difficult to quantify into monetary values. (Actually, it is still unknown how low-frequency sound accompanying wind power generation would affect human life or the Japanese economy. Such and other effects are unknown at present and may have to be excluded from power generation costs. But efforts to quantify these effects into monetary values should be continued.)

Meanwhile, there are many things that are originally unquantifiable into monetary values. They may include our own lives and our hometown landscapes that essentially transcend monetary values. Environmental losses accompanying climate change, as noted above, may apparently include quantifiable ones and originally unquantifiable ones. Among others that are unquantifiable into monetary values is energy security. Since the oil crises in the 1970s, Japan has diversified energy uses. But it still depends on fossil fuels for most of its energy supply and on the Middle East for most of its fossil fuel supply. A cut in Japan’s dependence on the Middle East has some value, while an increase in it represents a risk. But it is impossible to quantify a 1% drop in the dependence on the Middle East into a monetary value. Any unreasonable attempt to quantify it may fail to produce an appropriate result.

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[2] In fact, the HC (Human Capital), WTP (Willingness-To-Pay), WTA (Willingness-To-Accept), VOLY (Value of Life Year) and VSL (Value of Statistical Life) have been devised to quantify human lives and human damage into monetary values.

Risks that are unquantifiable into monetary values in principle cannot be included into power generation costs whether they are unique to a power generation technology subject to assessment. Here, we may have to refrain from converting such risks forcibly into monetary values for their quantitative comparison with others. Nevertheless, it is important to recognize that this does not necessarily mean such risks do not have to be taken into account. Rather, explaining global environmental problems only in terms of monetary losses may trivialize the problem. For a man, this may be close to explaining his death in terms of the amount of his life insurance. The same applies to risks accompanying nuclear power generation. As explained later, economic costs involved in the disposal of high-level radioactive wastes have no significant impact on the economics of nuclear power generation, contrary to some misperceptions. This does not mean that the radioactive waste disposal issue is not important. But this indicates the significance of the problem of not being able to be quantified into monetary values. (Here, the problem is how to secure extra-long-term safety or whether any such safety can be secured.) It is worthy of attention that "unquantifiable costs" in Fig. 2-2 are for energy security, environmental protection and safety among the so-called Three Es plus safety that are frequently cited in regard to energy problems. Costs or economic efficiency as the remaining E are nothing more than one factor for policy decisions. The other factors should not be unreasonably included into costs. As economic efficiency or cost assessment is taken as forcibly determining the relative merits of various things, we are sometimes prompted to convert everything into monetary values. But we must interpret those that are unquantifiable into monetary values as such and subject them to extensive comparison that does not depend only on monetary values. A simple terminological confusion frequently makes entire discussions ambiguous in media reports and policy decisions. But we must always avoid misunderstanding or confusion in discussions under concepts that should be as clear as possible.

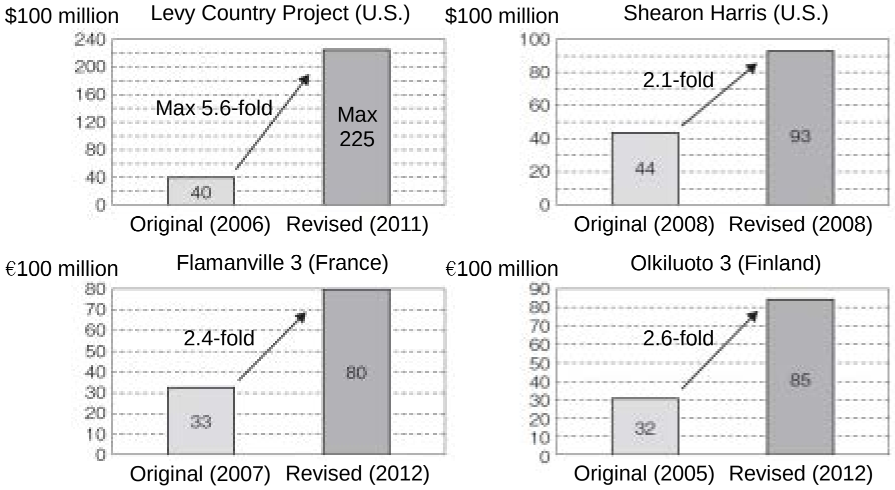
2-2-2　Reviewing issues on power generation cost assessments

Comparison of estimates in Fig. 2-1 roughly indicates the following:

(1) Capital cost

While capital cost estimates by the OECD and the Cost Review Committee are roughly close to the actual level, the estimate by the Japan Renewable Energy Foundation far exceeds the actual level. This is because the foundation estimates the unit nuclear power plant construction cost at 500,000-700,000 yen/kW, far higher than 310,000 yen/kW for the OECD and 350,000 yen/kW for the Cost Review Committee. The reason for the higher estimate by the foundation is that European and U.S. nuclear plant construction costs in recent years have risen from originally estimated levels, as shown in Fig. 2-3. But price hikes shown here arise from the conceptual confusion of overnight and total costs as explained later and from special conditions. These problems should be appropriately taken into account for considering a possible hike in the unit nuclear plant construction costs.

Fig. 2-3 U.S. and European Cases of Nuclear Power Plant Construction Cost Hikes



(Source) Japan Renewable Energy Foundation[11)]

There is another important issue regarding the capital cost. That is the discount rate. In most estimates, the capital cost accounts for a majority of nuclear power generation cost. The Cost Review Committee’s estimate of which the capital cost captures only less than 30% is rather exceptional. Factors behind the low share for the capital cost may include relatively a higher operation and maintenance cost and the inclusion of the abovementioned social costs. But the biggest factor is the low discount rate of only 3%[14)]. Consideration of this point is indispensable for assessing the economics of nuclear power generation.

(2) Other costs

The Cost Review Committee’s assumption of the nuclear fuel cycle cost differs from the actual data level. For the reason, see Reference 10). The Japan Renewable Energy Foundation has estimated the cost at 2.1 yen/kWh exceeding the actual data level. The foundation has explained that it has raised the Cost Review Committee estimate by 50% in consideration of the second reprocessing plant cost that the committee has failed to cover. In fact, however, the committee is based on an estimate by the Atomic Energy Commission of Japan[15)] that uses a unit nuclear fuel cycle cost and conceptually covers the second reprocessing plant cost, based on data for the Rokkasho reprocessing plant. The foundation’s description of the Cost Review Committee estimate as failing to cover the second reprocessing plant cost may amount to a misrepresentation of the facts.

Even more important is an operation and maintenance cost estimate gap. The cost is estimated at 1.7 yen/kWh by the OECD, at 3.3 yen/kWh by the Cost Review Committee and at 4.7-6.2 yen/kWh by the Japan Renewable Energy Foundation, against the actual data level of 2.1 yen/kWh. As for the gap between the Cost Review Committee estimate and the actual data level, see Reference 10). The OECD estimate is lower than the actual data level and may have failed to appropriately reflect realities in Japan. But it is difficult to find any reason for raising the actual data level more than two-fold, as is done by the Japan Renewable Energy Foundation. The reason for this may be that the foundation might have used a Cost Review Committee estimate MS Excel sheet that sets repair and miscellaneous costs for power generation as a percentage of the construction cost. If the construction cost assumption is doubled from 350,000 yen/kWh to 700,000 yen/kWh, the operation and maintenance cost may automatically double. We may have to give cautious consideration to this point.

The Cost Review Committee has estimated the policy cost at 1.1 yen/kWh. As explained above, the treatment of “future power generation technology development” is doubtful. On the other hand, the Japan Renewable Energy Foundation has raised annual power plant location subsidies 2.5-fold from 127.8 billion yen under an assumption that such subsidies would be increased in response to the expansion of the emergency planning zone (EPZ) radius to 30 kilometers. In fact, however, areas for the subsidies have never been revised in response to the EPZ expansion. The subsidies have never been increased. In addition, power plant location subsidies worth 111 billion yen under the FY2011 budget included only 24.3 billion yen in subsidies granted to local governments neighboring power plants16). Even if the scope of local governments subject to such subsidies were expanded, the expansion might not become a reason for the other portion than the grants to local governments.

A more difficult issue is the accident risk cost. As explained above, the Cost Review Committee has fallen short of giving a final conclusion on the cost while presenting an estimate of 0.5 yen/kwh or more. European estimates range from 0.000013 eurocents/kWh17) at the lowest end to 6,730 eurocents/kWh18) at the highest end, which means that the estimation methods themselves must be reconsidered. Although the accident risk cost is part of the so-called external costs, the Cost Review Committee has made little mention of any other external costs.

Given the above, we can detect key issues in assessing nuclear power generation costs by comparing the cost estimates. We have picked up the following items for discussion as presented in the next and later chapters:

- Rising unit costs for nuclear power plant construction
- How to assess the operation and maintenance cost
- External costs
- Discount rate issue
- Impact of fossil fuel prices

As for the fossil fuel prices, we have given an overview based on existing reports19) in consideration of wild fluctuations in crude oil prices. In respect to Chapter 1, the unit nuclear power plant construction, and operation and maintenance costs, the discount rate and fossil fuel prices are assumptions for the estimation and “old” issues that have been discussed since before the Fukushima accident. In contrast, the accident risk cost had never been demonstratively presented in traditional power generation cost estimation in Japan. It is a new issue that has attracted attention particularly since the Fukushima accident. Other new issues including plant siting costs and research and development costs have been addressed by the Cost Review Committee, leaving only the issue of the power generation cost concept unresolved. Therefore, this paper does not address these issues. The accident risk cost as part of external costs will be addressed by a different paper20). This paper briefly explains mainly the other external costs.

Other frequently discussed issues include costs for the decommissioning of nuclear power plants, the disposal of radioactive wastes and the reprocessing of spent fuel. In fact, these issues have been discussed well since before the Fukushima accident. Furthermore, the Cost Review Committee has assessed these issues and concluded that they would not be major issues for considering the economics of new nuclear power plants to be constructed. Chapter 4 reviewed their overview based on existing reports19).

3. Discussions on Major Issues

3-1 Construction Costs

3-1-1 Unit costs for nuclear power plant construction in major countries

As mentioned above, the Japan Renewable Energy Foundation cited rises in European and U.S. nuclear plant construction costs, based mainly on U.S. consulting firm Analysis Group's report21). This report points out that construction cost estimates announced by electric utilities two to three years after the presentation of the original estimates were higher than the original ones for seven of eight U.S. new nuclear power plant projects. In the United States, an application for the Combined Construction Permit and Conditional Operating License (COL) for a new nuclear power plant is required to specify the financial information including construction costs. But such costs are deleted from published COL application documents. Therefore, Analysis Group made estimates based on newspaper and other media reports.

Media report-based assessment has the problem of reliability as a secondary source (media reporters can make inaccurate or wrong reports even without intending to do so, as they are not experts in this field.) At the same time, media-reported costs are not specific. Analysis Group has acknowledged the problems and notes that whether construction costs include finance costs is unknown in many cases.

Generally, nuclear power plant construction costs include costs for designing, manufacturing, transporting, assembling and installing machines, parts and electrical instruments, as well as civil engineering and personnel expenses. The total is generally called "overnight costs." But actual power generation equipment construction cannot be completed overnight but can take several years, during which finance costs including loan repayments may emerge. If interest rates are high with the construction period prolonged, total plant construction costs including finance costs may be considerably higher than overnight costs. Unless the total construction costs are clearly differentiated from overnight costs, construction costs may fail to be compared correctly.

