Paper

Hidden Cost of Nuclear Power

Ichizo Aoki
Greenwood Office
iaoki@gakushikai.jp

Abstract

Suspicion on correctness of the cost of nuclear power generation officially announced by Japanese government is the motivation of this study. During this study, many hidden cost were found. This fact is a proof of “public lie” manipulated by Japanese government. It is anticipated that power companies will find difficult time after opening power market for new entities mobilizing cheaper energy sources such as renewable energy of which cost has potential for further cost reduction.

Keyword: cost estimation, nuclear power plant, power law distribution, melt-down accident, public lie, renewable energy

Index

Introduction

Before the World War II, it was a nightmare for Japanese Government of losing oil supply from abroad. It could be said that the main reason of starting Pacific war was the fear of oil shortage. This concerns remained even after the war. It was a kind of paranoia for Japanese Government. When Dwight D. Eisenhower released a doctrine called “Atoms for Peace”, introduction of nuclear energy became the main target for Japanese energy policy.

But after melt-down accident of the Three Mile Island, power companies and government started to find increasing anti-nuclear movements. To persuade people, they claimed that probability of accident is less than once per million-reactor years and the cost is cheapest among coal, oil, and gas fired power and hydraulic power.

After Fukushima Daiichi accident, it was realized that the probability of the accidents is much higher than expected and officially claimed cost of nuclear power seems too low. The purpose of this study is to find out hidden cost in government’s official power cost of nuclear power.

1. Officially Announced Power Cost

Officially announced power generation cost in December 2003.

Nuclear	5.6yen/kWh
Coal	5.9yen/kWh
LNG	6.3yen/kWh
Oil	10.9yen/kWh

Officially announced power generation cost in January 2014.

Nuclear	8.9yen/kWh
Coal	9.5yen/kWh
LNG	10.7yen/kWh
Oil	22.1yen/kWh
Hydraulic	10.6yen/kWh

But, revenue divided by annual power generation of The Japan Atomic Power

Company is 11.1yen/kWh. The same figure of J-power specialized in coal fired power plant is 8.2yen/kWh. This gives us the impression that officially announced nuclear power cost is lower than actual cost and cost of coal fired plant is higher than actual cost.

2. Method of Power Cost Estimation

Sum of discounted net cash flow NCF_k of k-th year at discount rate r over entire plant life of n-th year shall be equal to initial investment or equity E for construction of the plant and demolishing cost (or negative salvage value) S.

$$E + S/(1+r)^n = \Sigma NCF_k/(1+r)^k = NCF_k((1+r)^{n-1})/(r(1+r)^n) \quad \text{(yen)} \quad \text{Eq-1}$$

If we assume flat cash flow over n year, capital recovery factor NCF/E will become Eq-2.

$$NCF/E = (r(1+r)^n)/ (1+r)^{n-1}) + S/E(1+r)^n(r(1+r)^n)/ (1+r)^{n-1}) \quad \text{(fr)} \quad \text{Eq-2}$$

Ratio of Miscellaneous Expenditure and equity is called Miscellaneous Expenditure Factor as defined below:

(miscellaneous expenditure)/E = (property tax)/E + (business tax)/E + (insurance premium)/E + (maintenance cost)/E + (administration cost)/E + (deposit for demolishing cost)/E + (fund raising for spent fuel)/E (fr) Eq-3

Power cost is total of capital recovery factor and miscellaneous expenditure factor divided by annual power generation plus fuel cost as described by Eq-4.

Power cost =E((capital recovery factor) + (miscellaneous expenditure factor))/annual power generation + (fuel cost) (yen/kWh) Eq-4

If we assume 1kW plant as a basis of cost estimation, then;

annual power generation=1kW x 24h/d x 365d/y x capacity factor x (1 - internal consumption) (kWh/y) Eq-5

3. Capital Recovery Factor

When discount rate or earning rate of the capital r=4%, and plant life n is 40 years and salvage value S=0, capital recovery factor NCF/E as defined Eq-2 becomes

$$NCF/E=(r(1+r)^{n})/ (1+r)^{n-1})=0.05052$$

4. Miscellaneous Expenditure Factor

When,

(property tax)/E=0.014

(business tax)/E=0.013

(insurance premium)/E=0.005

(maintenance cost)/E=0.025

(administration cost)/E=0.01

From Eq-3,

Miscellaneous Expenditure Factor=0.014 +0,013 + 0.005 + 0.025 + 0.01 =0.067

Thus,

(Capital Recovery Factor and Miscellaneous Expenditure Factor of Existing Plant)=0.05052+0.067=0.11752

5. Annual Power Generation

From Eq-6 ,

(annual power generation)=1kW x 24h/d x 365d/y x (capacity factor) x (1 – (internal consumption))=24 x 365 x 0.8 x (1-0.035)=6,763kWh/y

Where,

(Capacity factor)=(availability) x (load factor)=0.8 x 1.0=0.8

(Internal Consumption)=3.5%

6. Power cost for Capital Recovery and Miscellaneous Expenditure

When average unit construction cost of existing nuclear plant is 279yen/W,

(Power cost for recovery of initial investment)= 279 x 1,000 x 0.11752 /6,763 =4.85yen/kWh.

