Japan's Long-term Energy Demand and Supply Scenario to 2050

– Estimation for the Potential of Massive CO_2 Mitigation –

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Executive Summary

In this analysis, we projected Japan's energy demand/supply and energy-related CO_2 emissions to 2050. Our analysis of various scenarios indicated that Japan's CO_2 emissions in 2050 could be potentially reduced by 26-58% from the current level (FY 2005) (Figure 1). These results suggest that Japan could set a CO_2 emission reduction target for 2050 at between 30% and 60%. In order to reduce CO_2 emissions by 60% in 2050 from the present level, Japan will have to strongly promote energy conservation at the same pace as an annual rate of 1.9% after the oil crises (to cut primary energy demand per GDP (TPES／GDP) in 2050 by 60% from 2005) and expand the share of non-fossil energy sources in total primary energy supply in 2050 to 50% (to reduce CO_2 emissions per primary energy demand (CO_2／TPES) in 2050 by 40% from 2005). Concerning power generation mix in 2050, nuclear power will account for 60%, solar and other renewable energy sources for 20%, hydro power for 10% and fossil-fired generation for 10%, indicating substantial shift away from fossil fuel in electric power supply. Among the mitigation measures in the case of reducing CO_2 emissions by 60% in 2050, energy conservation will make the greatest contribution to the emission reduction, being followed by solar power, nuclear power and other renewable energy sources (Figure 2). In order to realize this massive CO_2 abatement, however, Japan will have to overcome technological and economic challenges including the large-scale deployment of nuclear power and renewable technologies.

Figure 1. Japan's CO_2 Emissions for 2050

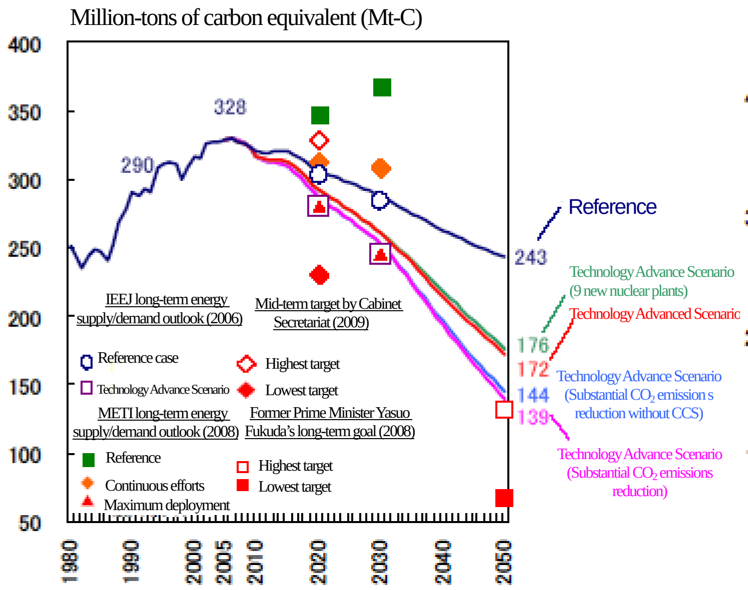
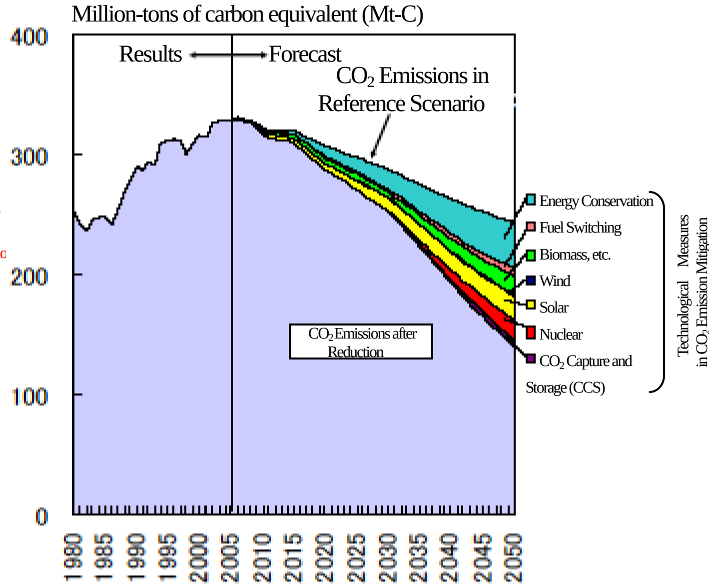


