Economics of Nuclear Energy

The Joint Japan-IAEA Nuclear Energy Management School in Tokaimura, 11-29 June 2012

June 11, 2012

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Note: The views expressed here are of my own and do not necessarily reflect those of the JAEC nor the government.

Summary

- Since the Fukushima Daii-ichi nuclear power plant accident, re-examination of economics of nuclear power became a major policy issue.
- The nuclear fuel cycle cost and new estimate for total power generation costs incorporating accident risks, government subsidies, etc. was published by the government.
- It shows that nuclear power can be competitive with fossil power generations but social costs associated with nuclear accident risks could be significantly large.
- In addition, comparisons of nuclear fuel cycle options including economics have been published by the JAEC recently. They show that "direct disposal" fuel cycle option is least expensive compared with other "total reprocessing" option and "mixed" option.

New Energy Policy: Three Philosophies (July 29, 2011) by Energy and Environment Min. Council

(1) Three principles toward new best energy mix (*reducing dependency on nuclear power*, strategic approach for energy security, *complete reevaluation of nuclear energy policy*)

(2) Three principles toward new energy system (realization of distributed energy system, international contribution, multi-eyed approach)

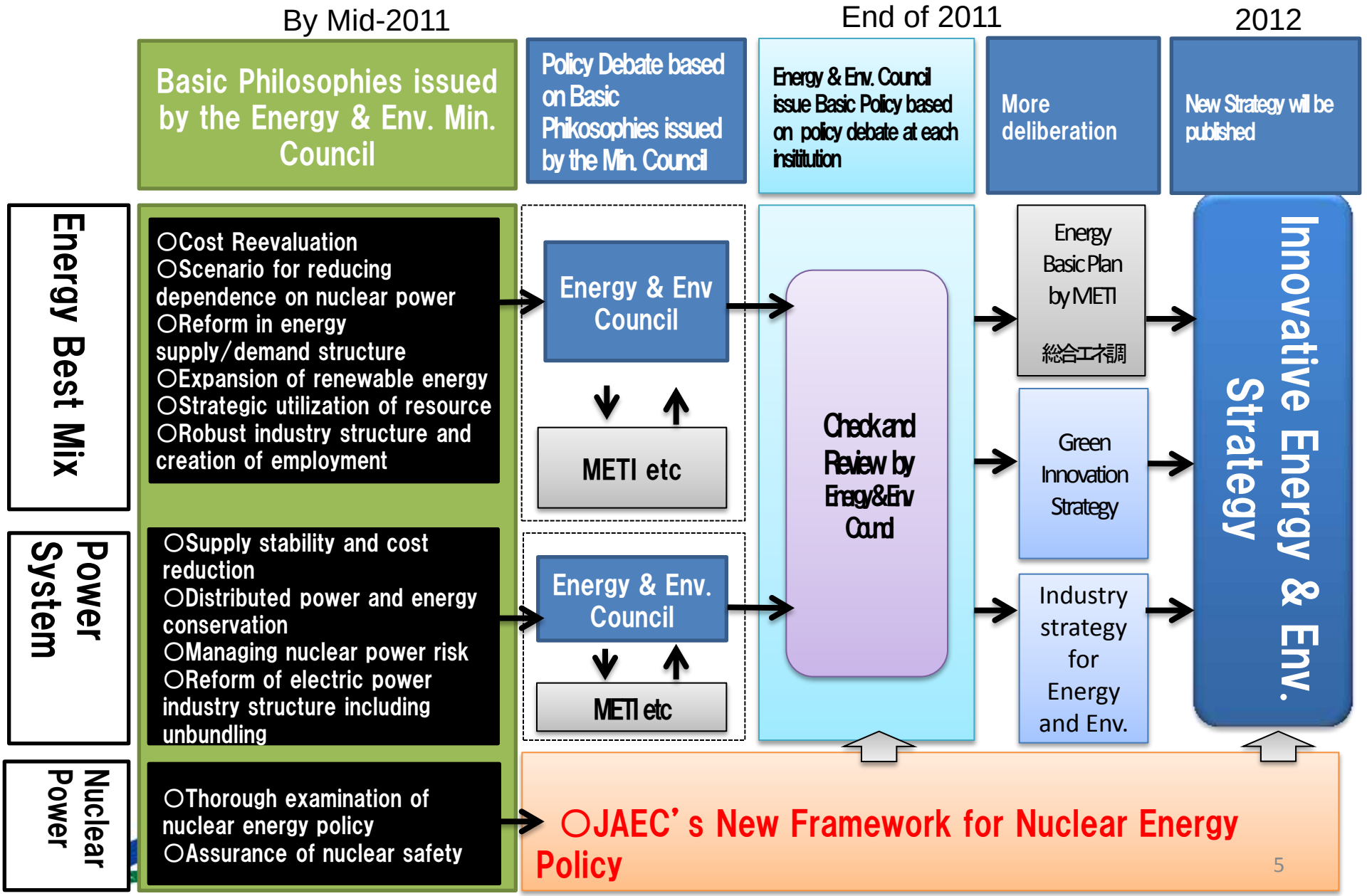
(3) Three principles toward national consensus (*national debate in order to overcome "pro-" "anti-" conflict*, strategy based on objective data, dialogue with various sectors of the public).

PM Noda's Speech at UN High-level meeting on Nuclear Safety and Security (11/09/22)

- Japan will disclose to the international community all the information related to this accident, in both swift and accurate manner.
- Japan is determined to raise the safety of nuclear power generation to the highest level in the world.
- Japan stands ready to respond to the interest of countries seeking to use nuclear power generation.
- Japan will also participate actively in efforts to ensure nuclear security.
- Energy is the 'lifeblood' of the economy and serves as a foundation for the daily human lives.
- I should like to close my remarks by pledging that Japan, as the country in which this accident occurred, will dedicate itself to shouldering its responsibilities and taking action.

http://www.kantei.go.jp/foreign/noda/statement/201109/22speech_e.html

6. Towards Innovative Energy and Environmental Strategy
—Structures for New Energy/Environmental Policy Making Processes—



（４）原子力 Nuclear Power Policy
高い安全性の確保と原発への依存度低減への挑戦: Securing High Standard of Safety and Reducing Dependence on Nuclear Power

ミッション Mission

- 聖域なき検証・検討: No “sacred area” (taboo)
- 原子力安全の徹底: Assuring Safety
- 原発への依存度低減に関する国民的議論を踏まえた対応: National Discussion on reducing dependence on nuclear energy

優先課題 Issues

短期 Short	中期 Mid	長期 Long
○より高い安全性のもとでの活用と原発への依存度低減に関する国民的議論を踏まえた対応の決定 Utilization of existing nuclear power plants with enhanced safety National discussion on reducing dependence on nuclear energy	○原発への依存度低減に関する国民的議論を踏まえた対応 Appropriate measures to the results based on national discussion on reducing dependence on nuclear energy	○原発への依存度低減に関する国民的議論を踏まえた対応 Reducing dependency on nuclear power

Administrative Organizations for Nuclear Energy Policy

Cabinet Office

Atomic Energy Commission (AEC)

- **Formulates the Framework of Nuclear Energy Policy**
- **Outlines the government budget for implementing nuclear energy policy**
- **Review the administrative judgments of other governmental agencies under 'the Law for the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors' etc.**

Nuclear Safety Commission (NSC)

- Development of the intellectual infrastructure for ensuring nuclear safety
- Ensuring safety of nuclear facilities
- Nuclear disaster countermeasures
- Promoting dialog on nuclear safety with the general public etc.

Report | **Basic policies & Principles**

Related Governmental Organizations

Ministry of Foreign Affairs (MOFA)

- Diplomatic policies for peaceful use of Science and Nuclear energy
- Negotiation and cooperation with the foreign government, participation to the international organization for peaceful use of nuclear energy
- Preparation and enforcement for conclusion of nuclear international engagement etc.

Ministry of Education, Sports, Culture, Science and Technology (MEXT)

- Nuclear policies on science and technology
- Nuclear development for the purpose of improving the level of science and technology
- Regulation on use of nuclear reactors for experiment and research, nuclear fuel resource and materials
- Prevention of radioactive hazards etc.

Ministry of Economy, Trade and Industry (METI)

Agency for Natural Resources and Energy

- Nuclear policies for energy use
- Development of nuclear engineering for energy use

Nuclear and Industrial Safety Agency (NISA)

- Regulation on project of nuclear refinement, processing, storage, reprocessing and disposal, and on nuclear power generation facilities etc.

Other related ministries

- Ministry of Internal Affairs and Communications
- Ministry of Health, Labor and Welfare
- Ministry of Agriculture, Forestry and Fisheries
- Ministry of Land, Infrastructure and Transport
- Ministry of the Environment etc

Japan Atomic Energy Commission (JAEC)

○The Role of Japan Atomic Energy Commission

The Japan Atomic Energy Commission is set up in the Cabinet Office and has five commissioners. Its mission is *to conduct planning, deliberations, and decision-making regarding basic policy for research, development, and utilization of nuclear energy, including the formulation of the Framework for Nuclear Energy Policy except matters related to nuclear safety*. When the JAEC deems it necessary as a part of its assigned mandate, *JAEC can recommend and demand reports of the head of relevant administrative organization through the Prime Minister*.

Members: 5 (appointed by the Prime Minister with the consent of the House of Representatives and House of Councilors)

Chairman
Dr. Shunsuke KONDO

Vice Chairman
Dr. Tatsujiro SUZUKI

Commissioner
Ms. Etsuko AKIBA

Commissioner
Dr. Mie OBA

Commissioner
Dr. Akira OMOTO

JAEC's Activities for Nuclear Energy Policy

- Restarted the deliberation process for new Framework for Nuclear Energy Policy (Sept. 27, 2011)
  - It was suspended after the 3/11 Fukushima accident
  - Members of the Committee have been changed slightly to reflect changing circumstances after the accident
  - Major issues: Safety, Cost, Nuclear Power and Fuel Cycle Options, Waste Management, International Perspectives, R&D planning, etc.
- Established Sub-Committee on Issues for Nuclear Power and Fuel Cycle Technology Technologies
  - 7 expert members (Chair: Tatsujiro Suzuki)
  - Identify options and criteria for evaluations
  - Identify key differences of cost estimates/evaluations over different options
  - Submit key findings to the JAEC (as necessary)

Cost Comparisons of Nuclear Fuel Cycle Options

Estimation Models

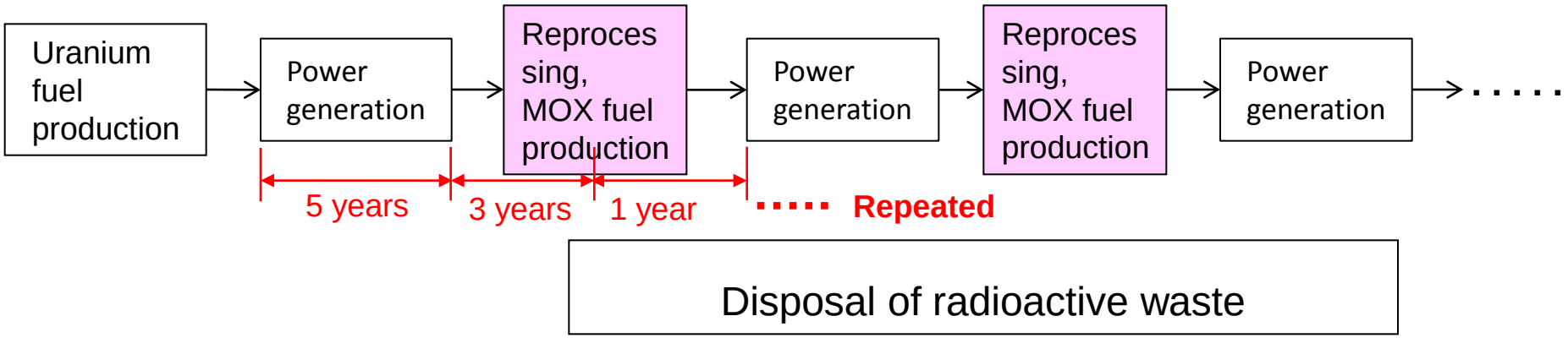
- This estimation will be used for comparisons with generation costs by electric systems, the fuel cost in nuclear power generation cost are estimated using the "model plant system."
- Two models are used for estimation:
  - With nuclear fuel cycle → Reprocessing model
  - Without nuclear fuel cycle → Direct disposal model
- Additionally, the present status of energy supply in Japan is still unfolding; estimations are being used → Latest model

Ref. : http://www.aec.go.jp/jicst/NC/about/kettei/seimei/111110_1.pdf
10 Nov. 2011 Technical Subcommittee on Nuclear Power, Nuclear Fuel Cycle, etc., Material No. 1 (Japanese)

Estimation Model

Reprocessing Model

- Spent fuel is reprocessed and recycled.