In fact, overnight costs for nuclear power plant construction have followed an upward trend in the United States. For example, the Massachusetts Institute of Technology raised nuclear plant construction costs from $2,000/kW in its 2003 report22) to $4,000/kW in an updated version23) in

2009, citing commodity price hikes accompanying the crude oil price spike as one of the factors behind the upward trend. The MIT report noted that construction cost growth was seen for coal and natural gas power plants as well, although the growth rates were different. As factors unique to nuclear power generation, the report cited construction project delays and enhanced regulations among others.

Nuclear power plant construction costs differ from country to country. This is because land acquisition, personnel and other costs, regulations, past power plant construction histories and experiences differ from country to country. The OECD document1) published in 2010 indicates the then unit overnight costs for nuclear power plant construction in major countries as shown in Table 3-1.

Table 3-1　Unit Costs for Nuclear Power Plant Construction in Major Countries (OECD: 2010)

	Unit construction costs, US$/kW	Notes
France	3,860	EPR
Germany	4,102	PWR
Belgium	5,383	EPR-1600
Netherlands	5,105	PWR
Switzerland	4,043/5,863	PWR
Czech Republic	5,858	PWR
Slovakia	4,261	VVER
Hungary	5,198	PWR
U.S.	3,382	3rd/later
Brazil	3,798	PWR
Russia	2,933	VVER-1150
Japan	3,009	ABWR
South Korea	1,876	OPR-1000
	1,556	APR-1400
China	1,748/1,763	CPR-1000
	2,302	AP-1000

(Source) OECD/NEA, IEA1)

Unit construction costs shown here are those after crude oil price hikes, rising from levels in the 2005 edition24) of the OECD document. Unit costs rose from $1,894/kW in the 2005 edition to $3,382/kW in the 2010 edition in the United States, from a low of $1,074/kW to $1,556/kW in South Korea and from $2,510/kW to $3,009/kW in Japan. Construction costs have risen further in line with delays in construction in Europe and the United States. In its latest assessment, the U.S. Energy Information Administration (EIA) estimated overnight unit costs at $5,530/kW in 2012 dollars25). In the United States, particularly, new nuclear power plant construction projects are the first in decades since the 1979 Three Mile Island nuclear plant accident and effectively close to first-of-a-kind ones. This might have led to delays in projects and higher costs.

How about future prospects? According to the EIA outlook26), the levelized capital cost is projected to fall from $71.4/MWh (in 2012 dollars) for nuclear plants starting operation in 2019 to $56.7/MWh (in 2012 dollars) for those starting operation in 2040. If the weighted average capital cost and other assumptions remain unchanged, the unit costs for nuclear plant construction may decrease from $5,530/kW at present to some 80% of the present level in 2040. Given that the recent rise in the unit construction costs stems from the effectively first-of-a-kind nuclear reactor construction and project delays, the unit costs can naturally be expected to decline if nuclear power plant construction projects make progress with multiple plants remaining under construction.

In the Japanese government's power generation cost estimation, the unit cost for nuclear power plant construction was estimated at 291,000 yen/kW in 1999 (by the Nuclear Energy Subcommittee of the Advisory Committee for Natural Resources and Energy)2), at 279,000 yen/kW in 2004 (by the Subcommittee to Study Costs and Other Issues)3) and at 350,000 yen/kW in 2011 (by the Cost Review Committee)9), indicating a hike in the unit construction cost assumption after crude oil price hikes in 2008[3]. This might have influenced the increase in Japan's unit construction cost assumption for nuclear power plants in the abovementioned OECD estimates. The latest estimate of 350,000 yen/kW represents an average for four sample plant reactors (Unit 1 at the Tohoku Electric Power Co. Higashidori Nuclear Power Plant, Unit 5 at the Chubu Electric Power Co. Hamaoka Nuclear Power Plant, Unit 2 at the Hokuriku Electric Power Co. Shika Nuclear Power Plant and Unit 3 for Hokkaido Electric Power Co. Tomari Nuclear Power Plant), which were constructed and started operation recently9).

The U.S. situation differs far from the Japanese one as the first nuclear plant construction in 30 years or the effectively first-of-a-kind reactor construction in the United States leads to additional costs accompanying an estimate based on non-actual costs while Japan's estimate is based on actual plant construction experiences. The difference is one of the factors behind the large gap between the U.S. estimate of $5,530/kW and the Japanese estimate of 350,000 yen/kW. While the U.S. unit cost is projected to decline for the abovementioned reasons, no similar decline can be expected in Japan. The Japanese estimate of 350,000/kW might have failed to fully reflect crude oil price hikes, while additional costs might have emerged to satisfy new regulatory standards after the Fukushima accident. Therefore, the Japanese unit cost is likely to increase in the future. The degree of increase may have to be considered further.

3-1-2 Rises in European and U.S. unit construction costs

In this way, unit costs for nuclear power plant construction have risen particularly in Europe and the United States. Factors behind the rise include the abovementioned hikes in crude oil prices and other factors common to all countries, as well as special factors unique to specific cases. Given that specific definitions or cost breakdowns are not given for specific cases, however, accurate assessment is difficult. While recognizing the abovementioned limitations, we here summarize the four new nuclear power plant construction projects shown in Fig. 2-3 and their construction cost hikes based mainly on media and other reports, following the Analysis Group approach.

(1) Levy County Nuclear Power Plant (U.S.)

The Levy Country Nuclear Power Plant construction project is undertaken by Progress Energy

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[3] Government documents have fallen short of specifying details of these unit cost estimates. Given that they are not assumed to change depending on the discount rate, however, the estimates may appropriately be interpreted as indicating overnight costs.

(acquired by Duke Energy in March 2012) in the State of Florida, U.S. The company applied to the Nuclear Regulatory Commission (NRC) for the COL in July 2008 to build two 1.1 GW Westinghouse AP1000 reactors (Units 1 and 2). The original plan called for launching Unit 1 in 2016 and Unit 2 in 2017. Although environmental impact assessment for the COL was completed in April 2012, the company delayed the launch of Unit 1 until 2024 and that of Unit 2 until 18 months after the Unit 1 start for reasons such as slack electricity demand and lower natural gas prices27).

Overnight construction costs for the two reactors had been estimated at $4-6 billion ($1,800-2,700/kW) as of 2006. But the cost estimate has been raised with commodity price hikes, land purchase costs, finance expenses, grid costs and other matters taken into account28). In 2008, total construction costs were estimated at $17 billion ($7,800/kW), including some $10.5 billion ($4,800/kW) in overnight costs for the reactors, $2.5 billion in power transmission equipment costs and $4 billion in such costs as interest payments during construction and initial nuclear fuel installation costs29)30).

In 2012, Progress Energy announced a further cost incease31). The total cost estimate was then boosted to $19-24 billion ($8,600-10,900/kW). The company attributed the increase to carrying cost hikes for delaying the construction, claiming that the overnight costs had essentially remained unchanged.

As shown in Fig. 2-3, the Japan Renewable Energy Foundation claimed that the Levy County nuclear plant construction cost estimate rose up to 5.6-fold from $4 billion to $22.5 billion. Given the above, however, the claim can be interpreted as confusing the overnight costs with the total costs. In fact, the overnight cost estimate for the power plant construction was raised from $1,800-2,700/kW in 2006 to $4,800/kW in 2008, as indicated by media reports.

(2) Shearon Harris Nuclear Power Plant (U.S.)

The project to construct Units 2 and 3 at the Shearon Harris Nuclear Power Plant in the State of North Carolina, U.S., has also been undertaken by Progress Energy (Duke Energy). The project calls for building two 1.1 GW AP1000 reactors in addition to a 958 MW pressurized water reactor that started operation in 1987 at the station. After filing the relevant COL application with the NRC in February 2008, Progress Energy in May 2013 decided to put a hold on the COL process for the reason of slack electricity demand32). The initial construction cost estimate for the two reactors stood at $4.4 billion ($2,000/kW) as of 2008 and was revised upward to $9.3 billion ($4,200/kW) later in the year33), according to media reports.

(3) Olkiluoto Nuclear Power Plant (Finland)

In Finland, Teollisuuden Voima (TVO) is going ahead with a plan to build Unit 3 at its Olkiluoto Nuclear Power Plant, with Areva-Siemens serving as primary contractor. Unit 3 under construction is a 1.72 GW European pressurized water reactor (EPR). Its construction started in August 2005 for its planned operation commencing in mid-2009. But the plan has been delayed so that the new unit’s operation is now expected to start around 2018.

Unit 3 construction costs had initially been estimated at €3.2 billion (€1,900/kW). But the estimate was raised to €8.5 billion (€4,900/kW) in late 2012 due to the delay[34)]. Whether this estimate represents overnight or total costs has not been clarified on a media report basis. Unit 3 at the Olkiluoto Nuclear Power Plant is the first new reactor in 25 years for TVO. For Areva, the Unit 3 project is a rare overseas nuclear plant construction deal and the first one for the EPR, known as the third generation reactor. The French nuclear plant builder has thus lacked specific experiences with EPR construction. The lack of construction experiences has worsened the quality of construction work and materials, causing a delay in the detailed design process for the reactor and more time consumption for adaptation to safety standards. As a result, construction costs might have risen.

(4) Flamanville Nuclear Power Plant (France)

At the Flamanville Nuclear Power Plant in France, a 1.63 GW EPR is under construction as Unit 3. Its construction started in December 2007, with Areva serving as primary contractor. This is the first new reactor construction in 15 years in France. As is the case with Unit 3 at the Olkiluoto plant, this is the first third-generation reactor. Its construction cost estimate was increased from the initial level of €3.3 billion (€2,000/kW) to €8.5 billion (€5,200/kW) in late 2012[35)], although whether the estimate represents overnight or total costs has not been clarified.

As is the case with Finland, a construction delay stemming from the lack of construction experiences can be cited as the biggest factor behind the cost expansion in the French case. According to Areva, it has failed to benefit from its experiences with the construction of the Olkiluoto Unit 3 reactor due to the delay in the construction. As a result, Areva has faced a so-called first-of-a-kind problem resulting in a rise in construction costs[36)]. The Flamanville Unit 3 is now planned to start operation in 2016, four years behind the original schedule[37)].

3-1-3 Relationship with unit power generation cost assessment in Japan

In many European and U.S. nuclear power plant construction projects, construction costs have been raised from initial estimates. In two European cases out of these projects, the cost estimate hikes clearly accompanied the lack of construction experiences that caused delays in construction. In the recent past, nuclear plant construction was implemented at a unit cost of around 350,000 yen/kW without any substantial delay in multiple cases in Japan. Therefore, it is unreasonable to use European and U.S. cases for projecting nuclear power plant construction costs in Japan to double in the future.

In multiple U.S. cases, estimated unit costs for nuclear power plant construction had initially been as low as $2,000/kW and have been raised in line with progress in projects. In the two abovementioned U.S. cases, we must remember the 2008 crude oil price spike as a special development to boost construction costs. In not only nuclear plant construction projects but also other major construction projects, it is not rare to see costs increase from initial estimates[4]. Such cost increases are frequent particularly for new-type plant construction or overseas plant construction. The unit costs ranging from $4,200/kW to $4,800/kW after overnight cost hikes for

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[4] For example, it is reported that Japan’s Kurobe dam construction actually cost 51 billion yen against an initial estimate of 37 billion yen.

the Shearon Harris and Levy Country nuclear power plants are still lower than the U.S. government estimate of unit overnight costs at $5,530/kW. This magnitude of unit costs for nuclear plant construction in the United States or Europe is not necessarily unreasonable.