Figure 2. Contributions of each Technology to CO_2 Emission Mitigation
-- In the case of reducing CO_2 Emissions by 60% in 2050 from 2005 level--



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1. Introduction

As indicated by increasing energy demand mainly in Asia including China and India, growing resources nationalism in Middle East nations, Russia and other energy-producing countries, and international negotiations towards a post-Kyoto Protocol framework, the present international situation involving energy and global environment problems has dramatically changed. Under the situation, resources-poor Japan is required to develop a long-term energy strategy well-organized in regard to energy supply and demand toward energy security and the resolution of the global warming problem. Particularly, the development of an energy and environmental technology perspective may be important for addressing energy and environmental problems. By promoting the research, development and deployment of innovative technologies, Japan may make great contributions to energy conservation, energy efficiency improvements and CO_2 emission reductions. The nation may also contribute to its sustainable economic development including the improvement of Japanese industries' international competitiveness through exports of excellent energy technologies. Taking into account energy and environmental technologies that could diffuse through future research and development progress, this report provides an outline of Japan's energy demand and supply to 2050 and consistently analyzes the potentials of technology to stabilizing Japan's energy supply/demand and reducing CO_2 emissions.

2. Scenario Analysis Framework

Energy supply/demand forecasts change greatly depending on background factors including the domestic and foreign economic situations, the international energy situation and technology developments. As preconditions of these factors are likely to change greatly, multiple scenarios should be developed in forecasting energy supply and demand over a long time span until 2050. This analysis makes energy supply/demand forecasts for the reference scenario envisaging standard energy and environmental technology developments and for technology advance scenarios which assumes the further penetration of innovative technologies (Table 2-1).

● Reference Scenario

This scenario is a trend based on the present economic and social situations, and the current technology system as preconditions.

● Technology Advance Scenario

For the technology advance scenario, energy and environmental technologies under research and development or in the initial introduction stage are expected to be introduced more dramatically than assumed for the reference scenario.

● Technology Advance Scenario (Nine New Nuclear Plants)

If electric utilities' electricity sales decline on further progress in energy conservation and a depopulation, the feasibility of new nuclear power plant construction may grow more uncertain. This scenario is based on the assumption that 9 of the 13 nuclear plants planned for future construction under the nuclear power supply program will be actually constructed between 2005 and 2050.

● Technology Advance Scenario (Substantial CO_2 Emission Reduction)

This scenario takes into account an additional expansion of nuclear power plant, and CCS (carbon capture and storage) technology and some other technology developments in addition to those for the "technology advance scenario" (Table 2-1). The maximum introduction of nuclear power generation is assumed from the technological and economic viewpoints for electricity generation. This means that nuclear energy is assumed to account for 60% of total electricity generation in 2050 at maximum. Nuclear power generation capacity in 2050 comes online to 77.5 GW, with the capacity utilization rate planned at 80%. In order to achieve the capacity, Japan will have to construct about 21 new nuclear plants –

about eight in addition to the planned 13 under the national nuclear power development program. The substantial CO_2 emission reduction scenario thus envisages the construction of about nine new nuclear plants by 2030, as assumed for the reference scenario, and the other four under the program and about eight additional plants after the year. This scenario also takes the CCS systems into account. The CCS is assumed to be introduced for coal and LNG thermal power generation gradually in or after 2030. These systems are estimated to capture about 30% of CO_2 emissions on coal and LNG combustion for storage in stably isolated locations within Japan. Furthermore, renewable energy sources (excluding hydro and geothermal) are assumed to expand their share of electric utilities' power generation to 20%.