- All spent fuel is reprocessed.
- Recovered Plutonium is recycled as MOX fuel.

Ref. : http://www.aec.go.jp/jicst/NC/about/kettei/seimei/111110_1.pdf
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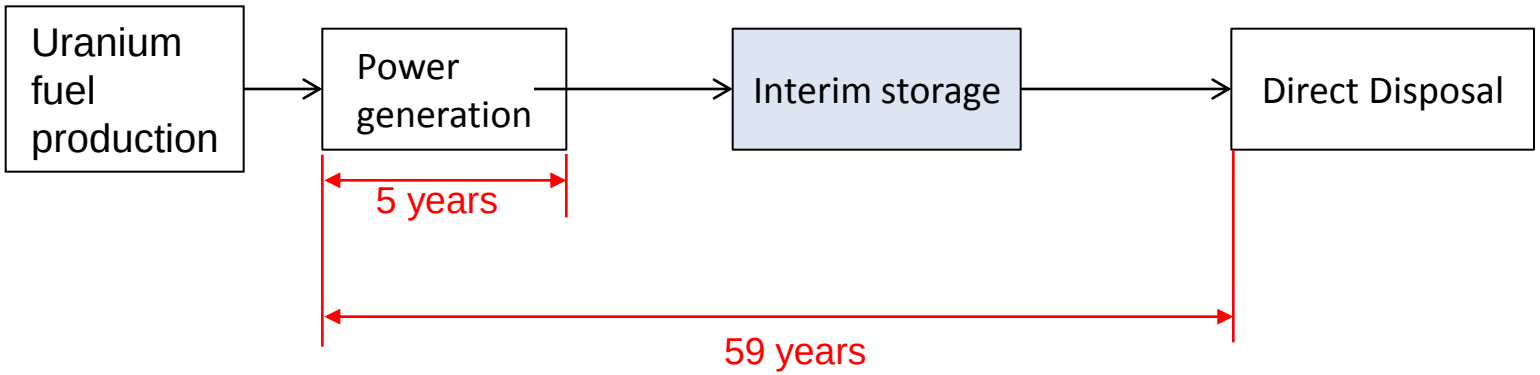
Estimation Model

Direct Disposal Model

- All spent fuel is directly disposed after interim storage.



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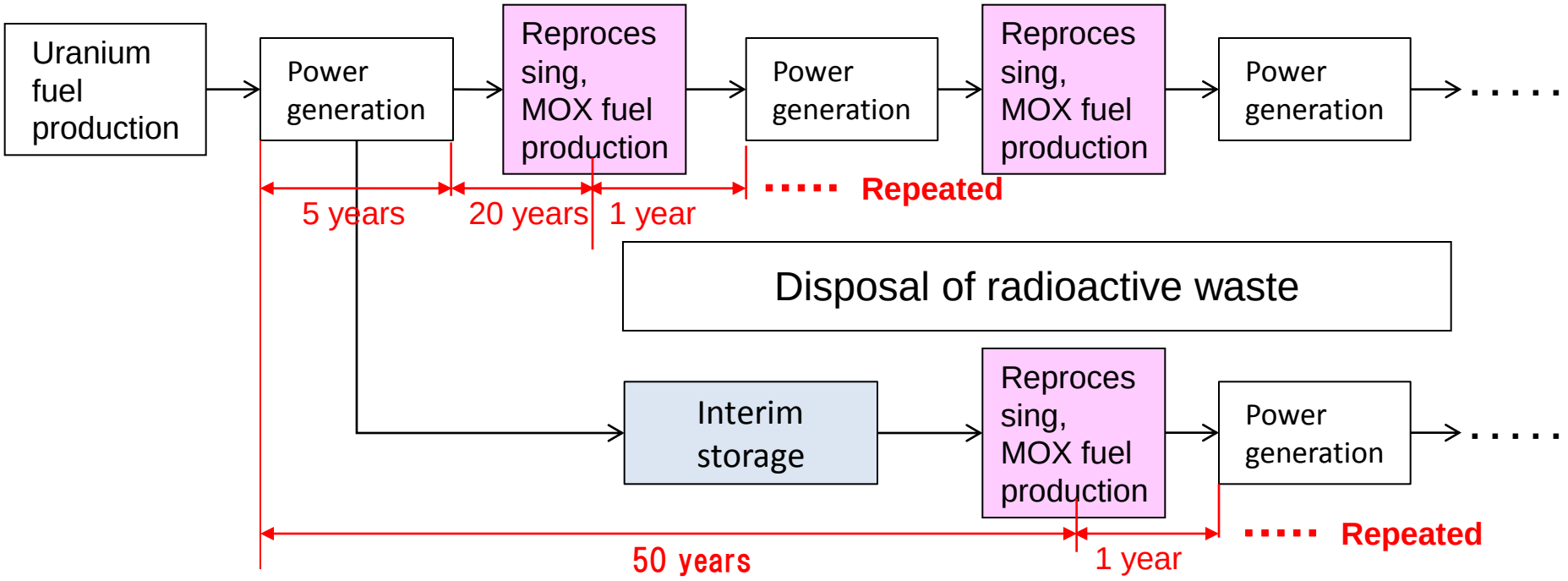
Estimation Model (reference)

Latest Model

- Part of spent fuel is reprocessed and recycled, and the remaining fuel is reprocessed after interim storage.



Ref. : http://www.aec.go.jp/jicst/NC/about/kettei/seimei/111110_1.pdf
10 Nov. 2011 Technical Subcommittee on Nuclear Power, Nuclear Fuel Cycle, etc., Material No. 1 (Japanese)

Cost Estimation Conditions

Cycle Cost Estimation Conditions (Common to All Models)

Item		Cost Subcom. (2004)	This time	
Uranium fuel enrichment		BWR 3.8% PWR 4.1%	RP model Latest model	BWR 3.7% PWR 4.6%
			DD model	PWR 4.5%
Average burn-up at discharged		UO_2 fuel: 45,000 MWd/t MOX fuel: 40,000 MWd/t	←	
Incore fuel dwelling time		5 years	←	
Heat efficiency		34.5%	←	
Exchange rate		121.98 yen/dollar	85.74 yen/dollar	
Discount rate		0, 1, 2, 3, 4 %	0, 1, 3, 5 %	
RP model, latest model	Reprocessing and interim storage ratio	64:36	50:50	
	Next generation production ratio	15%	←	

RP: Reprocessing Plant, DD: Direct Disposal Site

Ref. : http://www.aec.go.jp/jicst/NC/about/kettei/seimei/111110_1.pdf

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Front-end

- Recent spot prices of uranium concentrate (yellow cake: U_3O_8) have fluctuated significantly. Although the past market price were stable around $10/lb., recent price has increased to as high as $130 temporarily and it is fluctuating between $40 and $60/lb$U_3O_8$ during 2008 to 2010.
- As for exchange rates, the yen has strengthened significantly: although the rate in August 2004 was around 110 yen/dollar, an average rate is around 86 yen/dollar in 2010.

Ref. : http://www.aec.go.jp/jicst/NC/about/kettei/seimei/111110_1.pdf
10 Nov. 2011 Technical Subcommittee on Nuclear Power, Nuclear Fuel Cycle, etc., Material No. 1 (Japanese)

Back-end

- A fund system for reprocessing, etc. was established. (refer to p.12)
  - The costs concerning reprocessing, including decommissioning costs and TRU waste disposal costs, have been reserved from 2005. The fund is collected from electricity charges.
- Test operation using spent fuel (active tests) started at the Rokkasho Reprocessing Plant in March 2006.
  - The tests became stagnant in the vitrification process of high level radioactive waste, and the completion was postponed to October 2012.
- Four NPP started to use MOX fuel.
- Construction of the Rokkasho MOX Fuel Fabrication Plant started in October 2010.
  - The construction is expected to be completed in March 2016.
- Construction of the first spent fuel interim storage facilities in Japan started at Mutsu City of Aomori Prefecture in August 2010.
  - The construction is expected to be completed in July 2012.

Ref. : http://www.aec.go.jp/jicst/NC/about/kettei/seimei/111110_1.pdf
10 Nov. 2011 Technical Subcommittee on Nuclear Power, Nuclear Fuel Cycle, etc., Material No. 1 (Japanese)

Development of System and Provision for Spent Fuel Reprocessing Fund

- The Spent Nuclear Fuel Reprocessing Fund Act was enforced in 2005 (for the Rokkasho Reprocessing Plant)
  - Costs of reprocessing at the Rokkasho Reprocessing Plant are reserved for future use.
  - The yearly assignments of reprocessing costs and relevant spent fuel generated are simultaneously converted when the spent fuel is generated, using the discount rate to find the levelized cost for unit weight.
- The report of the Investment Environment Improvement Subcommittee (2007) of the Electricity Industry Committee indicated a decision to include the costs of reprocessing the spent fuel other than that reprocessed at the Rokkasho Reprocessing Plant in the reserve.

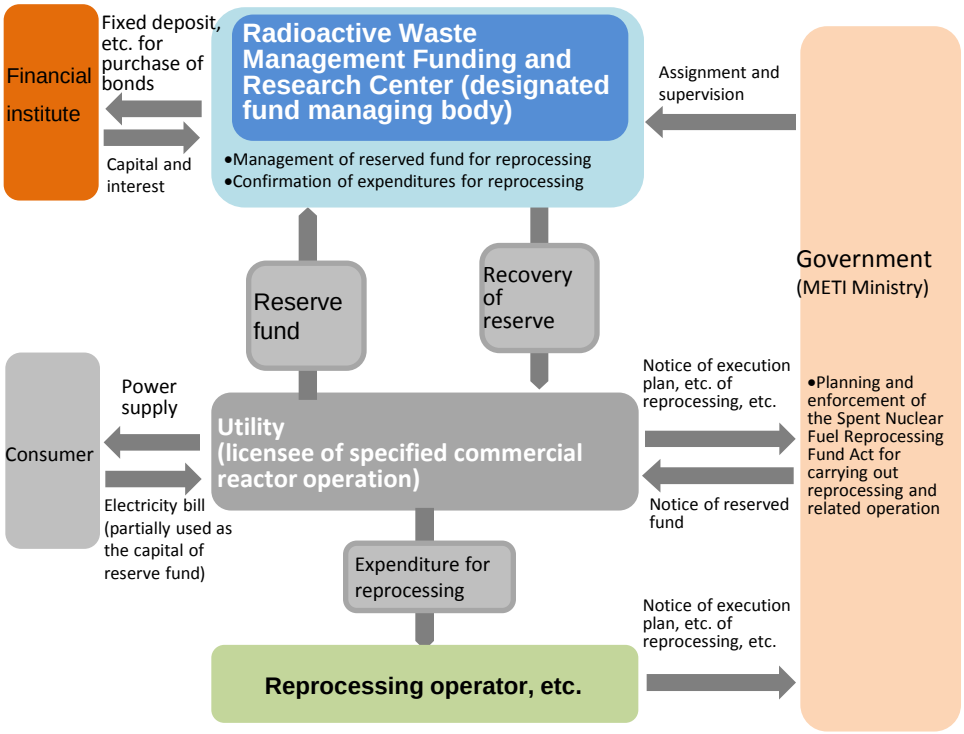
Ref. : http://www.aec.go.jp/jicst/NC/about/kettei/seimei/111110_1.pdf
10 Nov. 2011 Technical Subcommittee on Nuclear Power, Nuclear Fuel Cycle, etc., Material No. 1 (Japanese)

Costs of individual operations by processes (reprocessing)

Reprocessing Fund Scheme

- The reprocessing of nuclear fuel, which forms the basis of nuclear fuel cycle, requires a significantly long period and massive amounts of money, and ensuring the safety and transparency is essential for securing the necessary funds. For this reason, utilities deposit the money required for reprocessing according to the law*.
- The amount of reserved funds is estimated by the government, based on the notifications submitted from the utilities.