As explained above, the assumed unit costs at 350,000 yen/kW in Japan are based on actual plant construction experiences and should not be equated with any initial cost estimate for a new project. The two U.S. cases are interpreted as indicating that initial cost estimates were more optimistic compared with actual costs. It may be needless to say that these U.S. cases cannot be used as a ground for projecting the unit construction costs in Japan to rise sharply from actual data levels in the future.

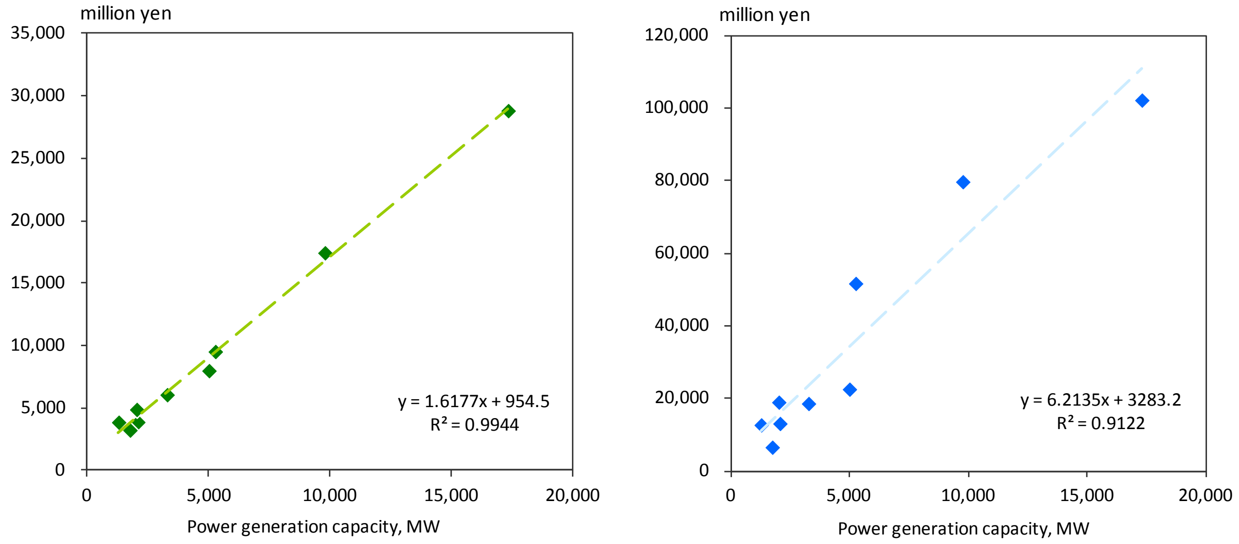
As explained already, additional safety measures in Japan are likely to cause an increase in construction costs for nuclear power plants. The accurate assessment of the increase is important for considering the economics of future nuclear power generation in Japan. There may be other factors contributing to a cost expansion. Given discussions in this paper, however, it may not be appropriate to apply the past cost estimate expansion for European and U.S. projects to Japan. On a possible increase in future construction costs in Japan, we may have to have realistic discussions based on actual costs for safety and other measures.

3-2　Operation and Maintenance Costs

In the estimates by the Cost Review Committee in 2011, annual repair and miscellaneous costs during plant operation are assumed proportionate to initial investment (i.e. construction costs). Specifically, the repair cost is assumed as 2.2% of the construction costs and the miscellaneous cost as 1.9%. The personnel cost is viewed as proportionate to the number of plants. The annual personnel cost is estimated at 2.37 billion yen per plant. These data represent averages for the abovementioned four sample plants. As noted above, the Japan Renewable Energy Foundation's estimates include abnormally high operation and maintenance costs apparently because it has used the Cost Review Committee's MS Excel sheet unrevised where repair and miscellaneous costs automatically expand in line with a rise in unit construction costs.

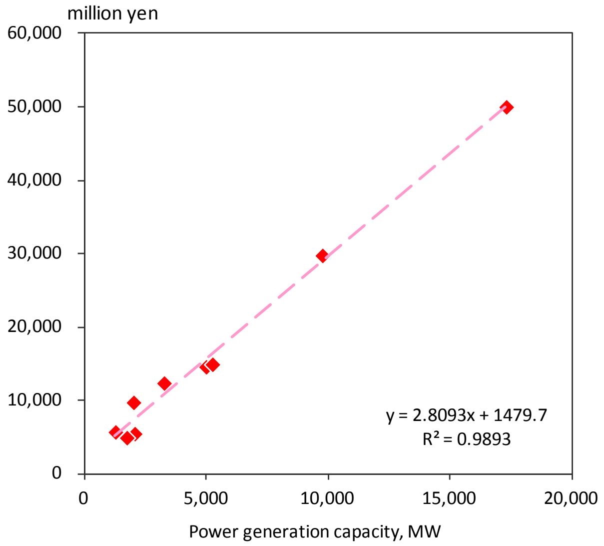
Power plant operation and maintenance costs depend on the plant size as indicated by actual data. Fig. 3-1 indicates average personnel, repair and miscellaneous costs between FY2001 and FY2010 based on financial statements38)39) of nine general electric utilities with nuclear plants in Japan, in comparison with their nuclear power generation capacity. Given that nuclear power generation capacity is roughly proportionate to the number of nuclear reactors and that total nuclear power plant construction costs are almost proportionate to capacity, these figures with horizontal scales indicating the number of reactors or construction costs show positive correlations between operation and maintenance costs and capacity. The correlation coefficients with personnel and repair costs are the highest for the number of reactors, while those with the miscellaneous cost is the highest for capacity. These costs' correlation coefficients with the number of reactors and capacity are slightly higher than construction costs' correlation coefficients with them. (For example, the repair cost's correlation coefficients with power generation capacity and the personnel cost stand at 0.91 and 0.95 against its correlation coefficient with the construction costs at 0.82.) As far as the unit costs for nuclear power plant construction are assumed in line with actual data levels (200,000-500,000 yen/kW), there may be no major problem with the Cost Review Committee’s choice to assume repair and miscellaneous costs as proportionate to construction costs.

Fig. 3-1 Power Generation Capacity’s Relations with Personnel, Repair and Miscellaneous Costs (FY200-2010 averages for nine general electric utilities)



Personnel costs

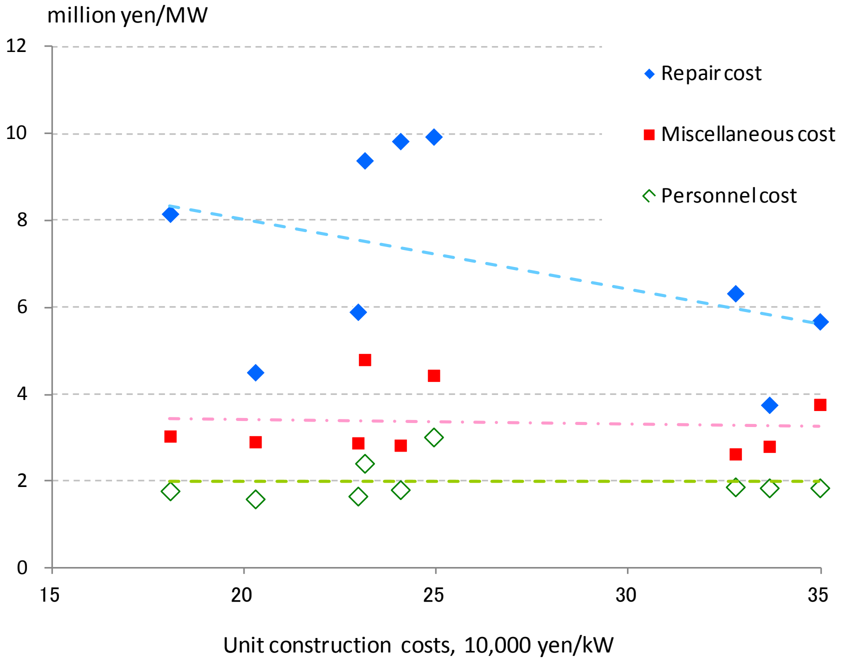
Repair costs



Miscellaneous costs

The problem is whether it is reasonable to project repair and miscellaneous costs to rise in proportion to the unit construction costs’ rise to 700,000 yen/kW as seen in the estimation by the Japan Renewable Energy Foundation. In this regard, we can find implications from actual data. As indicated in Fig. 3-2, miscellaneous and personnel costs per capacity do not rise in response to any hike in the unit construction costs (construction costs per capacity). The repair cost can decline (the higher unit construction costs can bring about better plant performances to help save the repair cost). In fact, even if the unit construction costs increase due to a prolonged construction process as is the case with the Olkiluoto Nuclear Power Plant, repair and miscellaneous costs during future operation are unlikely to proportionately increase. Given this point, we can find that operation and maintenance costs may fail to be accurately estimated if the Cost Review Committee’s estimation sheet is used for the extremely higher unit construction costs at 700,000 yen/kW. The finding has implications on how to assess power generation costs for various energy sources including nuclear. It also indicates that we must take sufficient care when using this kind of spreadsheet.

Fig. 3-2 Unit Construction Costs’ Relations with Personnel, Repair and Miscellaneous Costs (FY2001-2010 averages for nine general electric utilities)



※ The dotted lines indicate linear regression

3-3 External Costs

External costs as part of total costs for some business operations are generated outside the market economy and free from adjustments through the market mechanism. For example, if carbon dioxide is emitted to supply electricity for our consumption and causes climate change in the future, the relevant damage will amount to an external cost. When we (electricity consumers) pay higher electricity prices or some contributions to compensate for the damage, the external cost is “internalized.” The external cost may also be internalized if we pay higher contributions to implement energy conservation and emission reduction measures to avoid climate change, instead of directly compensating for the climate change damage. (If these measures fail to sufficiently reduce emissions or avoid climate change, the relevant damage will be left as an external cost.) Generally, various external costs are internalized for more appropriate market decisions for the entire society.

The assessment of various external costs is important for making optimum energy choices for the entire society, irrespective of whether these costs are internalized or not. But the assessment of external costs is generally far more difficult or inaccurate than that of internal costs that directly affect electricity prices. This is partly because the scope of external costs for assessment is very wide (the reader may remember the abovementioned sea lane defense). Even if the scope for assessment is identified as some specific costs, they generally cannot be uniquely computed from any specific literature or data but may be estimated roughly in such form as the number of people affected by an accident. Nevertheless, however, an attempt to assess external costs is useful and actually made. The following outlines European and U.S. cases of external cost assessments.

3-3-1 European and U.S. assessments

Table 3-2 indicates a European external cost assessment case by ExternE[40]. The assessment approach used here is a bottom-up approach called the Impact Pathway Approach. Under the approach, the generation of pollutants and the like (including PM_{10}, $PM_{2.5}$, SO_2, ozone, organics and heavy metals as well as accidents and noise) from each electricity source is assessed and their physical impacts on air, soil and water are calculated into monetary values as a common unit. Assessment covers all fossil, nuclear and renewable energy power generation, estimating impacts on humans, crops, noise, ecosystems and climate. Since environmental damage is not limited to countries that emit pollutants, the assessment characteristically covers details for the whole of Europe.