Table 2-1 Key Assumptions for Each Scenario

	Reference Scenario	Technology Advance Scenario	Technology Advance Scenario (Substantial CO_2 Reduction)
Introduction of highly efficient appliances	The present pace of introduction	Acceleration of the introduction pace, including the introduction of highly efficient lights (light emitting diode lights), highly efficient heat pumps (heat pump water heaters with the coefficient of performance at 6.0 and air conditioner heat pumps with the COP at 7.0), geothermal heat pumps, and BEMS	The same as for the technology advance scenario
Clean energy vehicles	About 22 million vehicles (almost all are hybrid vehicles) in 2050	About 45 million vehicles, including 25 million plug-in hybrids, 7 million electric vehicles and 6 million fuel cell vehicles	The same as for the technology advance scenario
Renewables	In 2050: Solar PV generation at 40 million kW, wind power generation at 5.6 million kW	In 2050: Solar PV generation at 100 million kW, wind power generation at 7 million kW	A further expansion of renewable energy power generation is added to the technology advance scenario assumptions.
Stationary fuel cells	300,000 kW in 2030	5 million kW in 2030	The same as for the technology advance scenario
Fossil-fired power generation	The present pace of power generation efficiency improvement	Further improvement of coal and LNG-fired power generation efficiency (introduction of the ultra-supercritical pressure power generation technology, and 1,700-degree-Celsius coal-IGCC and LNG-GTCC	The same as for the technology advance scenario
Nuclear power generation	Construction of 13 new plants between 2005 and 2050	The same as for the Reference scenario	Construction of about 21 new plants between 2005 and 2050
Carbon capture and storage	No consideration is given to the CCS.	No consideration is given to the CCS.	The CCS will be introduced from 2030; 30% of CO_2 emissions from coal and LNG thermal power plants is assumed to be captured.

(Note) For the "technology advance scenario (nine new nuclear plants)", the number of nuclear plants for construction between 2005 and 2050 is nine, changed from 13 for the "technology advance scenario". Other assumptions of the "technology advance scenario (nine new nuclear plants)" are the same as for the technology advance scenario.

According to the Institute of Applied Energy (Reference No. 11), Japan's underground CO_2 storage capacity for the CCS system totals 3.5 billion tons in terms of CO_2 for stable isolation. If possible leaks are additionally considered, the capacity expands to about 91.5 billion tons. As Japan's annual CO_2 emissions now total 1.3 billion tons, the stable isolation capacity is equivalent to emissions over 2.7 years. The capacity including possible leaks is equivalent to those over 70.4 years. In this analysis, we have assumed that the CCS system would be introduced for coal and LNG thermal power plants gradually from

2030. In our analysis, isolated CO_2 storage capacity is assumed at the stable category of 3.5 billion tons. For 2050, the CCS system is assumed to stably isolate about 30% of CO_2 emissions on coal and LNG combustion within Japan.

3. Key Assumptions

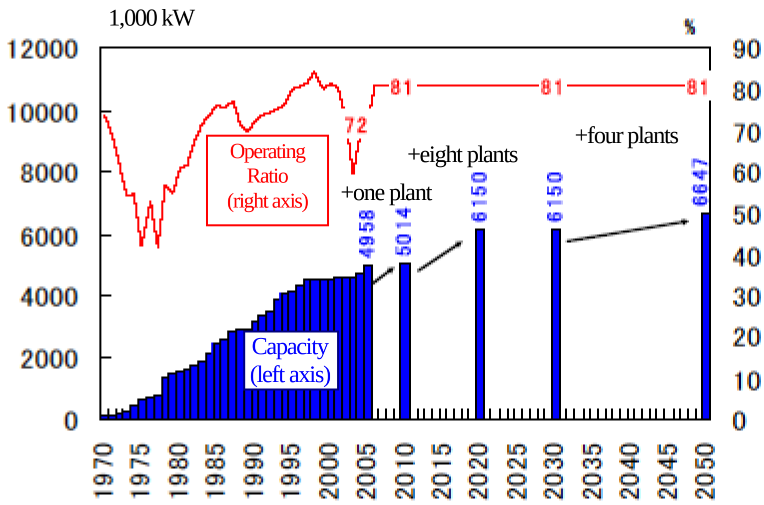
3-1 Economic Growth, etc.

Key assumptions including economic growth, population, crude oil prices, industrial materials production and the floor area of buildings follow References No. 8 and 9. Economic growth is assumed at 1.3% per year between 2005 and 2050. Population is assumed to decline from about 127.77 million in 2005 to 95.15 million in 2050. The imported crude oil price assumption is based on a U.S. Department of Energy estimate (a rise from about $53/bbl (the real price for U.S.-imported crude oil in 2006) for 2005 to about $78/bbl for 2050) (Reference No. 10). Technology assumptions, including improvements in the efficiency of various technologies and timings for the introduction of new technologies, are based on the energy technology roadmap (References No. 11 and 12) by the Institute of Applied Energy and "Cool Earth – Innovative Energy Technology Plan" (Reference No. 13) by the Ministry of Economy, Trade and Industry.