* Law: Act concerning Funding and Management of Reserve Fund for Reprocessing of Spent Fuel in Nuclear Generation (2005 law No. 48)



Basic scheme of reserve fun for reprocessing

Reservation of fund for reprocessing, etc.

(unit: 100 millionyen)

	2005	2006	2007	2008	2009	2010
Estimated sum	126,850	126,873	127,038	118,958	121,308	122,516
Balance	10,384	12,479	15,682	18,389	21,443	24,416

* Estimated sum in 2011: 12,223,700 million yen (Estimated based on notices from utilities in March 2011)

* The estimated sum is calculated according to the law.

- **The estimated sum is the costs for reprocessing of spent fuel (32,000 tU) at the Rokkasho Reprocessing Plant.**

Source: Data created by the Cabinet Office from data presented by the Natural Resources and Energy Agency

Ref. : http://www.aec.go.jp/jicst/NC/about/kettei/seimei/111110_1.pdf
10 Nov. 2011 Technical Subcommittee on Nuclear Power, Nuclear Fuel Cycle, etc., Material No. 1 (Japanese)

Costs of Individual Operations by Processes (reprocessing)

Total Cost of Reprocessing, etc.

		Latest notice	Cost Subcom.
Reprocessing project	Period	2005 to 2052	2005 to 2046
	Total amount	Approx. 32kt	Approx. 32kt

- Reprocessing costs are calculated by selecting the relevant figures from this table.

Unit: 10 billion yen

		Latest notice	Cost Subcom.	Difference	Basic calculation process	Major changes presented by Cost, etc. Subcom.
Rokkasho Reprocessing Plant	Operation	927	905	22	Investments (e.g. construction), operation and maintenance costs, and other expenditures based on latest business plan of Japan Nuclear Fuel Ltd.	• Increase in cost due to prolonged period of reprocessing by 6 years • Decrease in paid interest due to capital increase • Decrease in paid interest due to tax revision (front-load depreciation)
	Disposal	154	155	▲1	Changes (e.g. price fluctuation) based on unit costs and quantities at Cost Subcom.	• Decline of resource related indexes
Returned high-level radioactive waste management	Storage	29	27	2	Investments (e.g. construction), operation and maintenance costs, and other expenditures based on latest business plan of Japan Nuclear Fuel Ltd.	• Increase in cost due to prolonged storage period by 2 years
	Disposal	1	1	0	Changes (e.g. price fluctuation) based on unit costs and quantities at Cost Subcom.	• Decline of resource related indexes
Returned low-level radioactive waste management	Storage	18	35	▲16	Investments (e.g. construction), operation and maintenance costs, and other expenditures at Cost Subcom	• Decrease in low-level waste with acceptance of alternative
	Disposal	1	4	▲3	Changes (e.g. price fluctuation) based on unit costs and quantities at Cost Subcom.	• Decline of resource related indexes • Decrease in stored waste with acceptance of alternative
Transport of waste to disposal site	High-level	10	9	1	-ditto-	• Increase in high-level waste with acceptance of alternative • Increase in transport related indexes
	Low-level	21	22	▲1	-ditto-	• Increase in low-level waste with acceptance of alternative • Increase in transport related indexes
Disposal of waste	High-level	0.3	———	0.3	Contributed unit cost based on Final Disposal Act x Q'ty of alternative high-level waste	• Addition of items with acceptance of alternative
	Low-level [geological Disposal]	37	78	▲41	Unit price of contribution based on the Final Disposal Act x Q'ty of waste for geological disposal based on Final Disposal Act	• Decrease in quantity due to revised Final Disposal Act and application of unit price to contribution in accordance with this act
	Low-level	23	23	0	Changes (e.g. price fluctuation) based on unit costs and quantities at Cost Subcom.	• Increase in quantity due to revised Final Disposal Act • Decrease in low-level waste with acceptance of alternative
Total		1,222	1,259	▲37		

Ref. : http://www.aec.go.jp/jicst/NC/about/kettei/seimei/111110_1.pdf
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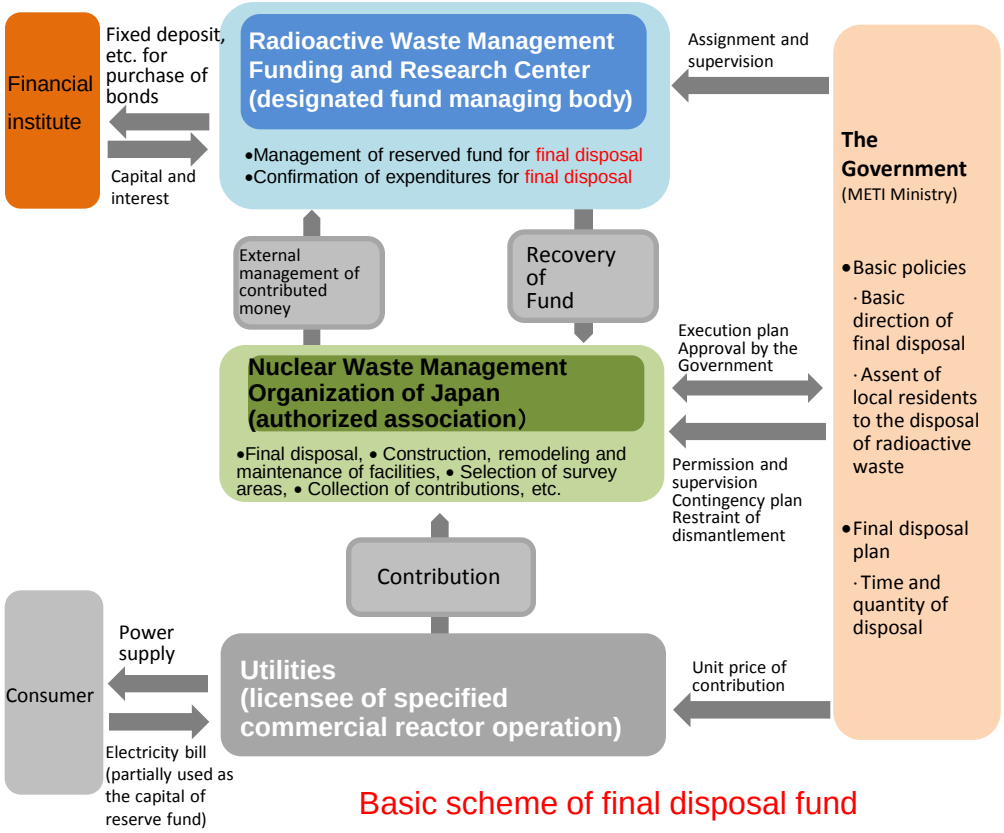
Contribution Scheme for Final Disposal Fund

- Considering the importance of a systematic accumulation of funds for the final disposal of vitrified radwastes, the Radioactive Waste Management Funding and Research Center was designated as the fund managing body in 2000 according to the related law, and manages a fund with contributions from the Nuclear Waste Management Organization of Japan (NUMO).
- The government reviews the unit price of contribution required for the reserve every year.
  * Law: Designated Radioactive Waste *Final Disposal Act*, Act No. 117 of 2000



Basic scheme of final disposal fund

Reservation of final disposal fund

(Unit: 100 million yen)

	2000	2001	2002	2003	2004	2005
Estimated sum	29,305	28,911	28,819	28,297	27,843	27,652
Balance	0	1,020	1,705	2,372	2,940	3,566

(Unit: 100 million yen)

	2006	2007	2008	2009	2010
Estimated sum	27,728	27,879	27,582	27,922	27,769
Balance	4,241	4,999	5,763	6,498	7,394

* Estimated sum in 2011: 2,718,300 million yen
* The estimated sum is calculated according to the accumulation method ensured at the Nuclear Energy Group of the Advisory Committee for Energy.

- The estimated sum is the costs required for the geological disposal of 40,000 bodies of vitrified radwaste by NUMO.

Source: Data created by the Cabinet Office from data presented by the Natural Resources and Energy Agency

Ref. : http://www.aec.go.jp/jicst/NC/about/kettei/seimei/111110_1.pdf
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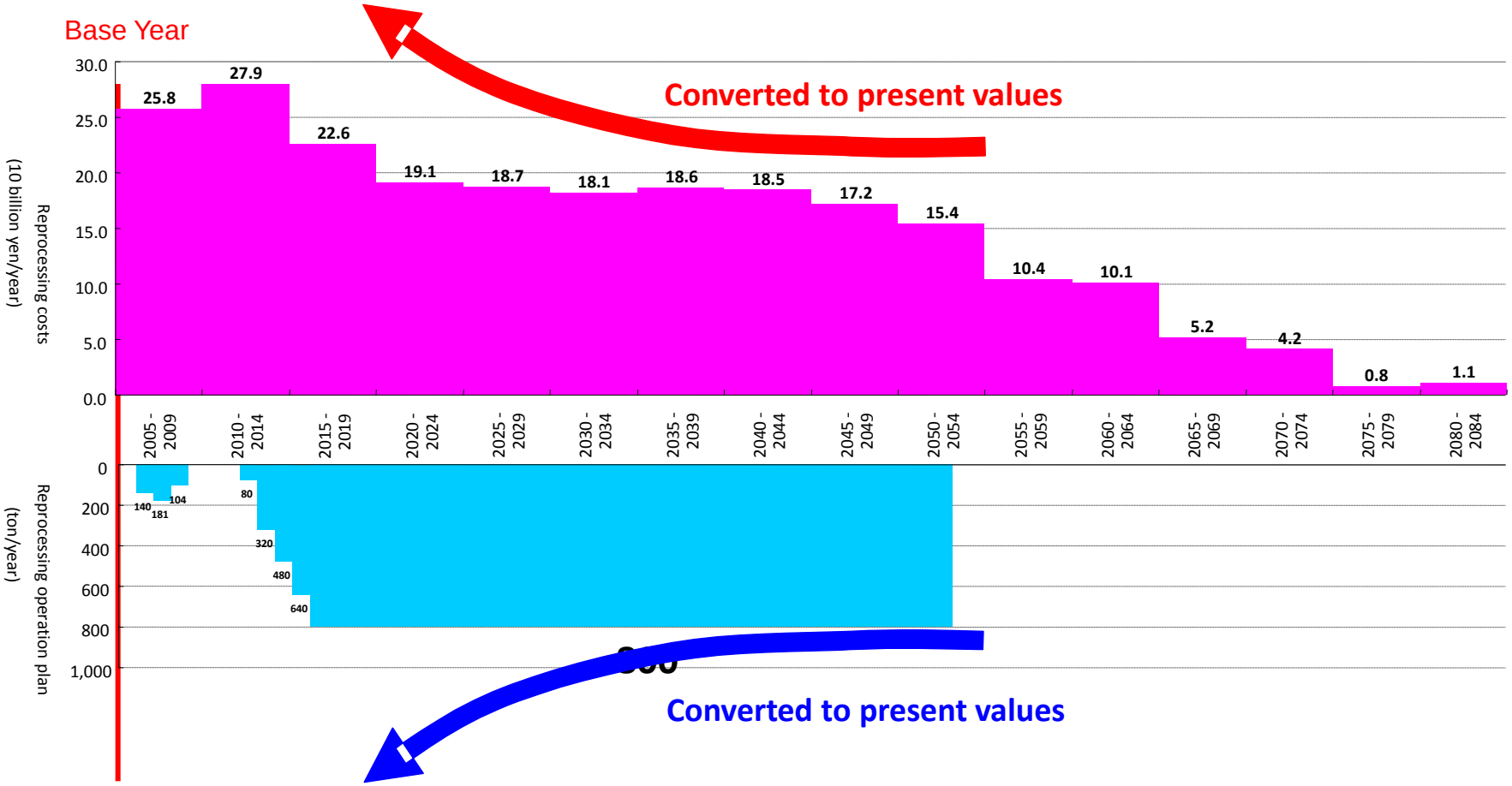
Cost Estimates (Reprocessing, etc.)