This is almost same level to government estimation.

As total capacity of existing nuclear plant in Japan is 36.6GW, total investment reaches 10.22trilion yen.

Unit construction cost of new nuclear plant is 370yen/W.

In this case,

(Power cost for recovery of initial investment)= 370 x 1,000 x 0.11752 /6,763=6.43yen/kWh.

If we replace existing nuclear plant in Japan of 36.6GW to new design, total investment reaches 13.54trilion yen. This does not include demolishing cost of existing one. This will be discussed in next paragraph.

7. Power Cost for Demolishing

From Eq-2, deposit for demolishing cost is

$$NCF/E=S/E(1+r)^n(r(1+r)^n)/ (1+r)^{n-1})=S/E \times 0.20829 \times 0.05052=S/E \times 0.01052$$

Basis of government estimation is unit demolishing cost of S=61yen/W.

In this case;

(Power Cost for Deposit for Demolishing)=61 x 1,000 x 0.01052/6,763 = 0.09yen/kWh

But, experience in Britain shows that S/E=3. Therefore, S=837yen/W.

In this case;

(Power Cost for Deposit for Demolishing)=837 x 1,000 x 0.01052/6,763 = 1.3yen/kWh.

Thus hidden cost of deposit for demolishing is 1.21 yen/kWh.

As total capacity of existing nuclear plant in Japan is 36.6GW, total demolishing cost reaches 30.64trilion yen.

8. Power Cost for Spent Fuel

Officially, policy of Japanese government is to recover plutonium from spent fuel. But this idea is no longer valid because of higher cost and threat to the proliferation of nuclear weapons. In addition, no one accept to dispose spent fuel in their back yard.

Acceptable political resolution is to store spent fuel over 1,000 years in each nuclear power plant. During this period, harmful radiation from fission products will deplete and become material which is easy to handle.

Life of power companies are shorter than 1,000 years. Therefore, they have to raise a fund for safe keeping spent fuel in the nuclear plant site. Government will do the rest of the work using this fund P. It was assumed that cost of safe keeping R is 10% of the construction cost of the nuclear plant.

When n=1000years;

$$P=R\Sigma 1/(1+r)^k = R((1+r)^{n-1})/(r(1+r)^n) = 25R$$

This P has to be raised during plant operating life of n=40years. Then

$$NCF_k=(P/(1+r)^n)\ (r(1+r)^n)/((1+r)^{n-1})=P \times 0.01052=0.263R$$

As cost of safe keeping R=0.1 x E

(Power Cost for Fund Raising for Spent Fuel)= 0.1 x 279 x 1,000 x 0.263/6,763 = 1.08yen/kWh

As government estimate of backend cost is 0.31yen/kWh, hidden cost of fund raising for spent fuel becomes 0.77 yen/kWh.

9. Uranium Fuel Cost

When Uranium cost is 50\$/U_3O_8 lb fuel cost becomes 0.95yen/kWh. This includes front end processing.

10. Capital Recover of Additional Safety Investment

After Fukushima Daiichi accident, despite public criticism, Japanese government decided to continue using nuclear power with condition to meet additional safety requirements set forth by Nuclear Regulation Authority of Japan. All nine power companies made huge investment reaching 2.24 trillion yen to meets those requirement as listed in Table-1. Unit construction cost reached 60yen/W as total output of Japanese nuclear plant is 36.6GW.

Power Company	Additional Safety Investment billion yen
TEPCO	470
Kyusyu	310
Chubu	300
Kansai	298
Chugoku	200
Tohoku	182
Hokkaido	160
Shikoku	120
Hokuriku	110
Japan Atomic Power Company	93
Total	2,243

Table-1

When price of oil and gas increase, proven reserves also increase and cost stabilize. On the other hand, cost of renewable energy decreases by technical innovation. Possible meltdown accidents increases cost of nuclear as discussed. As a conclusion, it is difficult to fore see any future usage of nuclear technologies, Therefore, it was assumed that this additional safety investment has to recover within the life of existing plant. This means n=20years. Thus,

$$NCF/E=(r(1+r)n)/ (1+r)n-1) =0.0736$$

(Power cost for recovery of additional safety investment)=0.0736+0.067=0.1406

(Power cost for recovery of additional safety investment)= 60 x 1,000 x 0.1406/6,763 =1.25yen/kWh