Table 3-2 External Cost Estimates for European Countries (ExternE)

Unit: Eurocent per kWh

	Coal	Oil	Natural gas	Nuclear	Biomass	Hydro	Photovoltaics	Wind
Austria			1～3		2～3	0.1		
Belgium	4～15		1～2	0.5				
Germany	3～6	5～8	1～2	0.2	3		0.6	0.05
Denmark	4～7		2～3		1			0.1
Spain	5～8		1～2		3～5			0.2
Finland	2～4				1			
France	7～10	8～11	2～4	0.3	1	1		
Greece	5～8	3～5	1		0～0.8	1		0.25
Ireland	6～8							
Italy		3～6	2～3			0.3		
Netherlands	3～4		1～2	0.7	0.5			
Norway			1～2		0.2	0.2		0～0.25
Portugal	4～7		1～2		1～2	0.03		
Sweden	2～4				0.3	0～0.7		
U.K.	4～7	3～5	1～2	0.25	1			0.15

(Source) European Commission[40)]

Table 3-2 indicates external cost estimates. Estimates for fossil power generation are particularly high for the carbon price as a climate change avoidance cost is taken into account. German external costs are broken down in Table 3-3. As indicated by the table, the global warming mitigation cost, the health cost (including the accident risk cost) and the ecosystems cost are relatively high.

Table 3-3 Quantified Marginal External Costs of Electricity Production in Germany (ExternE)

	Coal	Lignite	Natural gas	Nuclear	Photovolatics	Wind	Hydro
Noise	0	0	0	0	0	0.005	0
Health	0.73	0.99	0.34	0.17	0.45	0.072	0.051
Material	0.015	0.020	0.007	0.002	0.012	0.002	0.001
Crops	0	0	0	0.0008	0	0.0007	0.0002
Damage cost total	0.75	1.01	0.35	0.17	0.46	0.08	0.05
Ecosystems	0.20	0.78	0.04	0.05	0.04	0.04	0.03
Global warming	1.60	2.00	0.73	0.03	0.33	0.04	0.03

(Source) European Commission[40)]

A similar assessment has been made in the United States as well. Table 3-4 indicates an external cost assessment[41)] published in 2010. It assesses environmental impacts of SO_2, NOx, $PM_{2.5}$, PM_{10} and other emissions from almost all coal and natural gas power plants in the United States. External cost estimates for coal power generation average 3.5 cents/kWh and range very widely from 0.19 cents/kWh to 12.0 cents/kWh within the 5th-95th percentile confidence interval. Toward 2030, external costs are projected to decline in line with a fall in pollutant emissions, but the costs will never decline to zero.

Table 3-4 U.S. External Cost Estimates (impacts of non-global warming factors)

2007 cent/kWh

	Coal		Natural gas	
	2005	2030	2005	2030
Average	3.2	1.7	0.16	0.11
5th percentile	0.19		0.001	
95th percenntile	12.0		0.55	

(Source) National Academy of Sciences[41)]

Of these external costs, Japan's Cost Review Committee assesses only CO_2 costs and accident risk costs while failing to take all other external costs into account. While ExternE assesses most of nuclear power generation's health damage as attributable to uranium mining and nuclear fuel cycle operations rather than accident risks, such assessment has never been done in Japan. The assessment of external costs for Japan is an important future challenge. (We must pay attention to the point that the abovementioned European and U.S. assessments cannot be applied directly to Japan[5].)

The Cost Review Committee assumes the CO_2 cost at \$40/tCO_2 for 2030 based on the New Policies Scenario in the IEA's World Energy Outlook42) (the OECD1) has adopted a similar-scale assumption). We see no problem with the adoption of a central scenario for future carbon prices in an outlook of the relevant international organization. But attention must be paid to the IEA's New Policies Scenario in which a failure to hold down the temperature rise to 2 °C would be accompanied by additional climate change adaptation costs or damage. If more accurate climate change costs were taken into account in line with the IEA scenario, the carbon price in the New Policies Scenario would have to be taken into account along with the additional adaptation costs or climate change damage, or the carbon price of \$100/tCO_2 in the 450 Scenario rather than the price in the New Policies Scenario would have to be taken into account. In the 450 Scenario, the temperature increase would be limited to 2 °C with greenhouse gas concentration in the atmosphere limited to around 450 parts per million of CO_2. The future carbon price is very uncertain. Those who doubt the assessment by the Intergovernmental Panel on Climate Change (IPCC) and the climate change phenomenon itself may assert that the carbon price should be zero. But those with grave concern over climate change may claim that even a carbon price of \$100/tCO_2 would be too low. We may have to pay attention to the point that the actual occurrence of climate change may bring about far more damage than we expect now.

3-3-2 Accident risk cost

The accident risk cost is estimated variously as shown in Fig. 3-3. The highest estimate (Versicherungsforen Leipzig) is 500 million times as high as the lowest one (IER at the University of Stuttgart). The large gap stems primarily from a difference between accident frequency assessments. Other estimates than the highest and lowest ones increased after the Fukushima accidents, ranging from 0.1 eurocents/kWh to 1.0 eurocent/kWh. More details are given in a separate paper20).

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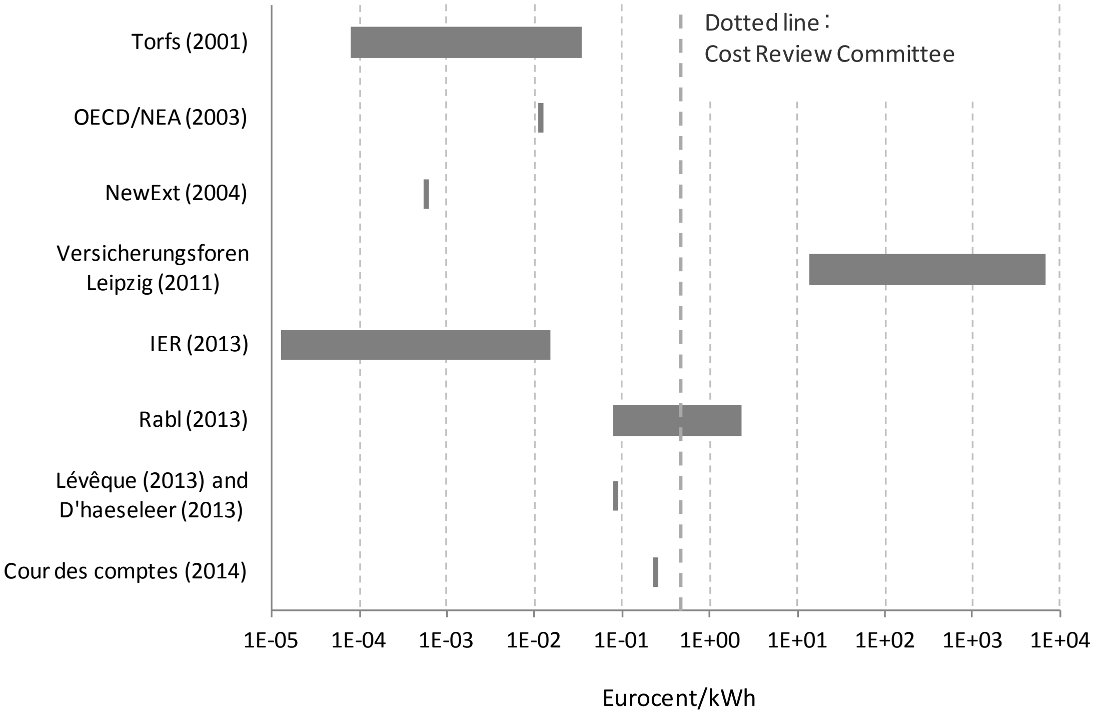
[5] The Federation of Electric Power Companies of Japan has estimated sulfur oxide (SO_x) emissions from coal power plants at 1.7 g/kWh in the United States, 1.6 g/kWh in France, 0.7 g/kWh in the United Kingdom, 0.6 g/kWh in Germany and 0.3 g/kWh in Italy, against 0.2 g/kWh in Japan. Therefore, health damage from SO_x emissions in Japan may be considerably less than in Europe and the United States.

Fig. 3-3 Comparison of Accident Risk Cost Assessments



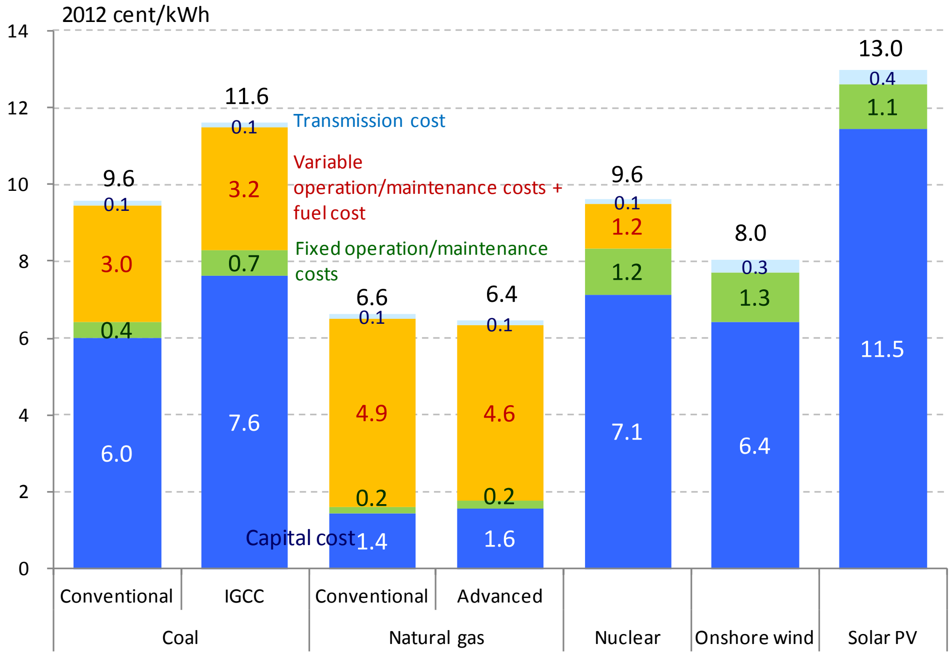
(Source) Prepared from various sources 20)

3-4 Discount Rate Issue and Power Generation Cost Estimates in Major Countries

Since before the Fukushima accident, it has been widely recognized that the discount rate has great influences on nuclear power generation costs14). Generally, the LCOE is assessed as the value per unit power output to make the monetary value of power output over a power plant service life (e.g., 40 years) equal to total costs. If a higher discount rate is set, discounts from the value of future power output will be more, with initial investment costs left free from discounting, resulting in a higher LCOE. In fossil power generation, the cost for fuel required for power generation accounts for a major part of total costs and is discounted in a similar way to the value of future power output. But initial investment costs account for a major part of total costs for renewable energy and nuclear power generation and are free from discounting. Therefore, the LCOEs for renewable energy and nuclear power generation are more influenced by the discount rate than that for fossil power generation. This point is important for comparing estimates in different countries. If we compare estimates without taking discount rate gaps into account, we may be easily led to reach a wrong conclusion.

In the U.S. EIA's power generation cost estimation26) as shown in Fig. 3-4, the unit nuclear power generation costs are put at 9.6 cents/kWh, as high as for conventional coal-fired power generation and higher than natural gas-fired power generation. Therefore, the EIA calls for providing a policy incentive equivalent to 1.0 cent/kWh to help expand nuclear power generation. Here, attention must be paid to the point that the capital cost accounts for 7.1 cents/kWh or more than 70% of the unit nuclear power generation costs at 9.6 cents/kWh, contrasting to Japan's actual data and Cost Review Committee estimates in Fig. 2-1.