Cost per ton = Reprocessing cost [converted to base year's value] / Reprocessing Amount [converted to base year's value]

Ref. : http://www.aec.go.jp/jicst/NC/about/kettei/seimei/111110_1.pdf
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Costs for Various Models (1) - Discount rate: 0% and 1% -

(yen/kWh)

Item	Discount rate: 0%			Discount rate: 1%		
	Reprocessing model	Direct disposal model	Latest model	Reprocessing model	Direct disposal model	Latest model
Uranium fuel	0.62	0.72	0.62	0.65	0.75	0.68
MOX fuel	0.17	-	0.17	0.16	-	0.12
(Front-end total)	0.79	0.72	0.79	0.82	0.75	0.80
Reprocessing, etc.	1.10	-	1.10	1.06	-	0.79
Interim storage	-	0.14	0.07	-	0.12	0.06
HLW disposal	0.24	-	0.24	0.16	-	0.12
Direct disposal	-	0.41 - 0.48	-	-	0.24 -0.28	-
(Back-end total)	1.34	0.56 -0.63	1.41	1.21	0.37 - 0.41	0.98
Total	2.14	1.28 - 1.35	2.21	2.03	1.11 - 1.15	1.78

Note) The total may not correspond to the sum of all the items due to rounding. (Sending end)

Ref. : http://www.aec.go.jp/jicst/NC/about/kettei/seimei/111110_1.pdf
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Costs for Various Models (2) - Discount rate: 3% and 5% -

(yen/kWh)

Item	Discount rate: 3%			Discount rate: 5%		
	Reprocessing model	Direct disposal model	Latest model	Reprocessing model	Direct disposal model	Latest model
Uranium fuel	0.73	0.81	0.77	0.81	0.88	0.86
MOX fuel	0.15	-	0.07	0.14	-	0.04
(Front-end total)	0.88	0.81	0.84	0.94	0.88	0.90
Reprocessing, etc.	1.03	-	0.46	1.04	-	0.30
Interim storage	-	0.09	0.05	-	0.07	0.04
HLW disposal	0.08	-	0.04	0.05	-	0.01
Direct disposal	-	0.10 - 0.11	-	-	0.05 - 0.05	-
(Back-end total)	1.11	0.19 - 0.21	0.55	1.08	0.12 - 0.12	0.36
Total	1.98	1.00 - 1.02	1.39	2.03	1.00 - 1.01	1.26

Note) The total may not correspond to the sum of all the items due to rounding. (Sending end)

Ref. : http://www.aec.go.jp/jicst/NC/about/kettei/seimei/111110_1.pdf
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Results of Estimation

- Front-end
  - In addition to yen appreciation in the exchange rate, substantial increases in the uranium concentrate price affect the costs of the direct disposal model.
  - The proportion of MOX fuel loaded in reactors is small and the effects of MOX fuel cost in the front-end costs are insignificant.
- Reprocessing, etc.
  - The difference between the costs of the reprocessing and direct disposal models is about 1 yen/kWh (at 3% discount rate), and this is caused by the presence of reprocessing etc.
  - When the nuclear fuel recycle is included, the difference between the costs of the reprocessing and latest models is about 0.6 yen/kWh (at 3% discount rate), and this is caused by the length of storage period.

A comprehensive evaluation of various nuclear fuel recycle options will be continued, including the perspectives other than economical efficiency.

Ref. : http://www.aec.go.jp/jicst/NC/about/kettei/seimei/111110_1.pdf
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Sensitivity Analysis (1) Reprocessing & MOX Cost

- The reprocessing, etc. and MOX fuel cost are subject to sensitivity analysis using a sensitivity of 1.5 times of unit cost (sensitivity analysis case) for the latest model (basic case).
- 【Reprocessing, etc.】
  - Complete denial is hard for a potential decrease in the reprocessing amount (reduced operating rate) due to the delayed achievement of the rated reprocessing quantity (800tU/year), and a potential increase in the cost of construction for the planned expansion of facilities in the future, and a possibility of additional investments for maintaining the operating rate.
- 【MOX fuel】
  - Construction cost have increased from 120 billion to 190 billion yen owing mainly to 1) increases in the price of construction materials and 2) requirement of antiseismic installation. Complete denial is hard for a potential increase in the construction cost due to the same reasons until the time the construction is completed in March 2016.

Ref. : http://www.aec.go.jp/jicst/NC/about/kettei/seimei/111110_1.pdf
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Results of Sensitivity Analysis (1) Reprocessing and MOX costs

(Discount rate: 3%)

(yen/kWh)

Item	Latest model		
	Basic case	Sensitivity analysis case	Cost ratio
Uranium fuel	0.77	←	---
MOX fuel	0.07	0.10	1.5
Reprocessing, etc.	0.46	0.68	1.5
Interim storage	0.05	←	---
HLW disposal	0.04	←	---
Total	1.39	1.64	1.2

Ref. : http://www.aec.go.jp/jicst/NC/about/kettei/seimei/111110_1.pdf
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Sensitivity Analysis (2) Front-end Costs

- The element of uranium concentrate in the uranium fuel price is subject to sensitivity analysis using a sensitivity of 2.0 times (sensitivity analysis case) for the reprocessing, direct disposal and latest models (basic cases).
  - The present spot uranium price is approx. $140/kgU, but the fluctuation in the latest three years ranged $100 to $180/kgU.
  - There is no publication for future price estimates by public organizations, but the report by OECD/NEA and IAEA is attached for reference.
    - "Uranium 2009" (July 2010) published by OECD/NEA and IAEA analyzed the amount of resources based on the new product costs up to $260/kgU (formerly up to $130/kgU) which reflect the rising uranium production costs and the basic moves of the uranium markets.
  - Considering the sharply rising spot uranium, which once exceeded $260/kgU, the future hike of the uranium price around twice the present level is taken into account.

Ref. : http://www.aec.go.jp/jicst/NC/about/kettei/seimei/111110_1.pdf
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Results of Sensitivity Analysis (2) Front-end Costs

(yen/kWh)

Item	Reprocessing model			Direct disposal model			Latest model		
	Basic case	Sensitivity analysis case	Cost ratio	Basic case	Sensitivity analysis case	Cost ratio	Basic case	Sensitivity analysis case	Cost ratio
Uranium fuel	0.73	1.04	1.4	0.81	1.16	1.4	0.77	1.10	1.4
MOX fuel	0.15	←	---	---	---	---	0.07	←	---
Reprocessing, etc.	1.03	←	---	---	---	---	0.46	←	---
Interim storage	---	---	---	0.09	←	---	0.05	←	---
HLW disposal	0.08	←	—	---	---	---	0.04	←	---
Direct disposal	---	---	---	0.10 - 0.11	←	---	---	---	---
Total	1.98	2.29	1.2	1.00 - 1.02	1.35 - 1.36	1.3 - 1.4	1.39	1.72	1.2

Ref. : http://www.aec.go.jp/jicst/NC/about/kettei/seimei/111110_1.pdf
10 Nov. 2011 Technical Subcommittee on Nuclear Power, Nuclear Fuel Cycle, etc., Material No. 1 (Japanese)

Results of Sensitivity Analysis (3) Burial Disposal Costs

- The HLW disposal and direct disposal are subject to sensitivity analysis with 1.5 times costs.

Discount rate: 3% (yen/kWh)

Item	Direct disposal model			Latest model		
	Basic case	Sensitivity analysis case	Cost ratio	Basic case	Sensitivity analysis case	Cost ratio
U fuel	0.81	←	-	0.77	←	-
MOX fuel	-	-	-	0.07	←	-
Reprocessing, etc.	-	-	-	0.46	←	-
Interim storage	0.09	←	-	0.05	←	-
HLW disposal	-	-	-	0.04	0.05	-
Direct disposal	0.10 - 0.11	0.15 - 0.17	-	-	-	-
Total	1.00 - 1.02	1.05 - 1.07	1.05 - 1.05	1.39	1.41	1.01

- The impact on the whole cycle is on order of 1% in the latest model which contains HLW disposal, or 5% in the direct disposal model though the latter depends on the disposal method.

Ref. : http://www.aec.go.jp/jicst/NC/about/kettei/seimei/111110_1.pdf
10 Nov. 2011 Technical Subcommittee on Nuclear Power, Nuclear Fuel Cycle, etc., Material No. 1 (Japanese)

Accident Risk Cost Method

Method

- Model LWR plant (1200MWe, capacity factor=60,70,80%, consider site characteristics variations such population density)
- Economic damage includes; lost assets (onsite and offsite), land decontamination, evacuation/relocation, loss of job, inspection of foods, human health (mental anguish), other socio-economic damages such as compensation to rumor-induced damage in the market
- Economic damage grouped into one-time damage (rumor-induced and inspection: not proportional to the amount of released FP) and yearly recurrent damages (proportional to level of contamination)
- As a result, accident cost is estimated to be about 5 trillion yen based on report by the Management and Finance Committee for TEPCO

Estimation of the Accident Risk Cost based on the Frequency of Occurrence of Damage

Accident Risk Cost of a Model Plant (based on 5 trillion yen accident costs)

Frequency of occurrence (/reactor year)	Accident risk cost of the model plant, by operation rate (yen/kWh)			Additional cost per increase in the amount of damage by 1 trillion yen (yen/kWh)		
	Utilization factor 60%	Utilization factor 70%	Utilization factor 80%	Utilization factor 60%	Utilization factor 70%	Utilization factor 80%
1.0×10^{-5} (IAEA safety goal for an early large release from an existing reactor)	0.008	0.007	0.006	0.002	0.001	0.001
3.5×10^{-4} (Frequency of severe accidents at commercial reactors around the world; equivalent to once every 57 years[1])	0.28	0.24	0.21	0.06	0.05	0.04
2.0×10^{-3} (Frequency of severe accidents at commercial reactors in Japan; equivalent to once every 10 years[1])	1.6	1.4	1.2	0.32	0.27	0.24

[1] Frequency of occurrence of accidents on the condition that 50 power reactors are in operation

Ref. : http://www.aec.go.jp/jicst/NC/about/kettei/seimei/111110_2.pdf
10 Nov. 2011 Technical Subcommittee on Nuclear Power, Nuclear Fuel Cycle, etc., Material No. 2 (Japanese)

Estimation of the Accident Risk Cost in Reference to the Insurance Scheme

Estimation of the Accident Risk Cost under the U.S. Mutual Aid Scheme

- Amount of damage, including expenses for decommissioning reactors, as estimated by the Subcommittee in relation to the model plant: 4.9936 trillion yen
- Exclusively for the purpose of making estimation, the Subcommittee calculated the amount of damage as 5 trillion yen based on the assumption that there is a mutual assistance scheme for nuclear plant operators in reference to the Price-Anderson Act. As a result of sensitivity analysis, the estimated amount of damage nearly doubled to 10 trillion yen.