3-2 Nuclear Power Generation

The nuclear power generation outlook is based on the government's electricity supply plan (Reference No. 14) and its long-term energy supply/demand outlook (Reference No. 8). According to a nuclear power station development plan in the FY 2008 electricity supply plan, the government will construct 13 nuclear power plants (with a total capacity of 17.23 million kW). It also plans nine new nuclear plants (with a total capacity of about 12.26 million kW) to go on stream over the next decade. The government's long-term energy supply/demand outlook projects about nine nuclear plants to be built by 2030. The reference and technology advance scenarios for our analysis follow the outlook, projecting the construction of about nine plants by 2030 and the remaining four out of the planned 13 after 2030 (Figure 3-1).

Figure 3-1 Nuclear Power Generation Capacity (Reference Scenario)



Sources: Our projection based on the government's electricity supply plan, etc.

The government's long-term energy supply/demand outlook projects Japan Atomic Power Co.'s Tsuruga-1 nuclear plant (357,000 kW) to suspend commercial operations in FY 2010. Our scenarios have taken this projection into account. The other existing nuclear plants are projected to undergo aging management measures to avoid their suspension or termination. As a result, Japan's nuclear power generation capacity is estimated to increase from 49.58 million kW in 2005 to 66.47 million kW in 2050 for the reference and technology advance scenarios. The capacity utilization rate is assumed to remain at about 80% until 2050 for the reference and technology advance scenarios, although the rate is expected to rise on changes to the legal framework for regular checkups. But we must pay attention to the possibility that the rate's rise beyond the assumed level could result in changes in nuclear power generation.

In the technology advance scenario (substantial CO_2 emission reduction), the maximum introduction of nuclear power generation is assumed from the technological and economic viewpoints for electricity generation. This means that nuclear energy is assumed to account for 60% of total electricity generation in 2050. Nuclear power generation capacity in 2050 required for the assumption comes to about 77.5 million kW, with the capacity utilization rate planned at about 80%. In order to achieve the capacity, Japan will have to construct about 21 new nuclear plants – about eight in addition to the planned 13 under the nuclear power development program (one plant's capacity is assumed at 1.38 million kW, with the capacity utilization rate at about 80%). The substantial CO_2 emission reduction scenario thus envisages the construction of about nine new nuclear plants by 2030, as assumed for the reference scenario, and the other four under the program and about eight additional plants after the year.

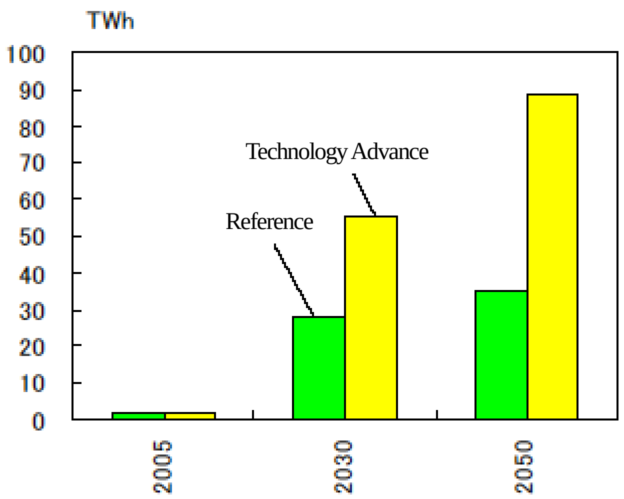
3-3 New Energy Sources

The introduction of new energy sources has been expanding for the enhancement of energy security and anti-warming measures. We have assumed that the introduction of solar photovoltaic and wind power generation will expand steadily on the improvement of power generation efficiency and other technological developments, and on manufacturing cost cuts backed by mass production.

Solar Photovoltaic Power Generation

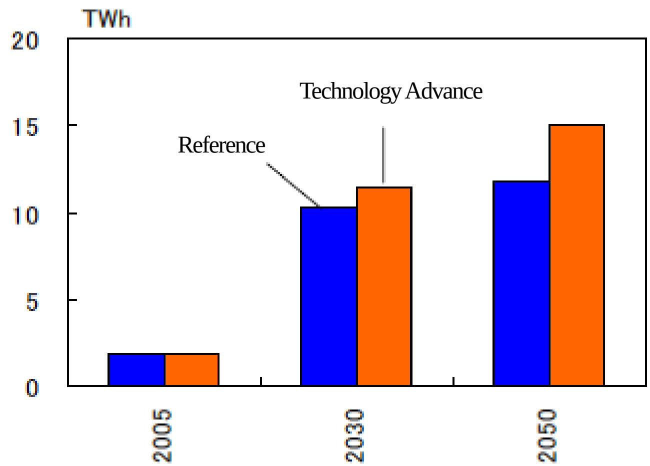
Japan's physically feasible solar photovoltaic power generation capacity using building roofs and the like is estimated at about 8 billion kW based on the present conversion efficiency levels (10-15%). The capacity translates into about 8 trillion kWh per year in electricity output, exceeding about 6 trillion kWh (530 million tons oil equivalent) in Japan's annual primary energy supply. Solar PV power generation is thus expected to cover Japan's domestic energy demand (Reference No. 11).