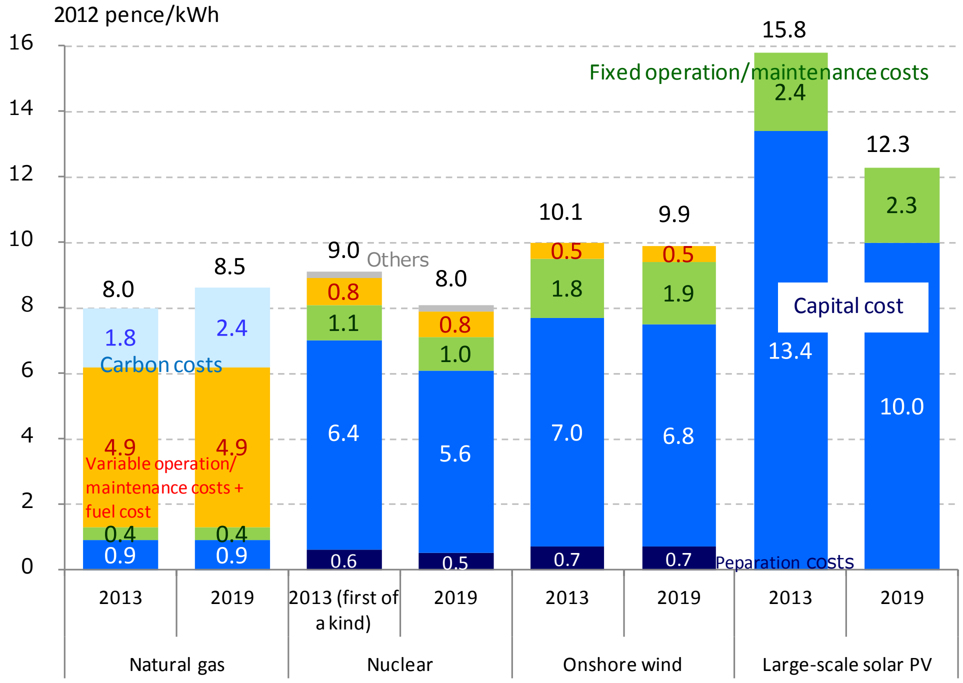
Fig. 3-4 Power Generation Cost Estimates by U.S. DOE



(Source) EIA[26)]

Fig. 3-5 indicates estimates by the U.K. Department of Energy and Climate Change (DECC). Here, the unit costs for nuclear power generation are put at 9.0 pence/kWh for plants starting operation in 2013 and 8.0 pence/kWh for those commencing operation in 2019. The capital cost here also accounts for 70% of the unit costs.

Fig. 3-5 Power Generation Cost Estimates by U.K. DECC

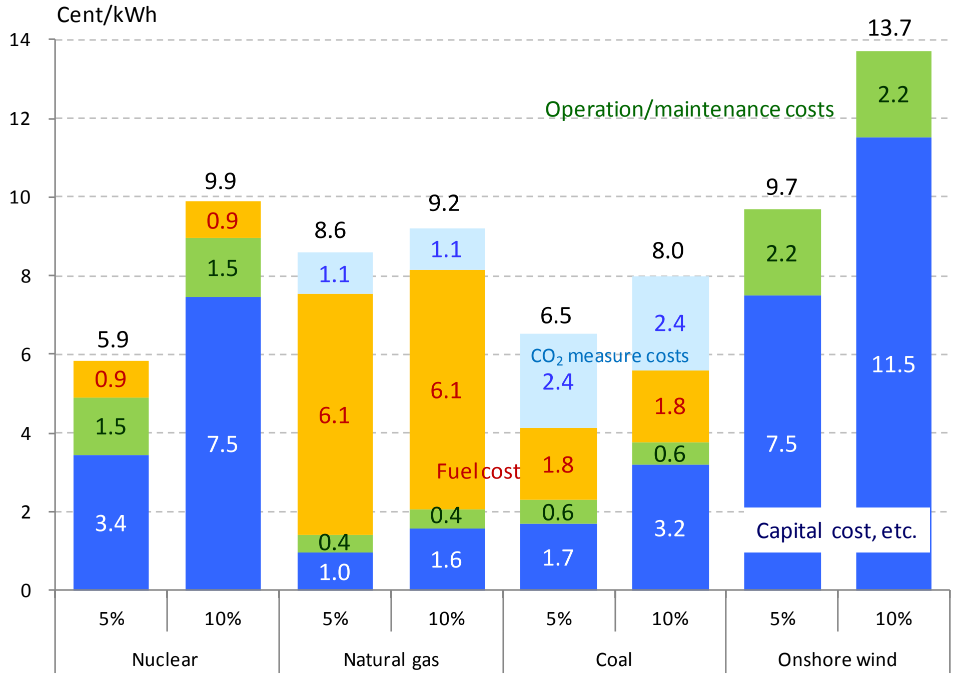


(Source) DECC[43)]

The reason for the high capital cost share is a higher assumed discount rate. DECC set the discount rate at 10%, remarkably higher than the 1-5% range (3% for a central case in Fig. 2-1) adopted by the Cost Review Committee. The EIA estimation fails to describe the discount rate and only explains that the after-tax weighted average cost of capital (WACC) was set at 6.5%. This may be converted into an estimated before-tax WACC of 10-11%[6].

An OECD power generation cost estimation case1) is given in Fig. 3-6. The document estimates power generation costs in major OECD member countries, including those in Japan as shown in Fig. 2-1. It specifies a median value of estimates for OECD members as well as country-by-country estimates, as shown in Fig. 3-6. As indicated here, nuclear power generation costs are lower than natural gas or coal power generation at the discount rate of 5% and become higher at the discount rate of 10%. The capital cost's share of nuclear power generation costs stands at 59% at the discount rate of 5% and at 76% at the rate of 10%, indicating that U.K. and U.S. estimates given in Fig.s 3-4 and 3-5 are close to those at the discount rate of 10% in Fig. 3-6.

Fig. 3-6 OECD' Power Generation Cost Estimation (Discount rate at 5% and 10%)



(Source) OECD/NEA, IEA1)

The capital cost's share of estimated nuclear power generation costs in Japan in Fig. 2-1 is lower due to the low discount rate of 3%. If the discount rate is raised to the U.S. or U.K. level of

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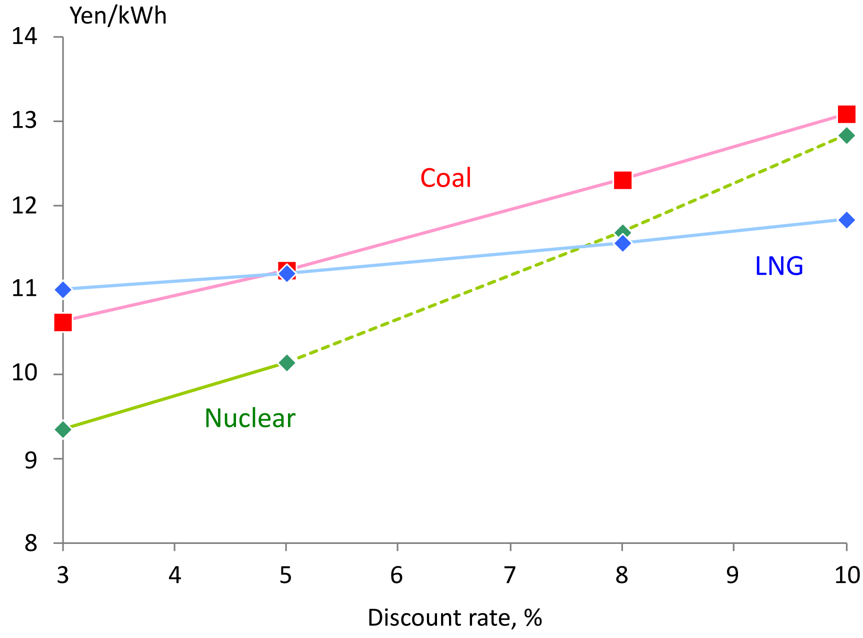
[6] Electric utilities and other companies generally raise funds through equity and debt issues. A weighted average of expected returns on these issues amounts to the WACC. The capital cost for power generation meets a before-tax WACC. As debt issues can save corporate tax payments, the capital cost can be cut through the deduction of the tax savings. The after-tax WACC is several percent lower than the before-tax WACC.

10%, nuclear power generation costs increase remarkably in line with the capital cost share hike. As is the case with the abovementioned operation/maintenance costs, we should be careful when using the estimation spreadsheet of the Cost Review Committee. The sheet discounts depreciation costs to be booked after a plant's operation start to a present value. In this sense, the sheet's approach differs from the ordinary LCOE approach1) used for the OECD estimation. The difference's impact is emphasized especially when the discount rate is changed. If the estimation sheet is revised to meet the ordinary LCOE approach (where depreciation costs are not discounted) and used for computation with the discount rate changed, the results emerge as indicated in Fig. 3-7. (Here, nuclear power generation costs are represented by a dotted line as nuclear fuel cycle costs for the discount rates of 8% and 10% are estimated.)

As seen here, LNG or coal power generation costs including a higher fuel cost are higher than nuclear power generation costs at the discount rate of 3%. If the discount rate is raised to 8% or 10%, however, nuclear power generation costs become higher than LNG power generation costs.

Fig. 3-7　Discount Rate Change's Impact on Power Generation Costs



Lower discount rates are adopted for cost estimation in Japan as Japanese electric utilities have remained in a more favorable fundraising environment in which interest rates are lower than in other countries. For raising funds, these Japanese companies have depended on bank loans including low-interest loans from the Development Bank of Japan. Lower discount rates have met actual Japanese conditions as indicated by actual data given in Fig. 2-1. Therefore, nuclear power generation has actually been cheaper than other power generation in Japan in the past10). In the United Kingdom or the United States, fundraising environments have not been so favorable for electric utilities. U.K. and U.S. electric utilities raise funds primarily from the stock market, marking a difference from their Japanese counterparts.

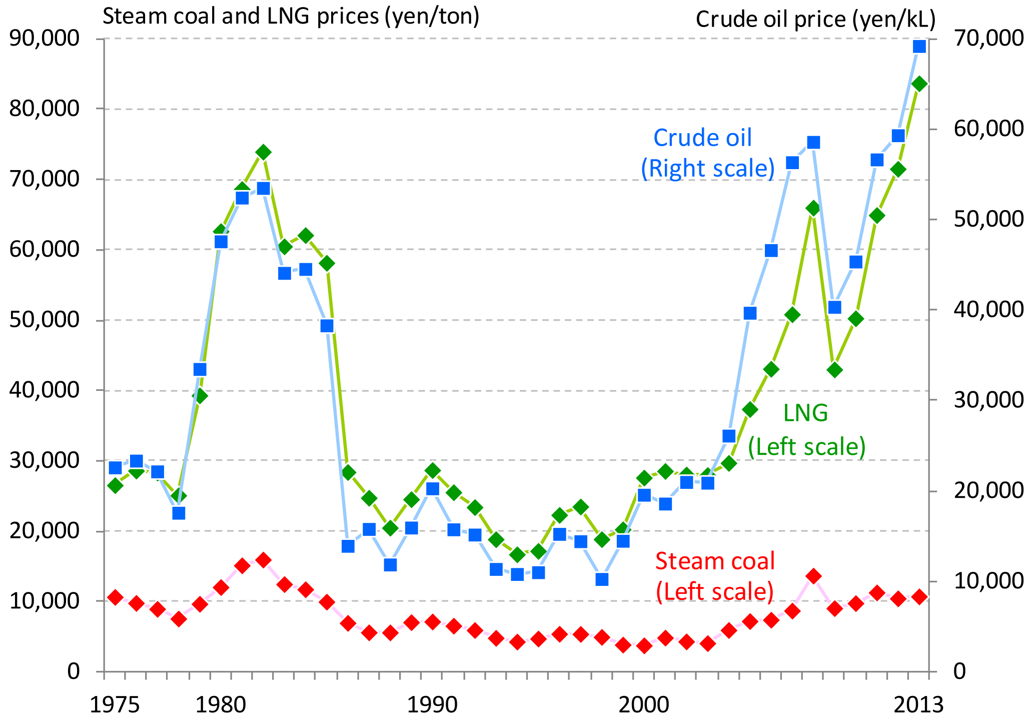
In the United Kingdom where electricity market deregulation started in the 1990s, earlier than in other countries, credit ratings for electric utilities were lowered in 2002, boosting their finance costs. A major factor behind the lowering of credit ratings was a steep drop in wholesale prices of base electricity due to the introduction of the more competitive market system. In fact, an argument noted that the assumed discount rate for estimating power generation costs was raised from 5% to 10% amid the privatization of electric utilities in the United Kingdom, seriously affecting the economic advantage of nuclear power generation5). At present, both the United Kingdom and the United States provide government loan guarantees for nuclear plant construction costs to improve the fundraising environment for electric utilities.