Amount of damage	Period of payment	Total nuclear power generation [1]	Accident risk cost
5 trillion yen	40 years	280.0 billion kWh	0.45 yen/kWh
10 trillion yen			0.89 yen/kWh

[1] Actual result in FY2010, Energy and Environment Council

– The amount of damage could be further reduced if it is shared among nuclear plant operators around the world.

Ref. : http://www.aec.go.jp/jicst/NC/about/kettei/seimei/111110_2.pdf
10 Nov. 2011 Technical Subcommittee on Nuclear Power, Nuclear Fuel Cycle, etc., Material No. 2 (Japanese)

All Reprocessing　Latest Model　Direct Disposal

再処理モデル
使用済燃料全量を再処理してリサイクルするモデル

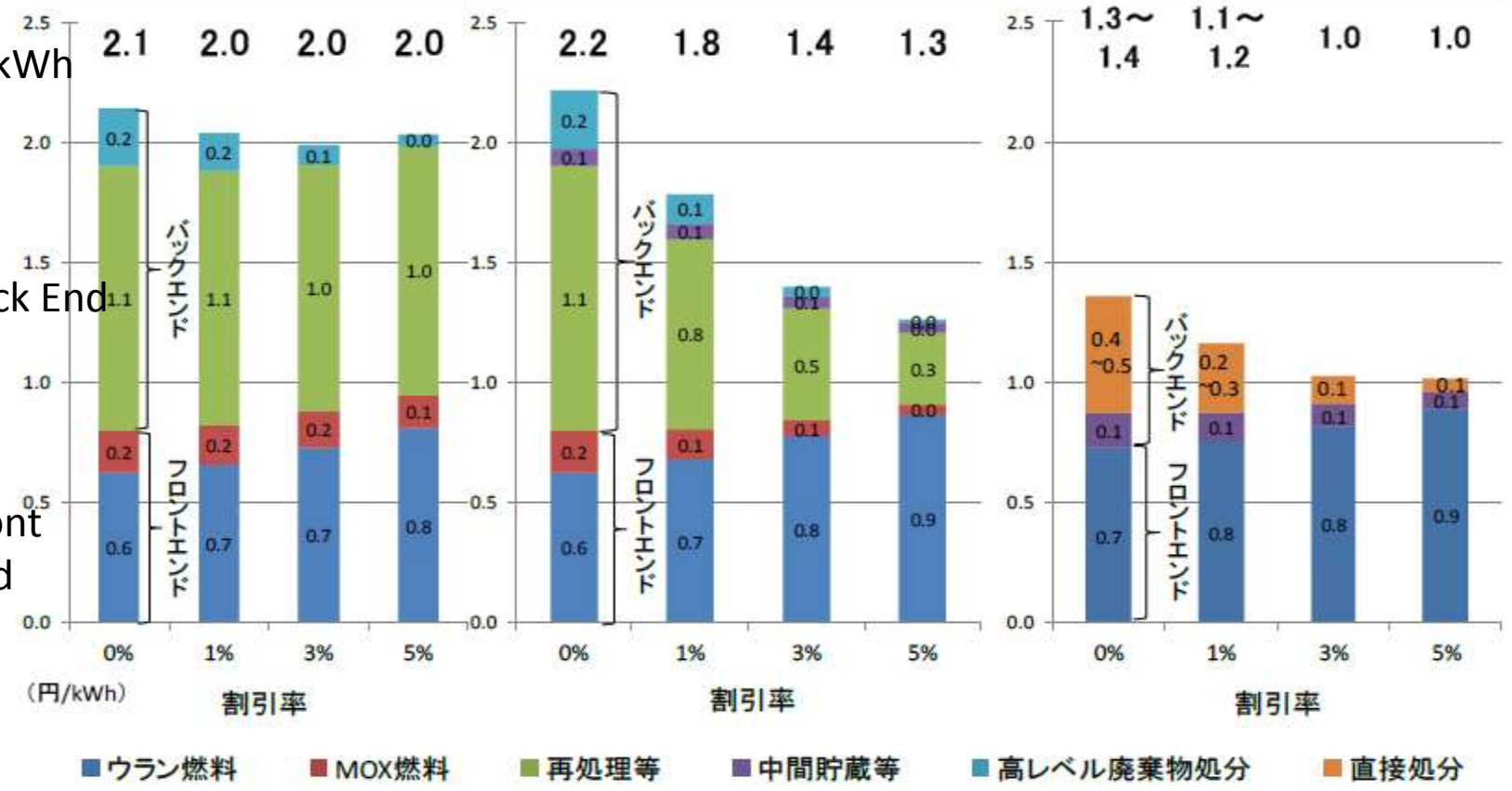
現状モデル
使用済燃料全量を適切な期間貯蔵しつつ再処理していく現状を考慮

直接処分モデル
使用済燃料全量を中間貯蔵後に直接処分するモデル

Yen/kWh

Back End

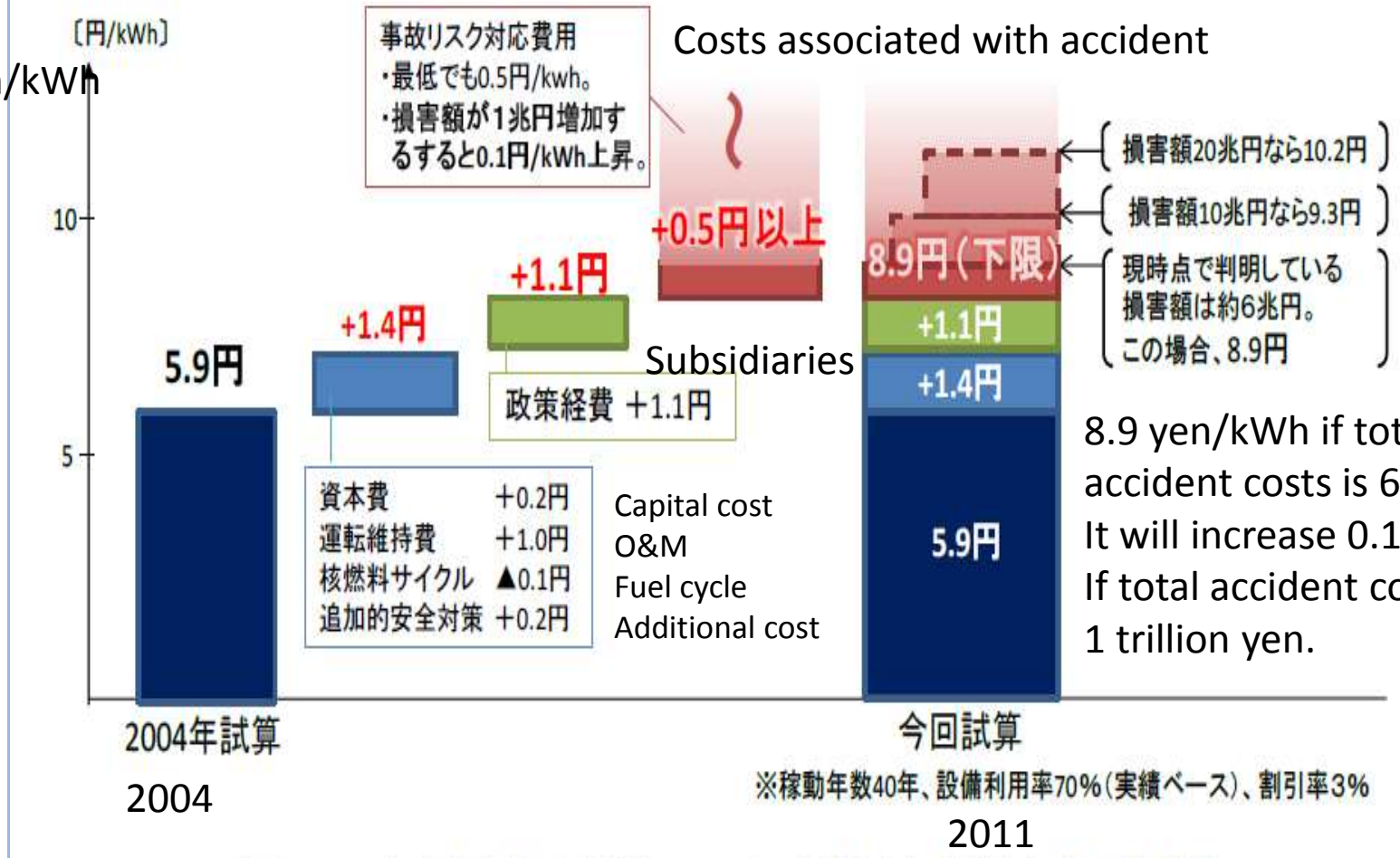
Front End



（図　１７）核燃料サイクル費用の比較

（再処理モデルと現状モデルと直接処分モデル）

出所:コスト等検証委員会報告書、2011年12月19日
http://www.npu.go.jp/policy/policy09/pdf/20111221/siryo3.pdf

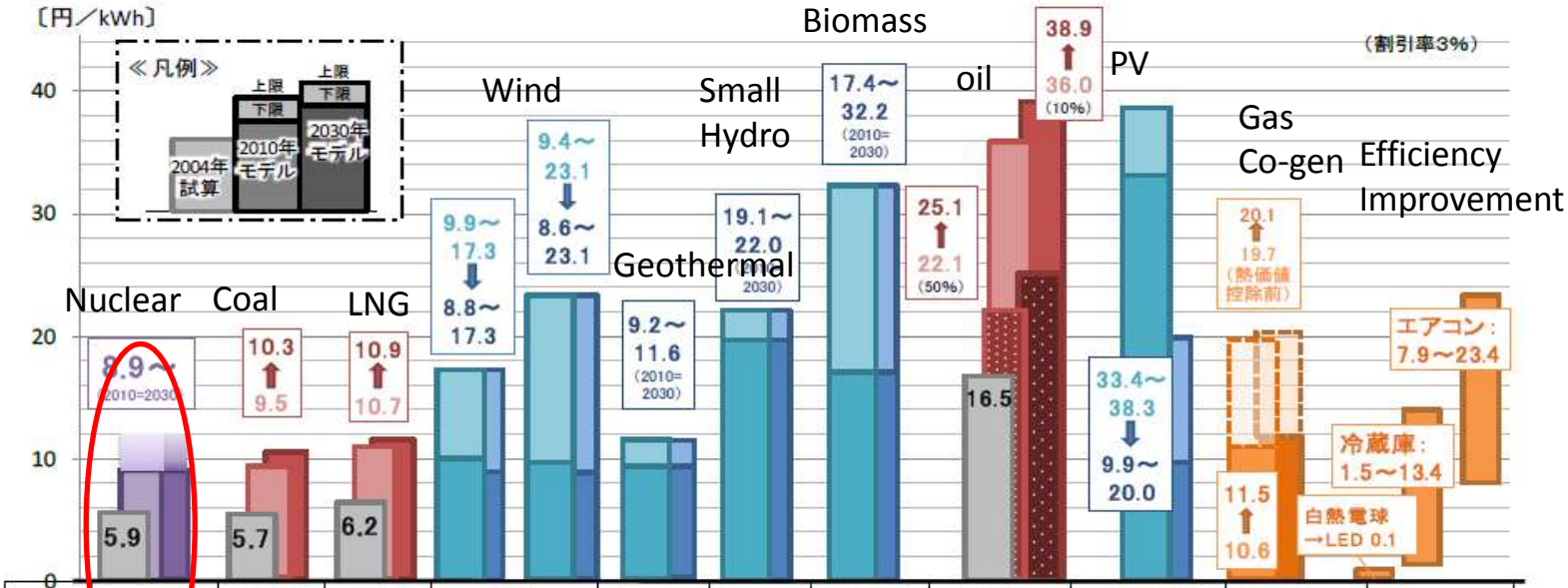


（図 ２０）原子力の発電コスト（2004 年試算と今回試算）

Nuclear Power Generation Costs (2004, 2011)