(Power cost for recovery of initial and additional safety investment)= 4.85 + 1.25= 6.1yen/kWh

11. Effect of Lower Capacity Factor due to Prolonged Stoppage of Nuclear Plant

Four years has passed for construction and approval process of additional safety investment. This correspond 10% stoppage of entire plant life. This means capacity factor degradation of 10% and increase of power cost for recovery of initial investment. Thus;

(Power cost for recovery of capacity factor degradation)=4.85 x 0.1=0.49 yen/kWh

12. Cost of Dedicated Power Transmission Line

Cost of dedicated transmission line for TEPCO's Kashiwazaki-Kariha Plant is reported as 22million yen/year. Corresponding capacity is 8.21GW. Assuming capacity factor of 80%, cost of dedicated power transmission line becomes 0.38yen/kWh.

13. Pumped Storage Cost

As nuclear plant is capital driven facility, Power company want to operate at maximum capacity. But power demand of night time in week end is less than output of nuclear plant, Therefore, they installed pumped storage in mountain range between nuclear plant and consumption center. The capacity of this pumped storage is about 10% of nuclear facility. Unit construction cost of this pumped storage is 238yen/W which is almost same level to that of nuclear facility. Therefore, capital related cost for pumped storage is almost 10% of power cost for recovery of initial investment of 4.85yen/kWh, namely 0.49 yen/kWh.

Power loss of pumped storage is 29%. When we assume 5% of power is stored in the facility, loss of fuel cost of 0.95 yen/kWh will be 0.95 x 0.05 x 0.29=0.01yen/kWh

Thus total pumped storage becomes 0.5yen/kWh.

14. Government subsidies

After oil crisis in 1973, Japanese government decided to shift oil fired power plant to nuclear plant. For this purpose, a subsidy system of collecting dedicated tax of 0.375yen/kWh from power companies and distribute this money to local people who is against installation of this harmful plant. Such money is 1.1yen/kWh for nuclear plant and 0.14yen/kWh for hydraulic power.

15. Cost of Compensation for the Accident

Recorded numbers of meltdown accidents of commercial reactors are 10. This means average cumulative frequency of the accidents is once in 1,450 reactor-year. But, according to author, analysis of past 10 meltdown accidents of nuclear reactors follow power law distribution. In power law distribution, cumulative frequency of accidents in logarithmic scale is plotted against radioactive fallout per power generated in logarithmic scale. Detail of this will be disclosed elsewhere. The curve has a long tail and has no average figure. This means that nuclear power companies have to be prepared for mega accidents like Chernobyl. Nuclear Regulation Authority did not request to change basic design concept of BWR, therefore, their requirements does not change cumulative frequency of accidents nor radioactive fallout per power generated.

In addition, insurance company's maximum liability is around 200billion yen. If compensation amount exceed this limit, nuclear power companies has to pay this gap from their account. This means power cost need to be inflated to cover this loss.

It is roughly estimated that total compensation of Fukushima-Daiich class reach 9.2trilion yen/accidents and cumulative frequency of accidents once in 2,900reactor-year. This corresponds to power generation cost of 3.17yen/kWh. In case of Chernobyl class accidents, total compensation reach 109trilion yen/accidents and cumulative frequency of accidents is once in 14,500reactor-year. This corresponds to power generation cost of 7.5yen/kWh. In any case, power companies have to be prepared to this maximum case.

16. Total Hidden Cost

The results of the power cost calculation as described above were summarized in Table-2. Power generating cost of existing nuclear plant is 6.2yen/kWh. Power generating cost of restarted nuclear plant after addition of safety facilities is 19.4yen/kWh. Hidden cost of existing plant becomes 13.2yen/kWh.

This figure 19.4yen/kWh is larger than guaranteed purchase cost of nuclear power of 15yen/kWh of British government (93stirling pound/MWh). We understand British figure does not include cost of compensation for the accident of 7.5 yen/kWh. Therefore, if we deduct this figure both has a good agreement.