Japan now seeks to deregulate the electricity market through electricity system reform, as seen in the United Kingdom in the past. If the introduction of a more competitive electricity market affects credit ratings of electric utilities in Japan as seen in the United Kingdom in the past, these companies may have difficulties in raising funds at traditional low interest rates. Given that U.K. and Japanese electric utilities are put in different situations, however, future developments accompanying electricity market deregulation in Japan are uncertain at present. The deregulation will become the most important problem in considering the economics of nuclear power generation.

3-5 Effects of Fossil Fuel Prices Change

Fossil fuel prices greatly influence the economics of nuclear power generation. For example, major factors behind the stagnation in the construction of nuclear power plants in the United

Fig. 3-8 Fossil Fuel Price Trends (nominal CIF import prices in Japan)



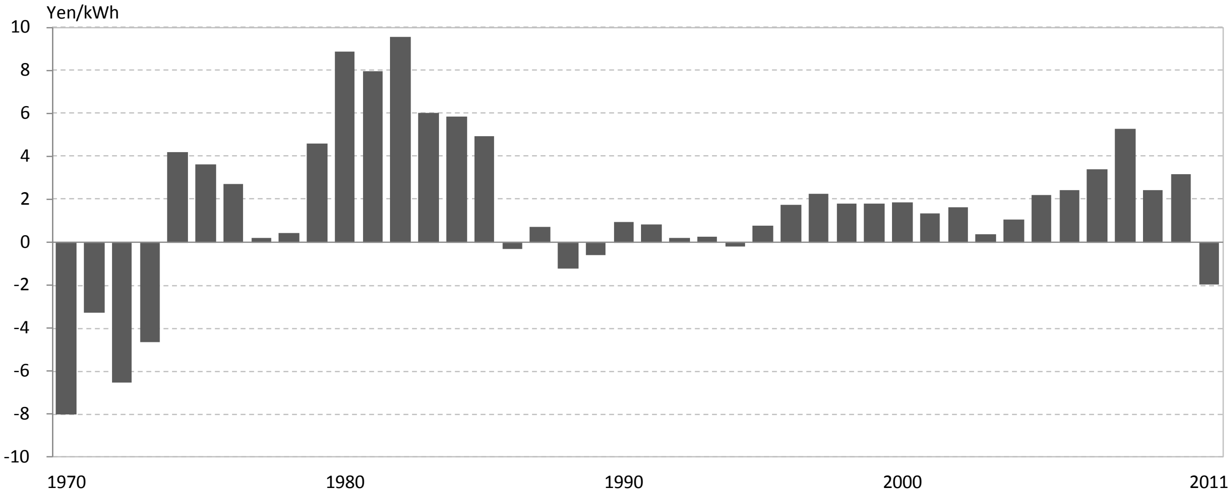
(Source) Institute of Energy Economics, Japan 44)

Kingdom after the electricity market deregulation included not only the deregulation's effects but also the then primary energy price declines. In Japan as well, primary energy prices greatly influence the economics of nuclear power generation.

Fig. 3-8 indicates prices of fossil fuels imported into Japan. Crude oil prices spiked in the 1980s after oil crises, remained stable at low levels in the 1990s and shot up again from 2005. As Japan's LNG import prices are linked to crude oil prices, LNG and oil prices have very strong correlations. Imported steam coal prices have tended to follow changes in crude oil prices. But their linkage is relatively weak.

Fig. 3-9 indicates the difference between unit costs for fossil and nuclear power generation[19). As seen here, the gap between fossil and nuclear power generation costs widened as crude oil (and LNG) prices rose. (But the gap after crude oil price spikes in 2005 was relatively narrower than in the 1980s due to progress in fuel switching.) In the 1990s when fossil fuel prices weakened, however, the gap almost disappeared, with nuclear power generation's cost advantage dropping. In FY2011, the gap became negative as nuclear power generation unit cost rose on the shutdown of existing nuclear plants.

Fig. 3-9　Gap between Unit Costs for Fossil and Nuclear Power Generation



※ Unit fossil power generation costs minus unit nuclear power generation costs (nominal)

(Source) Matsuo et al.19)

As seen in Fig. 3-8, international primary energy prices (including crude oil and LNG prices) soared rapidly from around 2005, exerting great impacts on national energy policies in the world. Slightly later, meanwhile, shale gas and oil production expanded rapidly mainly in North America, causing signs of a looser supply-demand balance. Future energy prices will be affected by the combination of growing energy demand in emerging countries and increasing supply through energy resources development.

In the second half of 2014, the world experienced a sudden crude oil prices collapse. The

Dubai crude oil price plunged from $108/barrel (about 70,000 yen/kL) in June to less than $60/barrel in late 2014. But the price level is still far higher than levels below $20/barrel in the second half of the 1990s. Energy outlooks by the IEEJ (Reference Scenario)45) and the IEA (New Policies Scenario)46) forecast that real primary energy prices will rise moderately over a long term from levels in 2013. As energy demand is likely to expand rapidly mainly in Asian emerging countries, such forecast is dominant now. Given that fossil fuel prices have great influences on the economics of new nuclear plant construction particularly, we must keep close watch on their future trends.

4. Other Issues Regarding Power Generation Cost Assessment

In addition to the five issues discussed in the previous chapter, frequently cited issues regarding nuclear power generation include costs for decommissioning, disposal of high-level radioactive wastes and reprocessing of spent fuel. In fact, however, these are not major issues for discussing the economics of future nuclear options, as indicated by the estimation by the Cost Review Committee. In the following, we outline estimates by the committee and compare them with overseas estimates for readers' reference.

4-1 Decommissioning Cost

As nuclear power plants are structurally complex and generate massive radioactive wastes, their decommissioning costs more than that of other power plants. But an outline of the nuclear plant decommissioning cost has been made available based on actual decommissioning experiences in the United States. The nuclear plant decommissioning cost in Japan is expected to be similar to that in the United States. Even if the decommissioning cost in Japan were much higher, however, the cost would not account for any large share of overall nuclear power generation costs.

4-1-1 Assessment by the Cost Review Committee

In Japan, nuclear power plant operators accumulate reserves for decommissioning their facilities. Based on the system, the Cost Review Committee has estimated the per-unit decommissioning cost at 68 billion yen. The cost translates into 0.1 yen/kWh at the discount rate of 3%. This means that the decommissioning cost, even if being doubled or tripled, would make little contribution to the unit costs for nuclear power generation for nuclear plants to be constructed.

As indicated below, overseas decommissioning experiences and assessments as well result in decommissioning estimates similar to those in Japan. In Japan, however, no nuclear plant has actually been decommissioned. Attention must be paid to the point that decommissioning cost is in an estimation stage. At the same time, apart from the issue of considering future energy choices, we must take note of the possibility that how to raise funds for decommissioning nuclear reactors would be a great challenge for electric utilities if reactors were to be decommissioned before their decommissioning reserves reach sufficient levels[7].

4-1-2 Other assessments

Among overseas assessments, the OECD estimation1) assumes the decommissioning cost as 15% of construction costs. According to the Cost Review Committee's construction cost estimate at 420 billion yen (1.2 GW × 350,000/kW), the percentage amounts to 63 billion yen. But the other overseas estimates indicate some differences, noting that the decommissioning cost may differ depending on the reactor type, particularly in the United Kingdom.

(1) United States

In the United States, several nuclear reactors have already been decommissioned with relevant costs specified. For example, the Maine Yankee Nuclear Power Plant (a 900 MW PWR) in the state of Maine operated between 1972 and 1996 at an average cost of 2.5 cents/kWh, was shut down for economic efficiency reasons in 1997 and underwent a decommissioning project that was completed in the spring of 2005. The decommissioning cost totaled about $568 million (about 66 billion yen)[8], covering decommissioning, decontamination, waste storage and licensing47).

Fig. 4-1 Maine Yankee Nuclear Power Plant

Before decommissioning

After decommissioning

(Source) Maine Yankee47)

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[7] The Working Group for Reviewing the Accounting System Concerning the Decommissioning of Nuclear Power Plants, through its meetings between July and August 2013, recommended that a fixed amount be reserved for each reactor annually, instead of an amount proportionate to electricity output in the year, to secure a steady accumulation of reserves for decommissioning. In addition, The Working Group recommended that electric utilities be allowed to add up the decommissioning cost as an asset and amortize it within ten years, instead of adding up all the cost at once, through its meetings between November 2014 and January 2015. In response, the relevant ordinances were revised. The Working Group also argued that additional policy that would lead electric utilities to securely proceed with decommissioning should be considered continuously, taking the progress in electricity system reform into account.

[8] Hereinafter, costs are converted into yen in accordance with the Bank of Japan arbitrated exchange rates (in January 2015) for reference. The adopted exchange rates are 116 yen per dollar, 145 yen per euro, 183 yen per pound sterling and 16 yen per Swedish krona.

(2) United Kingdom

The United Kingdom was the first Western country to launch commercial nuclear power generation. A total of 29 reactors (including fast-breeder and prototype reactors) have already been shut down, waiting for decommissioning. Among them are 25 Magnox gas-cooled reactors. This type is different from light-water reactors used widely in the rest of the world. Since massive high-level radioactive graphite blocks are left in the reactor vessel, this type of reactor will have to be stored for at least 80 years before dismantlement that can be safely implemented without expensive remotely control systems. In 2005, the Nuclear Decommissioning Authority (NDA) was created to undertake such long-term decommissioning projects. It will put all Magnox reactors under its control and integrally implement their decommissioning projects.

The NDA's annual report48) explains that the decommissioning of 21 Magnox reactors other than four at the Calder Hall Nuclear Power Plant is expected to cost 8.19 billion pounds (1.5 trillion yen), or 390 million pounds (71 billion yen) per reactor. But the estimated costs represent the present value to which projected costs have been discounted with the discount rate at 2.2%. Attention must be paid to the point that the costs characteristically differ from the Cost Review Committee estimate of 68 billion yen[9], for example.

(3) France

Cour des comptes (French Accounting Office)49) has estimated costs for decommissioning EDF-owned nuclear facilities as indicated in Table 4-1. The estimation covers 58 nuclear reactors and four other facilities in operation and 12 shutdown reactors. Costs indicated here are future costs, excluding the past spending on the shutdown reactors.

The decommissioning cost for the 58 operating reactors is estimated at €19.2 billion (2.8 trillion yen). If the costs are divided by the number of reactors, per-reactor costs turn out at €330 million (48 billion yen).