出所：コスト等検証委員会報告書、２０１１年１２月１９日
http://www.npu.go.jp/policy/policy09/pdf/20111221/siryo3.pdf

【コスト試算のポイント】
○モデルプラント形式（最近7年間の稼働開始プラント、最近3年間の補助実績等を基に設定）
○CO2対策費用、原子力の事故リスク対応費用、政策経費等の社会的費用も加算。
○2020年、2030年モデルは燃料費・CO2対策費の上昇、技術革新等による価格低減を見込んで試算。



	原子力	石炭火力	LNG火力	風力 陸上	風力 洋上着床式	地熱	小水力	バイオマス（木質専焼）	石油火力	太陽光（住宅用）	ガスコジェネ	省エネ
シナリオ等	核燃料サイクル現状モデル	新政策シナリオ	新政策シナリオ	横ばい～低減	横ばい～低減	－	－	－	新政策シナリオ	参照～パラダイムシフト	新政策シナリオ	－
設備利用率	70%	80%	80%	20%	30%	80%	60%	80%	50%・10%	12%	70%	－
稼働年数（2030年モデル）	40年	40年	40年	20年	20年	40年	40年	40年	40年	20年（35年）	30年	－
留意点・ポイント（赤：増加要因 青：低減要因 黒：その他（導入ポテンシャルに関する記述を含む。）	8.9円は下限。事故の損害額が5.8兆円から1兆円増えるごとに0.1円増。次世代軽水炉による合理化は、定量的には見込まず。	燃料費・CO2対策費用上昇。発電効率向上	燃料費のウェイト大。発電効率向上。シェールガスのメリットは資源戦略が鍵。	量産効果でコスト低減の可能性あり。立地の拡大には、規制・制度改革、系統強化等が必要。		安定電源として有望。電源線のコストの問題がある導入可能量拡大には、立地に係る課題の解決などが必要。	安定的な発電が可能。多くの場所で可能性あり。	未利用間伐材の収集・運搬距離等により燃料費が変動。	主に燃料費が上昇	量産効果でコスト半減の可能性あり。次世代太陽電池が実現すれば、コストはさらに下がる可能性あり。大量導入には、系統対策が必要。	熱の利用を勘案すると大規模集中電源並み。電気代（業務・産業：13.7円）の節約を考慮すると需要家のメリット大。	機器によって幅あり電気代（家庭：20.4円）の節約を考慮するとメリット大。
今後の対応	○原子力の事故費用：最新の情報が得られ次第、数字を見直し。　○技術革新や量産効果によるコスト低下：技術革新の進歩や普及の動向に応じて、試算結果の見直しや試算への組込み。 ○系統安定化対策：エネルギーミックスのシナリオが固まった段階でシナリオ毎に試算。　○経済効果：エネルギーミックスのシナリオが決まった段階でマクロ的な効果として分析・試算。											

（図　３６）主な電源の発電コスト（2004 年試算／2010 年・2030 年モデルプラント）

出所：コスト等検証委員会報告書、2011年12月19日
http://www.npu.go.jp/policy/policy09/pdf/20111221/siryo3.pdf

Summary of economics of nuclear power

- Total reprocessing option is most expensive among three options, and it is about 2 yen/kWh, and cost of direct disposal option is about 1 yen/kWh.
- Cost associated with accident is difficult to estimate, but it is around 0.5 yen/kWh, based on the current cost estimate. This could increase by 0.1 yen/kWh each if total accident cost increase 1 trillion.
- Total nuclear power generation cost is estimated to be around 8.9 yen/kWh, which is still competitive with other fossil fuel power generation. But the costs associated with risk could be significantly high.

Comparison of Fuel Cycle Policy Options for Japan up to 2030

Comparison of Fuel Cycle Options - Criteria for Assessment -

Short Term

- Spent Fuel Management
- International Perspective
- Issues associated with policy change

Mid-Long Term

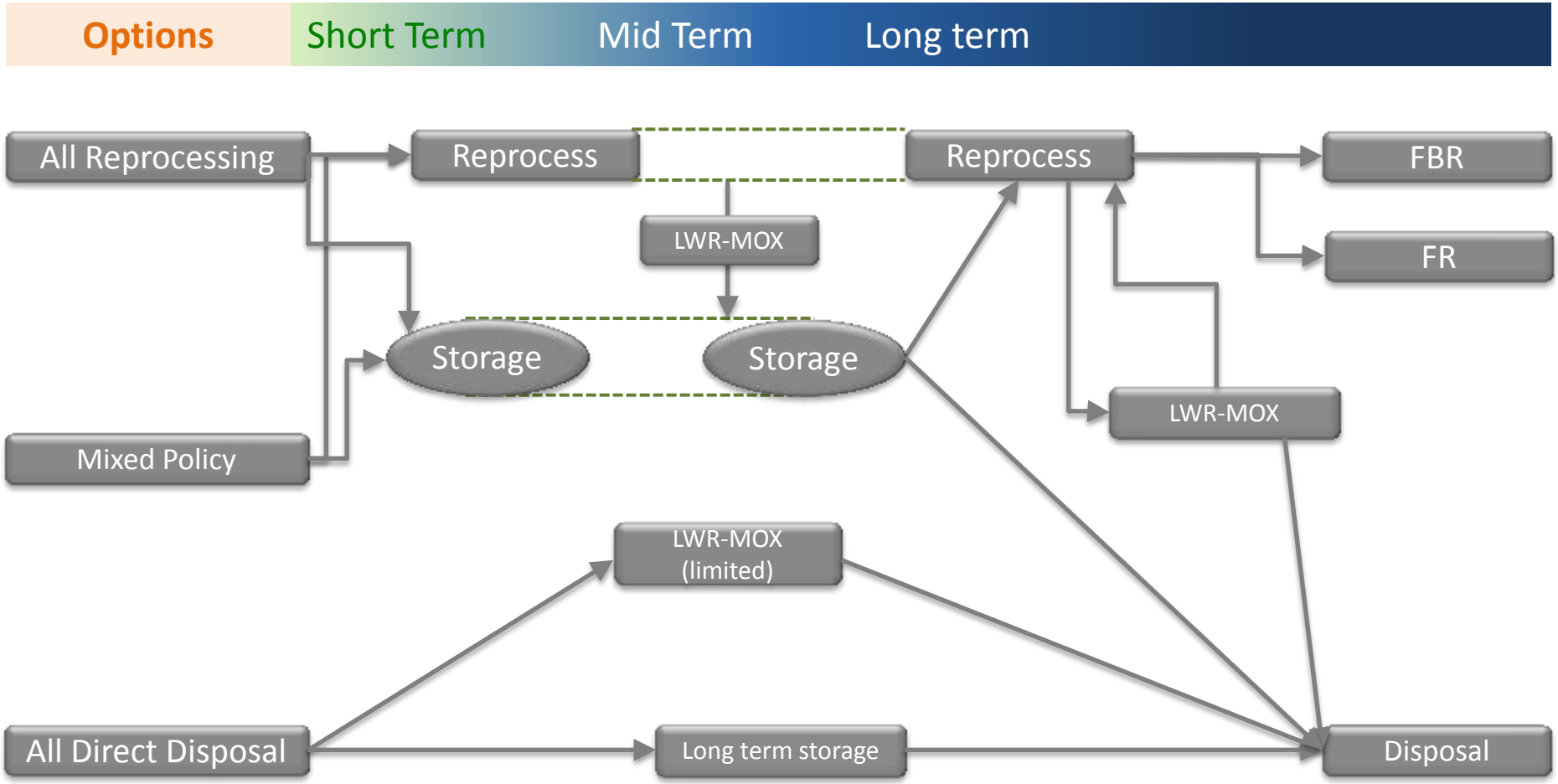
- Total costs
- Energy security, uranium saving
- Waste management and disposal
- Flexibility

Three Basic Policy Options

- Total Reprocessing Policy:

  All spent nuclear fuel is to be reprocessed and recovered uranium and plutonium will be used based on the assumption that Fast Breeder Reactor(FBR)/Fast Reactor (FR) will be commercialized.
- Reprocessing/Direct Disposal Mix Policy:
  Spent nuclear fuel is either reprocessed or directly disposed of. FBR/FR is considered one of energy options for uncertain future.
- Direct Disposal Policy
  Spent nuclear fuel will be stored and eventually directly disposed of without reprocessing. FBR/FR is not considered as an option.

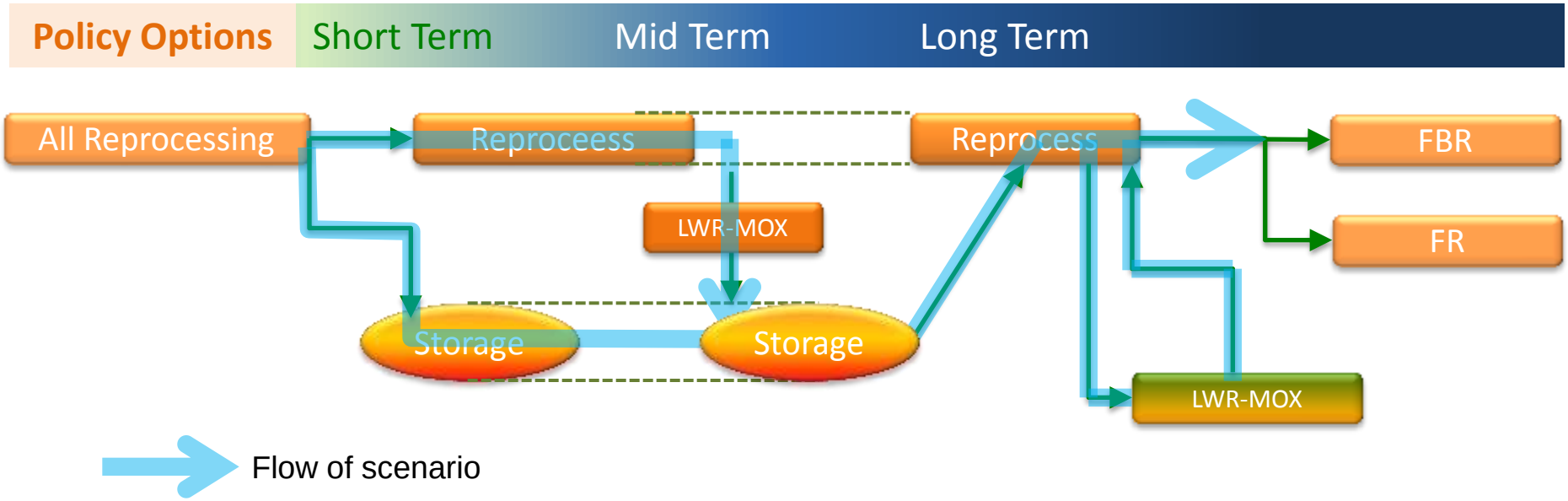
Flow/Scenario of Policy Options



Ref. : http://www.aec.go.jp/jicst/NC/tyoki/hatukaku/siryo/siryo15/siryo3-1.pdf
16 May 2012 Technical Subcommittee on Nuclear Power, Nuclear Fuel Cycle, etc., Material No. 3-1 (Japanese)