	unit	Existing Plant	Additional Safety Facilities	Restarted Plant	Hidden Cost of Existing Plant	Newly Built Plant
construction cost	yen/W	279	60	279+60		370
demolishing cost	yen/W	61		837		837
internal consumption	%	3.5	3.5	3.5		3.5
capacity factor	%	80	80	80		80
annual power generated	kWh/y	6,763	6,763	6,763		6,763
plant life n	y	40	20	40+20		40
discount rate r	%	4	4	4		4
capital recovery factor	fr/y	0.05052	0.0736			0.05052
miscellaneous expenditure factor	fr/y	0.067	0.067			0.067
capital recovery factor and miscellaneous expenditure factor	fr/y	0.11752	0.1406			0.11752
power cost for capital recovery and miscellaneous expenditure	yen/kWh	4.85	1.25	6.1	1.25	6.43
effect of 10% lower capacity factor	yen/kWh	0		0.49	0.49	0
power cost for demolishing	yen/kWh	0.09		1.3	1.21	1.3
power cost for spent fuel	yen/kWh	0.31		1.08	0.77	1.08
uranium fuel cost	yen/kWh	0.95		0.95	0	0.95
dedicated transmission line	yen/kWh	0		0.38	0.38	0.38
pumped storage cost	yen/kWh	0		0.5	0.5	0.5
government subusidies	yen/kWh	0		1.1	1.1	1.1
cost of compensation for the accident	yen/kWh	0		7.5	7.5	7.5
power cost of nuclear plant	yen/kWh	6.2		19.4	13.2	19.24

Table-2

17. Cost Comparison with Other Energy

Table-3 shows cost comparison of various power generation method with it's conditions. Nuclear plant is a little bit cheaper than current cost of photo-voltaic cell (PV) but more expensive than cost of future PV.

	construction cost	oil price	capital recovery and miscellaneous expenditure	Power Cost @CF1.0	Power Cost @CF0.5
	yen/W	$/bbl	yen/kWh	yen/kWh	yen/kWh
Restarted Nuclear Power Plant	279+60	50$/lb	6.1	19.4	
New Nuclear Plant	370	50$/lb	6.43	19.2	
LNG combined cycle	197	100	3.37	14	17.37
LNG combined cycle	197	50	3.37	10	13.37
Coal Fired	272	100$/t	4.86	8	12.86
Hydraulic	732		9.24	9	18.24
Current Photovoltaic Cell	242		24	24	
Future Photovoltaic Cell	150		15	15	
Wind	200		11	11	

Table-3

Even if the current cost for carbon emission trading for coal fired of 0.7yen/kWh or for LNG combined cycle of 0.3yen/kWh are added to Table-3, no significant change occur in cost competitiveness. The maximum cost of carbon dioxide recovery and sequestration of 4yen/kWh or for LNG combined cycle of 8yen/kWh for coal fired plant may put nuclear cost at same level as fossil fuel power. However, nuclear power could not provide lord balancing services. Ironically, cost competiveness of renewable energy will be further increased.

In Table-3, power cost at capacity factor of 0.5 are also shown for LNG, coal, and hydraulic power, as those are operated at partial lord to make supply and demand balancing. Power companies can mix all those power source and dilute expensive nuclear cost. If we assume mix ratio of 0.3 for nuclear, 0.4 for LNG, 0.2 for coal, and 0.1 for hydraulic, Power generation cost becomes 17.1yen/kWh. But they have heavy burden of transmission and distribution network cost of 9.6yen/kWh for consumers and 1.6yen/kWh for business use in the 500-50kW range. Those are the figure in year 2000. At that time, grid cost for consumers was 23yen/kWh, and 15yen/kWh for business use.

This means future grid cost for consumers will be 26.7yen/kWh and grid cost for business will be 18.7yen/kWh. Even though nuclear power plant is not restarted, consumer grid cost of TEPCO is 28yen/kWh and business grid coat is 17.1yen/kWh at the end of 2014. This means TEPCO is assuming zero transmission cost for business use. Regardless of this effort, TEPCO has lost many business use clients.

After opening consumers market in 2016, this high grid cost may stimulate consumers interest in installing PV on their roof top and sell power at 28yen/kWh. Feed in tariff is no longer needed. If selling pressure goes up, this pressure causes difficulty of grid control and has to cut purchase. If a grid company fails to buy those PV powers, PV owners will fail to recover their investment. What happens next is firstly, a spread of internet driven power companies who would make purchase agreement with PV owners through smart meters and make purchase agreement with coal fired power generation companies who are willing to provide load balancing services. If internet driven power companies can purchase matching power from coal fired power company within 30 minutes, only obligation to a grid company is paying transmission cost. Any power company who operate grid together with nuclear power generation will lose cost competitiveness. Secondly, what happens next is off-grid operation by PV+ battery or distributed power generation. This might lead to a collapse of Edison's generate, distribute and consume paradigm.

The Stone Age came to an end, not because we had a lack of stones　　Yamani

18. Conclusion

As stated above, there are many hidden costs which largely reduce the surface value of power generation cost of Nuclear Power Plant. Therefore, the statement saying that "nuclear power is the cheapest among various energy sources" is a public lie manipulated by Japanese government and miss lead society.

Because of this mislead, it is anticipated that power companies will find difficult time after opening consumer power market in year 2016 for new entities mobilizing cheaper energy sources such as renewable energy of which cost has potential for further cost down.