Table 4-1 Nuclear Facility Decommissioning Cost (France, EDF)

	Number	Decommissioning cost (2013 € million)
Facilities in operation	62	19,558
Nuclear reactors	58	19,208
Facilities shut down	12	2,890
Total for EDF	74	22,448

(Source) Cour des comptes49)

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[9] According to the annual report, the NDA's negative assets (including Magnox reactors) total 58.9 billion pounds. Before discounting, its negative assets are 1.8-fold higher at 105 billion pounds. Magnox reactors take more time to be decommissioned than other reactors, indicating that discounting has a greater impact on them.

4-2　High-level Radioactive Waste Disposal Cost

4-2-1　Assessment by the Cost Review Committee

An internationally common policy on high-level radioactive waste disposal calls for burying these wastes deep in the ground. For this purpose, Japanese electric utilities contribute funds for accumulation. At present, the accumulated reserves are under management by the Radioactive Waste Management Funding and Research Center. As shown in Table 4-2, the cost was estimated at 2.7 trillion yen for disposing 40,000 vitrified waste units, as estimated before the Fukushima accident, to be generated by around 2021 if nuclear power generation continues, including those from the spent fuel generated through the past power generation.

Table 4-2　Total Costs for Disposing Wastes

Unit: 100 million yen

Cost	FY2011			FY2000			Mean difference	Major changes from FY2000	Principle of estimation
	Soft rock	Hard rock	Mean	Soft rock	Hard rock	Mean			
Technology R&D	1,031	1,031	1,031	1,118	1,118	1,118	▲87	Decrease in unit personnel costs	<Accumulation method> - Accumulation of direct costs of personnel, materials, machinery, etc. and indirect costs of on-site management and general management, etc. - Costs and methods used for general civil work, geological survey and general public work are used for the accumulation method, and the estimation of personnel and material costs. <Estimation case setting> - Because of the dependency of final disposal costs on the rock types and depth settings, a case of 500m for a soft rock system, and a case of 1,000m for a hard rock system (crystalline rock) are estimated and their average is used. <Scale of facilities> - Facilities that can accommodate 40,000 bodies of vitrified radwaste. <No. of sites in cost estimation stages > - Together with TRU waste, costs are estimated given 10 areas for literature search, 5 areas for general survey, 2 areas for detailed survey and 2 areas as the site of final disposal facilities. <Disposal schedule> - 2000 The executing body was selected. - 2036 Operation is commenced. - 2086 Teardown and closure of the facilities begin. - 2096 The disposal tunnels are closed. - Afterwards, the site will be monitored for 300 years.
Survey and land purchase	1,591	1,782	1,687	2,252	2,501	2,376	▲689	Decrease in unit personnel costs; decrease due to proportional changes with introduction of TRU; decrease in land price	
Design and construction	9,750	8,110	8,930	10,476	8,725	9,600	▲670	Decrease in personnel costs, fall of installation related indexes	
Operation	7,041	7,674	7,358	6,805	7,736	7,271	87	Increase in material related indexes	
Teardown and closure	861	909	885	801	884	842	43	Increase in material related indexes	
Monitoring	1,187	1,187	1,187	1,236	1,236	1,236	▲49	Fall of installation related indexes	
Project management	5,407	4,722	5,065	6,132	5,396	5,764	▲699	Decrease in unit personnel costs; decrease due to proportional changes with introduction of TRU; decrease in property tax	
Consumption tax	1,055	1,020	1,037	1,107	1,087	1,097	▲60		
Total	27,927	26,438	27,183	29,927	28,683	29,305	▲2,122		

(Source) Atomic Energy Commission of Japan

The estimated waste disposal cost’s contribution to the unit costs for nuclear power generation is estimated at 0.04 yen/kWh with the discount rate at 3% under the “latest model” for the Cost Review Committee estimation (where 50% of spent fuel will be reprocessed for recycling with the remainder subjected to some 50 years of interim storage before being reprocessed for recycling). If spent fuel is disposed directly without being reprocessed, the unit waste disposal cost may increase slightly but may still be limited to 0.1 yen/kWh. Even if waste disposal costs as much as 3 trillion yen, the unit cost representing the total cost divided by cumulative power output may not be so great.

The estimated costs totaling 3 trillion yen cover the disposal facility's construction, operation (burial of vitrified waste) and shutdown, and monitoring over the next 300 years. Basically, a facility for disposing high-level radioactive wastes must be designed to secure safety (preventing wastes from exerting any significant impact on the ecosphere over hundreds of thousands of years) before the burial of radioactive wastes to leave no burden on future generations. Massive money and labor have been spent on the assessment of safety. According to technical reports by the Japan Nuclear Cycle Development Institute (Japan Atomic Energy Agency at present)50) and the Nuclear Waste Management Organization of Japan51), Japan has a wide range of geological environments that fulfill requirements for the geological disposal of high-level radioactive wastes. A method to assess the long-term future safety of geological disposal has been developed and used for confirming the safety. A quantitative assessment has found that even if radioactive materials leak into underground water, the impact of the relevant radiation on the earth surface will take about 800,000 years to peak with an annual radiation level of 0.005μSv. The safety of geological disposal technology has been discussed anew after the Fukushima accident. A report released by the Geological Disposal Technology Working Group indicated anew that Japan has a wide range of regions that have favorable geological environment characteristics for geological disposal52). But the report noted that geological characteristics could differ from region to region and that safety should be demonstrated based on data accumulated through progress in gradual on-site surveys. It also suggests future research challenges.

How to actually secure safety over an extra-long term is a very important problem for disposing radioactive nuclear wastes. Therefore, we will have to further consider how to secure safety as necessary, without sticking only to the existing research achievements. The problem of how to conceive the time scale of several hundreds of thousands of years may be left unsolved. As no additional costs exceeding 3 trillion yen have been assumed, however, a claim that nuclear power generation would lose its economics due to costs for managing radioactive waste disposal over a very long period may be wrong. The problem here is whether safety could actually be secured over several hundreds of thousands of years as planned at present. Economics cannot be a major issue for discussions. As noted above, extra-long-term safety may have to be discussed based on scientific data with reference given fully to existing research achievements.

Having said that, let's consider costs for maintaining and managing disposal facilities for several hundreds of thousands of years just for argument's sake. Annual costs are assumed at 1 billion yen with the discount rate put at 3%. Cumulative cost can be computed with a simple geometric series. Cumulative costs turn out at about 33 billion yen whether the period for maintenance is one million years or one trillion years or more. Even if the annual costs expand several times from 1 billion yen with the discount rate lowered to 2% or 1%, the maintenance costs are far less than 3 trillion yen for burying vitrified wastes. Considering the problem of high-level radioactive waste disposal from the viewpoint of costs may only lead to underestimating the problem. Therefore, the problem should be faithfully considered from the other viewpoints, such as how to secure extra-long-term safety.

4-2-2 Other assessments

Each country is highly interested in costs for high-level radioactive waste disposal and has assessed such costs in line with its waste generation and characteristics of assumed waste disposal sites. Particularly, estimated costs are massive for the United States which has been generating massive wastes and relatively less for Sweden or Finland. Foreign estimates do not differ remarkably from the abovementioned Japanese estimates.

(1) U.S.

In the United States, the Office of Civilian Radioactive Waste Management (OCRWM) at the Department of Energy (DOE) is designed to take leadership in disposing radioactive wastes. But the OCRWM has been abolished in line with the Obama administration’s decision to suspend the Yucca Mountain project and consider a replacement project. The DOE’s Office of Nuclear Energy has taken over OCRWM operations.

Under the 1982 Radioactive Waste Policy Act, nuclear power plant operators are set to shoulder costs for disposing high-level radioactive wastes by paying contributions ($0.001/kWh) to the Nuclear Waste Fund set up at the Department of the Treasury. In line with the suspension of the Yucca Mountain project, however, the collection of contributions has been suspended. According to a DOE report53), costs for disposing high-level radioactive wastes are estimated at $96.2 billion (11.2 trillion yen) in 2007 prices, including $64.7 billion (7.5 trillion yen) for geological disposal, $20.3 billion (2.4 trillion yen) for transportation and $11.2 billion (1.3 trillion yen) for management of wastes and programs. A total of $13.5 billion (1.6 trillion yen) in contributions to the fund were accumulated between 1983 and 2006 to help cover the costs, with the shortfall planned to be covered with contributions between 2007 and 2133.

(2) U.K.

In the United Kingdom, the Radioactive Waste Management Directorate (RWMD) at the NDA is set to take leadership in disposing radioactive wastes. The NDA’s annual report54) estimates a geological disposal cost for high-level radioactive wastes at 12.2 billion pounds (2.2 trillion yen), including 10.1 billion pounds to be shouldered by the NDA. The sum can be converted with the discount rate of 2.2% into the present value of 3.4 billion pounds (620 billion yen).

(3) France

In France, the National Agency for Radioactive Waste Management (Agence nationale pour la gestion des déchets radioactifs, or ANDRA) undertakes the disposal of radioactive wastes. The agency became independent from the Atomic Energy and Renewable Energy Commission

(Commissariat à l'énergie atomique et aux énergies alternatives, or CEA) in 1991. Under the radioactive waste management planning law, EDF, Areva and CEA as owners of basic nuclear installations (Installations nucléaires de base, or INBs, including nuclear reactors, front end and back end facilities, radioactive waste and nuclear fission material facilities, and particle accelerators) shoulder the radioactive waste disposal cost. INB owners secure reserves for constructing and operating interim storage facilities and geological disposal sites. From the construction stage, ANDRA will establish a fund for radioactive waste disposal. A French Accounting Office report49) estimates the cost for disposing high-level and long-life medium-level radioactive wastes at €24.8 billion in 2013 prices, including €22 billion (3.2 trillion yen) to be shouldered by EDF, €1.15 billion (170 billion yen) by Areva and €1.63 billion (240 billion yen) by CEA.

(4) Sweden

Implementing the disposal of radioactive wastes in Sweden is Swedish Nuclear Fuel and Waste Management Co. (Svensk Kärnbränslehantering AB, or SKB) that has been established and owned jointly by nuclear power plant operators. Under a fund securing law implemented in 1981, nuclear power plant operators make annual contributions to a nuclear waste fund to finance radioactive waste disposal. SKB estimates the disposal cost every three years. Based on SKB estimates, the Swedish Radioactive Safety Authority (Strålsäkerhetsmyndigheten, or SSM) makes proposals to the government on contribution and security money amounts over three years from the next year and the government fixes these amounts based on the SSM proposals An SKB report55) published in January 2014 estimates the high-level radioactive waste disposal cost until 2014 at 4.8 billion krona (77 billion yen) in 2013 prices and that from 2015 at 44.4 billion krona (710 billion yen). Cumulative costs are also estimated at 23.4 billion krona (380 billion yen) for decommissioning existing nuclear reactors and at 18.1 billion krona (290 billion yen) for constructing, operating and decommissioning an interim storage facility called CLAB.