1. All Reprocessing Scenario

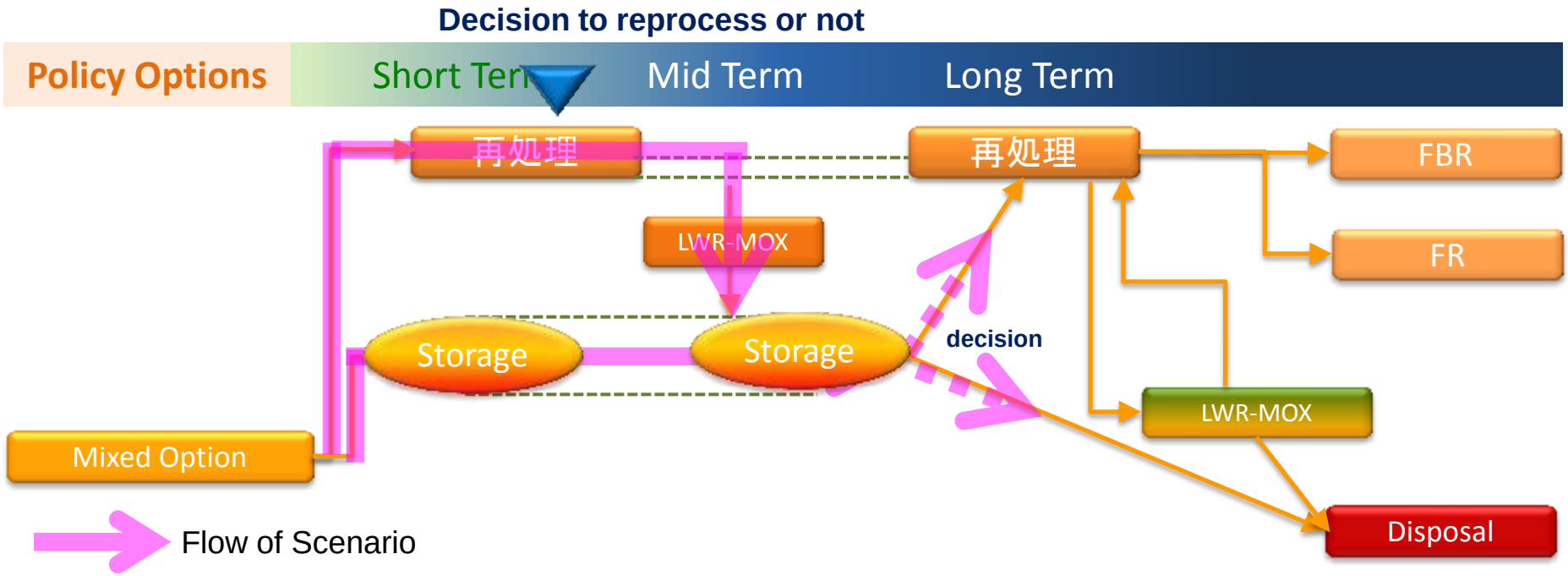
- Spent fuel will be reprocessed at Rokkasho reprocessing plant and the rest will be stored until further reprocessing.
- MOX spent fuel will be reprocessed based on the assumption that FBR/FR will be commercialized.



Ref. : http://www.aec.go.jp/jicst/NC/tyoki/hatukaku/siryo/siryo15/siryo3-1.pdf
16 May 2012 Technical Subcommittee on Nuclear Power, Nuclear Fuel Cycle, etc., Material No. 3-1 (Japanese)

2. Mixed Policy Scenario

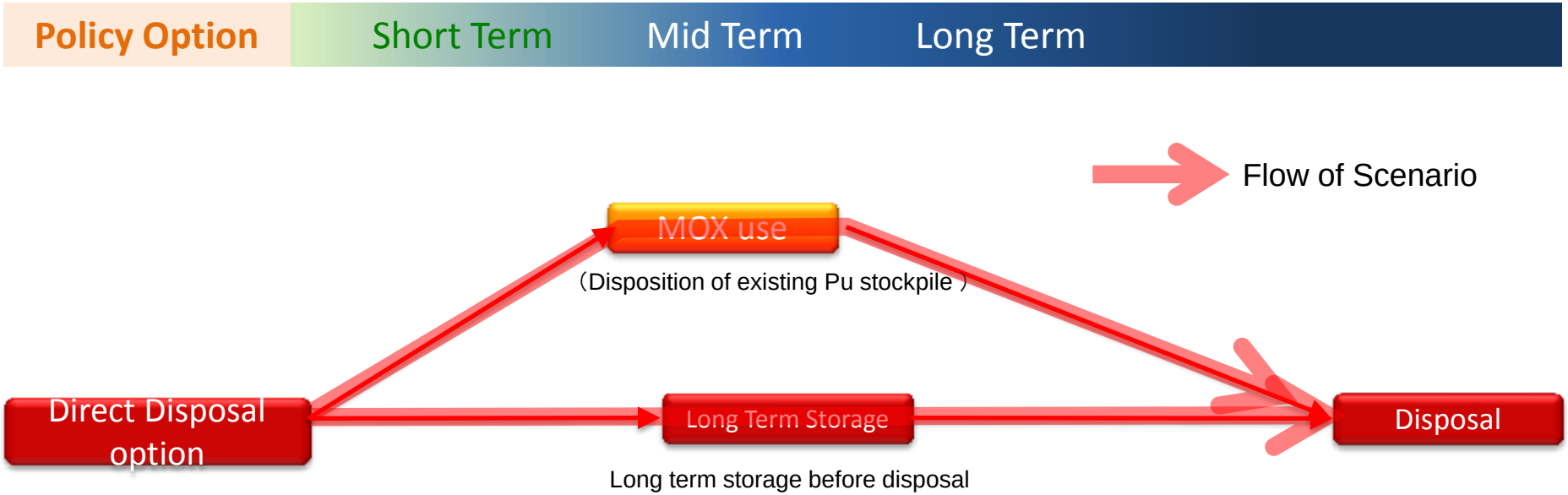
- Spent fuel will be reprocessed at Rokkasho, but the decision to reprocess or to be disposed of will not be made with the rest of spent fuel which will be stored until such decision will be made.
- FBR/FR R&D will be continued and the decision to commercialize or not will be decided later. If not, MOX spent fuel will be directly disposed of.



Ref. : http://www.aec.go.jp/jicst/NC/tyoki/hatukaku/siryo/siryo15/siryo3-1.pdf
16 May 2012 Technical Subcommittee on Nuclear Power, Nuclear Fuel Cycle, etc., Material No. 3-1 (Japanese)

3. Direct Disposal Scenario

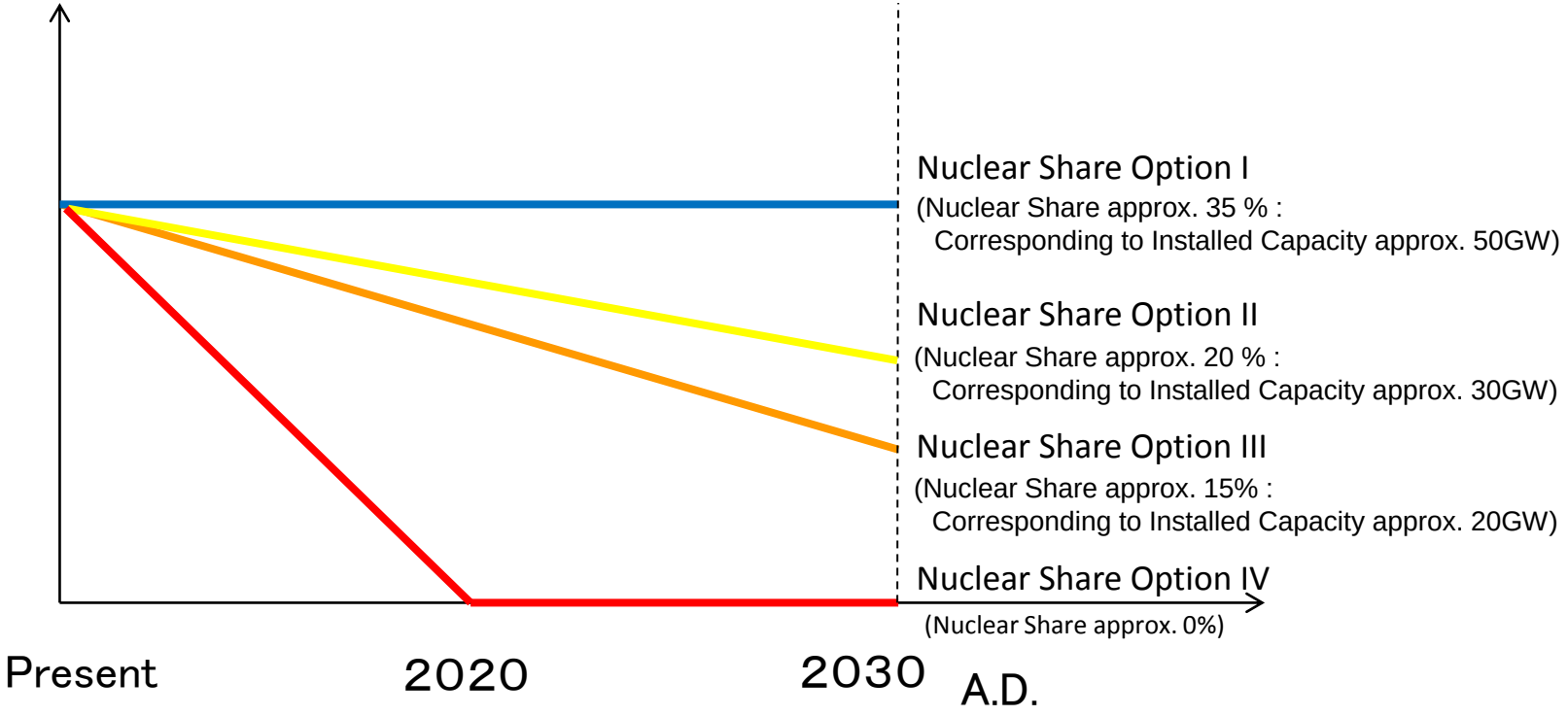
- Stop reprocessing immediately, and all spent fuel will be stored for long term storage until directly disposed of.
- Existing plutonium stockpile will be used as MOX fuel until all stock will be consumed.



Ref. : http://www.aec.go.jp/jicst/NC/tyoki/hatukaku/siryo/siryo15/siryo3-1.pdf
16 May 2012 Technical Subcommittee on Nuclear Power, Nuclear Fuel Cycle, etc., Material No. 3-1 (Japanese)

Conditions of Evaluation
-Nuclear Share in Energy Mix-

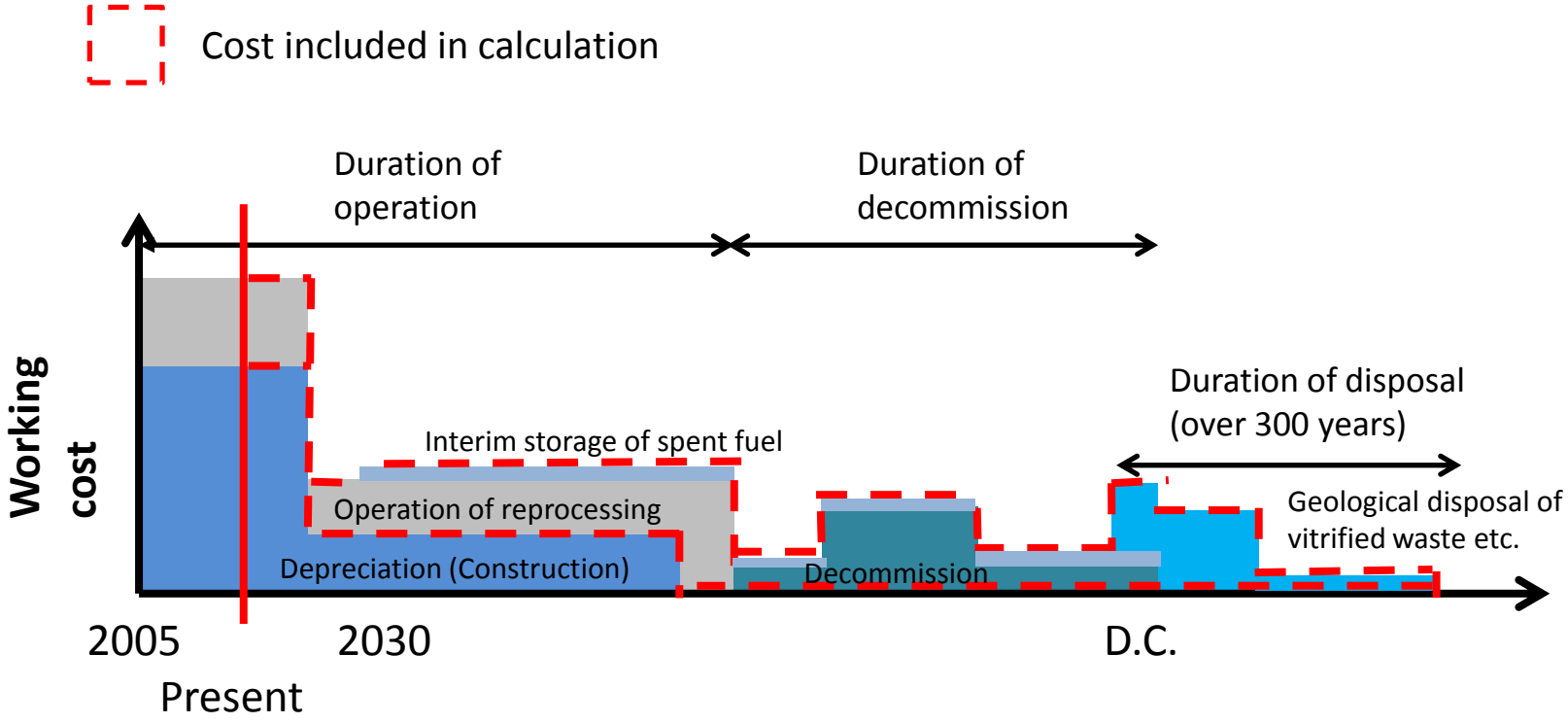
4 nuclear share options based on discussion at the fundamental issues subcommittee of the Advisory Committee for Natural Resources and Energy



Ref. : http://www.aec.go.jp/jicst/NC/tyoki/hatukaku/siryo/siryo15/siryo3-1.pdf
16 May 2012 Technical Subcommittee on Nuclear Power, Nuclear Fuel Cycle, etc., Material No. 3-1 (Japanese)

Method of Economic Analysis
-Schematic of Calculation (Total Reprocessing)-

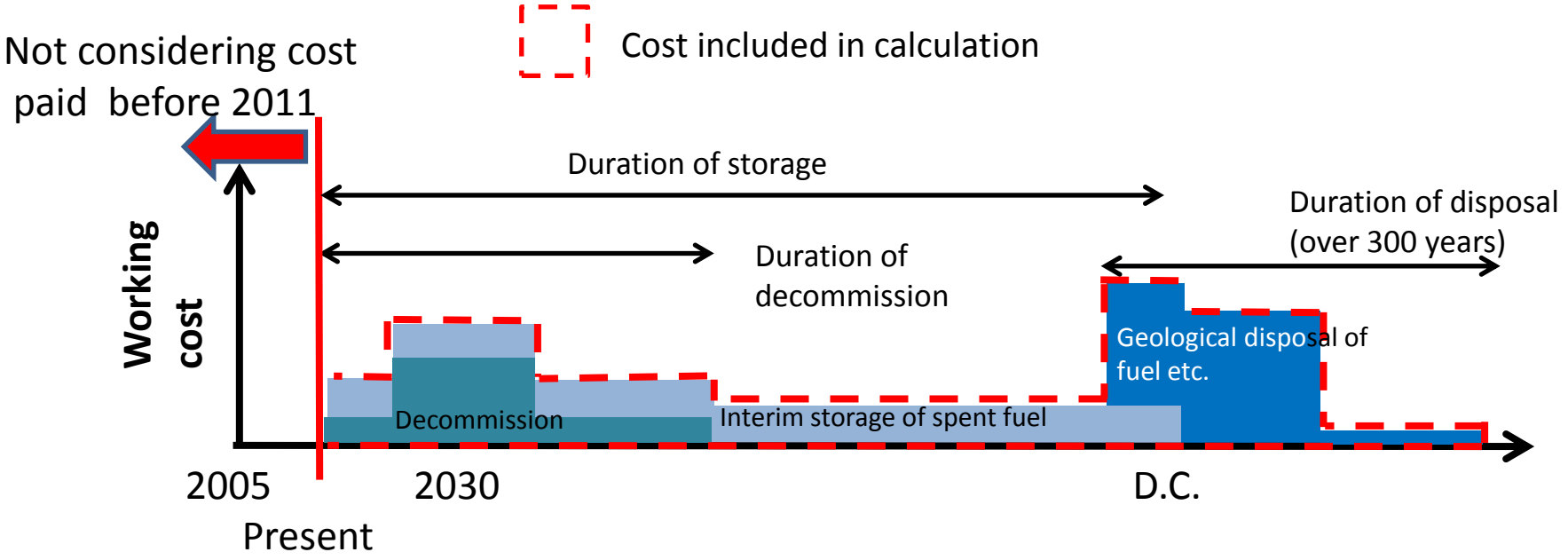
Fiscal allocation expanding total back-end cost for 32ktU spent fuel



Ref. : http://www.aec.go.jp/jicst/NC/tyoki/hatukaku/siryo/siryo15/siryo1-1.pdf
16 May 2012 Technical Subcommittee on Nuclear Power, Nuclear Fuel Cycle, etc., Material No. 1-1 (Japanese)

Method of Economic Analysis
-Schematic of Calculation (Total Direct Disposal)-

Fiscal allocation expanding total back-end cost for 32ktU spent fuel



Sum of cost to directly dispose spent fuel discharged from reactors until 2030 and cost to decommission Rokkasho Reprocessing Plant

(Assuming the decommission to be started from 2012)

Ref. : http://www.aec.go.jp/jicst/NC/tyoki/hatukaku/siryo/siryo15/siryo1-1.pdf
16 May 2012 Technical Subcommittee on Nuclear Power, Nuclear Fuel Cycle, etc., Material No. 1-1 (Japanese)

Economic Analysis of Fuel Cycle

-Total Estimated Costs-

Calculation of the total prospective cost:

RP construction + SF Reprocessing + Disposal of vitrified waste and/or SF + RP Decommission + etc. – Payment by 2011 – Depreciation for RRP

Unit: trillion yen Discount rate: 0 %	F.C. Option 1 Total reprocessing	F.C. Option 2 Coexistence of reprocessing/disposal		F.C. Option 3 Total disposal
		All interim-storage SF is reprocessed.	All interim-storage SF is directly disposed.	
Uranium fuel MOX fuel (Sum of front-end)	4.56 0.75 (5.31)	4.56 0.75 (5.31)	4.56 0.75 (5.31)	4.94 0.16 (5.10)
Reprocess etc. Interim Storage HLW disposal Direct disposal (Sum of back-end)	9.94 0.18 2.97 (13.1)	9.94 0.18 2.97 (13.1)	8.58 0.18 2.68 0.52～0.61 (12.0～12.0)	1.78 1.82 0.04 5.19～6.07 (8.83～9.71)
Total sum	18.4	18.4	17.3～17.4	13.9～14.8

Other cost would be added by amendment in previous commitments between Government and local governments.

Ref. : http://www.aec.go.jp/jicst/NC/tyoki/hatukaku/siryo/siryo15/siryo1-1.pdf
16 May 2012 Technical Subcommittee on Nuclear Power, Nuclear Fuel Cycle, etc., Material No. 1-1 (Japanese)

Economic Analysis of Fuel Cycle

-Total Estimated Costs -

Reference data in the case of discount rate: 3 %

Unit: trillion yen Discount rate: 3 %	F.C. Option 1 Total reprocessing	F.C. Option 2 Coexistence of reprocessing/disposal		F.C. Option 3 Total disposal
		All interim-storage SF is reprocessed.	All interim-storage SF is directly disposed.	
Uranium fuel MOX fuel (Sum of front-end)	3.57 0.57 （4.14）	3.57 0.57 （4.14）	3.57 0.57 （4.14）	3.85 0.14 (3.99)
Reprocess etc. Interim Storage HLW disposal Direct disposal (Sum of back-end)	4.45 0.08 0.88 (5.41)	4.45 0.08 0.88 (5.41)	4.22 0.07 0.86 0.08～0.09 (5.23～5.24)	1.19 1.11 0.02 1.19～1.36 (3.51～3.67)
Total sum	9.5	9.5	9.4	7.5～7.7

Other cost would be added by amendment in previous commitments between Government and local governments.

Ref. : http://www.aec.go.jp/jicst/NC/tyoki/hatukaku/siryo/siryo15/siryo1-1.pdf
16 May 2012 Technical Subcommittee on Nuclear Power, Nuclear Fuel Cycle, etc., Material No. 1-1 (Japanese)

Fuel Cycle Economics in Variation of Options (Summary)

～3 Fuel Cycle Options～	～4 Nuclear Share Options～
1. Total reprocessing	1. Nuclear share: 35 % (Installed capacity: 50 GW)
2. Mixed option	2. Nuclear share: 20 % (Installed capacity: 30 GW)
3. Total disposal	3. Nuclear share: 15 % (Installed capacity: 20 GW)
	4. Nuclear share: 0 %

○For all nuclear share option, **total expense of F.C. option 3 is less than the other F.C. options**.

○As for F.C. option 3, SF stored in Aomori pref. may have to be sent back and under the worst case, **nuclear power operation could be suspended if new SF storage capacity is not available**.

Total Expense of Fuel Cycle (Unit: trillion yen) <Discount rate: 0 %>

	F.C. Option 1 Total reprocessing	F.C. Option 2 Coexistence of reprocessing/disposal	F.C. Option 3 Total disposal
Nuclear Share Option I: 35 %	18.4	17.3～18.4	13.9～14.8
Nuclear Share Option II: 20 %	15.4	15.3～15.4	12.0～12.8
Nuclear Share Option III: 15 %	14.4	14.4	10.9～11.6
Nuclear Share Option IV: 0 %	—	—	8.1～8.7

Ref. : http://www.aec.go.jp/jicst/NC/tyoki/hatukaku/siryo/siryo15/index.htm
16 May 2012 Technical Subcommittee on Nuclear Power, Nuclear Fuel Cycle, etc., Material No. 1-1, No. 1-2, No. 1-3, No. 1-4 (Japanese)

Overall Assessment

- Total Reprocessing policy option:

  This might be the best option if nuclear power will be either maintained or expanded in the future. But the total economic cost could be the largest while social/political cost could be almost none.

- Mixed policy option:

  If nuclear power is declined or its future is uncertain, this option is the best, while social/political cost could be moderately high.

- Direct disposal policy option:

  If nuclear power will be phased out soon, this option is the best. The total cost is smallest while social/political costs could be largest.