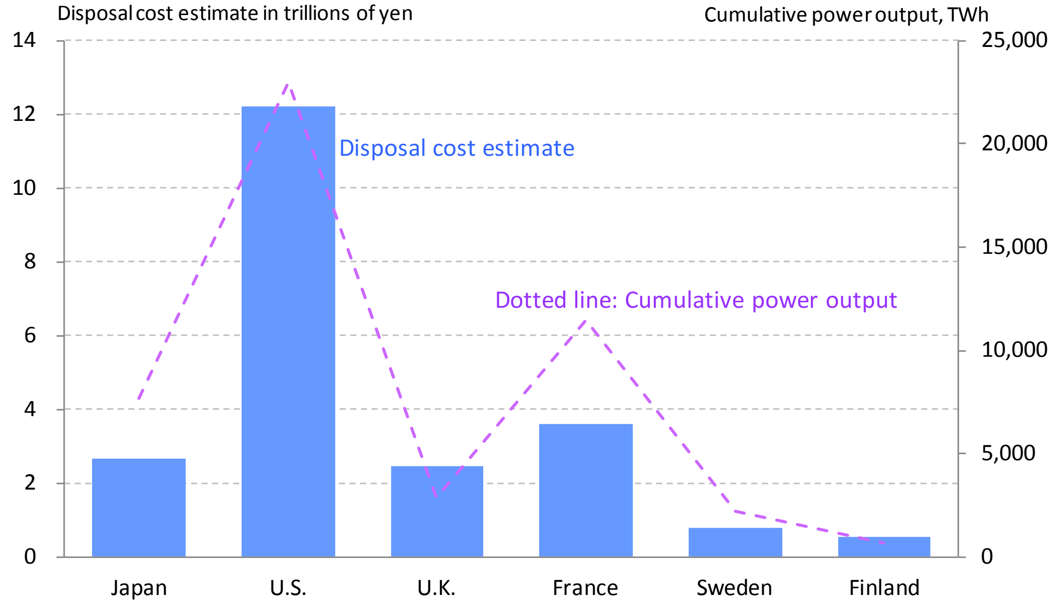
(5) Finland

Implementing radioactive waste disposal in Finland is Posiva founded jointly by nuclear power plant operators. After a disposal site is closed, the Radiation and Nuclear Safety Authority (Säteilyturvakeskukseen, or STUK) will confirm the permanent disposal of radioactive wastes and the government will own the wastes and take all relevant responsibilities. Under the 1987 nuclear energy law (revised in 2008), nuclear power plant operators make annual contributions to a radioactive waste management fund under control by the Ministry of Employment and Economy to finance radioactive waste management. Posiva estimates the cost for disposing high-level radioactive wastes and the ministry finally fixes contributions. A Posiva report56) estimates the cost for disposing high-level radioactive wastes at €3.33 billion (480 billion yen), including €710 million (100 billion yen) for construction, €2.34 billion (340 billion yen) for operation and €280 million (41 billion yen) for decommissioning and closure.

(6) Conclusion

Fig. 4-2 compares costs for disposing high-level radioactive wastes in these countries. In this figure, costs in these countries are converted into 2013 prices with GDP deflators and into Japanese yen. Cumulative nuclear power generation values are also given for reference. A massive cost is required for the United States with far greater accumulated power output (meaning far greater high-level radioactive waste generation), while radioactive waste disposal costs are relatively lower for Sweden and Finland with less accumulated power output. The estimate of 2.7 trillion yen for Japan is not internationally outstanding.

Fig. 4-2 Estimated Costs for Disposing High-level Radioactive Wastes in Major Countries



4-3 Reprocessing Cost

4-3-1 Assessment by the Cost Review Committee

As is the case with the waste disposal cost, electric utilities make contributions to cover the spent fuel reprocessing cost as estimated by the government. As for the Rokkasho reprocessing plant, Table 4-3 indicates the total cost at about 12.2 trillion yen, including 11.7 trillion yen for domestic reprocessing and the remainder for such purposes as the management of returned high/low-level radioactive wastes.

Table 4-3 Total Costs for Reprocessing, etc.

Unit: 10 billion yen

Rokkasho reprocessing plant	Operation	927
	Decommissioning	154
Returned high-level radioactive waste management	Waste storage	29
	Decommissioning	1
Returned low-level radioactive waste management	Waste storage	18
	Decommissioning	1
Waste transportation to disposal site	High-level	10
	Low-level	21
Waste disposal	High-level	0.3
	Low-level (geological disposal)	37
	Low-level (others)	23
Total		1,222

(Source) Atomic Energy Commission of Japan

Under an assumption that reprocessing facilities will operate for 40 years with the reprocessing cost totaling 11.7 trillion yen, the unit reprocessing cost per ton of uranium is estimated at 372 million yen (at the discount rate of 0%), 411 million yen (3%) or 464 million yen (5%). By multiplying the unit reprocessing cost by the quantity of uranium required for generating 1 kWh, we can compute the reprocessing cost’s contribution to unit power generation costs. The contribution comes to 1.03 yen/kWh for the “reprocessing” model where all spent fuel will be reprocessed immediately and to 0.46 yen/kWh for the “latest” model where half of the spent fuel will be reprocessed immediately with the other half being subjected to interim storage for later reprocessing (the discount rate is assumed at 3% for both models). As explained above, the estimation covers the cost for the second reprocessing plant that could be required in the future, based on data for the Rokkasho reprocessing plant.

The committee has also assessed a cost hike for a case in which the Rokkasho reprocessing plant construction project will be delayed. If the facility’s operation start-up is delayed for five years with the facility’s reconstruction costing an additional 3 trillion yen, the unit reprocessing unit is projected to come to 0.68 yen/kWh, according to the assessment. This indicates that a delay in the Rokkasho reprocessing plant construction project will bring about no major change in nuclear power generation costs. At the same time, however, the nuclear fuel cycle cost is estimated at 2.0 yen/kWh for the abovementioned “reprocessing” model, at 1.4 yen/kWh for the “latest” model and at 1.0 yen/kWh for the “direct disposal” model, indicating that nuclear fuel cycle options can exert due impacts on nuclear power generation costs. Only from the viewpoint of economics, the direct disposal option is the cheapest. For the actual selection of options, however, consideration may have to be given to the effective utilization of uranium resources and the decline in radioactive wastes. These viewpoints cover costs that cannot be quantified into monetary values or discussed only from the viewpoint of power generation costs.

4-3-2 Other assessments

It is widely recognized in the world that reprocessing of spent nuclear fuel costs more than direct disposal. As shown in Table 4-4, an MIT report57) has estimated unit nuclear power generation costs at 8.54 cents/kWh for a reprocessing and recycling ("twice-through cycle") case, 0.16 cents/kWh more than 8.38 cents/kWh for a direct disposal ("once-through cycle") case. So, it has been concluded that the once-through cycle would be reasonable in the United States for the immediate future. In the estimation, reprocessing in the first cycle can cut the waste disposal cost from 0.13 cents/kWh for the direct disposal case to 0.04 cents/kWh, while costing 0.24 cents/kWh with the recovered uranium or plutonium being recycled. From the viewpoint of a balanced overall cycle, unit power generation costs for the first cycle must be almost equal to those for the second cycle. Therefore, plutonium is assumed to have a negative price of $15,734/kgHM. In the first cycle, the reprocessing cost may have to make a positive contribution of 0.03 cents/kWh to unit power generation costs to allow plutonium to have a negative price. In the second cycle, the use of plutonium may make a negative contribution of 0.44 cents/kWh. Based on Reference 58), the final disposal cost for spent MOX fuel generated in the second cycle at 0.70 cents/kWh is characteristically and remarkably higher than the final disposal cost of 0.13 cents/kWh for the direct disposal case.

The reprocessing cost (at 0.24 cents/kWh) in Table 4-4 is half the Japanese estimate (at 0.46 yen/kWh). This is because that the reprocessing unit per ton of uranium is estimated at $1.6 million, far less than in Japan.

Table 4-4 Nuclear Fuel Cycle Cost Estimates (MIT)

Unit: 2007 cent/kWh

	Once-Through Cycle	Twice-Through Cycle	
		1st cycle	2nd cycle
Nuclear fuel	0.71	0.71	0.30
Uranium	0.28	0.28	0.003
Plutonium			-0.44
Other costs	0.44	0.44	0.74
Capital cost	6.77	6.77	6.77
Operation/maintenance costs	0.77	0.77	0.77
Waste disposal, etc.	0.13	0.04	0.70
Reprocessing		0.24	
Uranium recovered		-0.01	
Plutonium recovered		0.03	
Total	8.38	8.54	8.54

(Source) MIT57)

Other researchers and research organizations have made similar nuclear fuel cycle cost estimation attempts. The OECD/NEA[59) has conducted a comprehensive model estimation of the economics of the back end of the nuclear fuel cycle and compared its estimates with those by others such as the MIT, the U.S. DOE's Advanced Fuel Cycle Initiative (AFCI) and Harvard University. As shown in Table 4-5, the nuclear fuel cycle cost's contributions to the unit power generation costs are given for the once-through cycle case, the twice-through cycle case and the advanced recycling case using fast reactors. Each assessment indicates that the implementation of the twice-through or more nuclear fuel cycle can increase overall power generation costs. The increase is estimated to range from 0.1 cents/kWh to 0.5 cents/kWh.

The NEA estimates in Table 4-5 show that the cost varies depending on the system size (25-800 TWh/yr). For example, the back end cost for a system size of 400 TWh/yr comes to 0.1 cents/kWh for the once-through cycle case and to 0.4 cents/kWh for the advanced recycling case, indicating a gap of 0.3 cents/kWh. In the recycling case, the gap may be offset to some degree as nuclear fuel supply from outside the system decreases. The total nuclear fuel cycle cost rises by 0.1 cents/kWh from 0.67 cents/kWh to 0.77 cents/kWh.

Table 4-5 Comparison of Nuclear Fuel Cycle (front end and back end) Cost Estimates

2010 cent/kWh

	AFCI (2009)	MIT (2011)	Rothwell (2011)	Harvard (2003)	NEA (2013) 25TWh/yr	NEA (2013) 400TWh/yr	NEA (2013) 800TWh/yr
Once-through	0.67	0.82	0.75	0.65	0.89	0.67	0.68
Twice-through	-	0.97	1.24	0.81	0.92	0.73	0.66
Adv. Recycling	0.84	1.03-1.13	-	0.92	0.89	0.77	0.70

(Source) OECD/NEA[59)

5. Conclusion

This paper reviewed issues involving the assessment of nuclear power generation costs, explained present assessments in Japan including those by the Cost Review Committee, and specified and considered the remaining issues. As far as the assessment of levelized unit power generation costs covering from plant construction and operation to decommissioning and waste disposal, and discussions based on specific and scientific grounds are concerned, various factors involving nuclear power generation costs have mostly been properly assessed, with only a few problems left unsolved. Further discussions are required on the methodology for assessing the accident risk cost. This matter will be discussed in a separate paper[20). The most important point for considering future energy policy is the discount rate or the fundraising environment for business operators, which greatly influences the economics of future nuclear power generation.

Since before the Fukushima accident, it has been widely recognized in Japan that the discount rate can greatly influence nuclear power generation costs. In this sense, the basic situation involving the economics of nuclear energy has fundamentally remained unchanged despite the Fukushima accident. Therefore, we must tackle traditional problems more coolly than earlier. In fact, however, the electricity market deregulation problem, progress in renewable energy power generation and fossil fuel price hikes have emerged as new factors unseen until the early 2000s and exerted great impacts. The nuclear power generation problem should not be discussed as a problem of whether one likes or dislikes nuclear power generation. But it should be positioned as part of the wider energy problem for discussions. As noted in the beginning of this paper, we should clarify the definition of power generation costs in line with purposes for their estimation, prevent relevant arguments from being confused with others, separate relevant problems from others and discuss energy policy from a broader perspective. The reduction of energy costs is an extremely important challenge for national policies. Each person must consciously tackle the challenge. In this respect, discussions and considerations on how best to estimate power generation costs should be continued further to provide useful information.

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