Figure 3-2 Solar PV Generation Assumption



Sources: Our assumption based on NEDO estimates

Figure 3-3 Wind Power Generation Assumption



Sources: Our assumption based on NEDO estimates

According to the New Energy and Industrial Technology Development Organization (NEDO), the maximum potential solar PV generation capacity using roofs and walls of residential and other buildings in the residential and commercial sectors is estimated at about 200 million kW (about 200 billion kWh in electricity output) (Reference No. 15). NEDO puts the target capacity for around 2030 at about 100 million kW (about 100 billion kWh in electricity output) for the case in which solar PV generation technologies will be developed and diffused smoothly. In this analysis, we have assumed solar PV generation in the residential and commercial sectors to increase from 1.5 billion kWh in 2005 to 2.8 billion kWh in 2030 and

35 billion kWh in 2050 for the reference scenario and to 55 billion kWh in 2030 and 89 billion kWh in 2050 for the technology advance scenario. Under the reference scenario, the sectors' solar PV generation capacity in 2050 would come to about 400 million kW, or one-fifth of the maximum potential capacity, with solar PV systems installed at most single-family houses. Under the technology advance scenario, solar PV systems would be installed at almost all houses and other buildings available for such installation. The sectors' capacity would be about 100 million kW, or about a half of the maximum potential capacity.

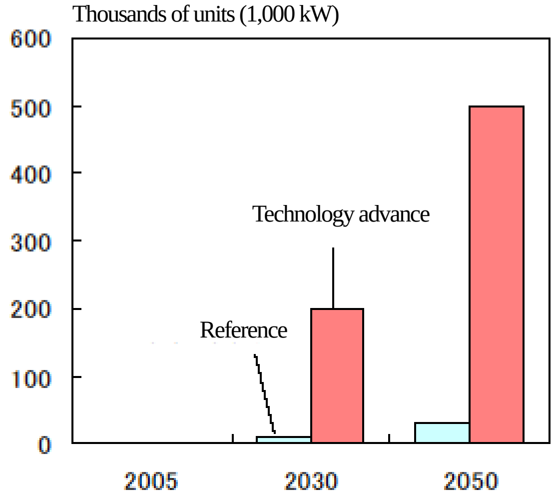
Wind Power

Japan's potential wind power generation capacity is estimated at 35 million kW on shore and 250 million kW off shore (Reference No. 11). Existing NEDO wind power generation capacity targets include 10 million kW for 2020 and 20 million kW for 2030. The 2030 target consists of 7 million kW in onshore capacity and 13 million kW in offshore capacity (Reference No. 16). If the capacity utilization rate were 24%, the 2030 NEDO target capacity would produce 42 billion kWh in electricity – 15 billion kWh on shore and 27 billion kWh off shore. In this analysis, we have assumed Japan's wind power generation to increase from 1.9 billion kWh in 2005 to about 12 billion kWh in 2050 for the reference scenario and 15 billion kWh in 2050 for the technology advance scenario. Wind power generation capacity in 2050 for the technology advance scenario is assumed to reach about 7 million kW. In the reference scenario, wind power generation capacity in 2050 is assumed at about 5.6 million kW. Japan's wind power generation facilities could be forced by typhoons and other natural disasters to suspend operations for a long time. Facilities will have to be installed in a manner to suit the natural environment. If floating wind power generation systems are developed and used widely, overall capacity may expand further on an increase in offshore capacity. Since wind power generation systems are connected to electricity grids, technological measures for grid connection may have to be taken in accordance with the capacity expansion.

Fuel Cells

The introduction of distributed generation sources is expected to help reduce investment in electricity transmission and distribution equipments by improving buildings' energy self-sufficiency rates, to contribute to CO_2 emission reductions by replacing large fossil fuel-based generation sources and to improve overall energy efficiency by allowing waste heat from power generation to be used for heating water. Polymer electrolyte fuel cell (PEFC) cogeneration systems are expected to diffuse widely in the residential sector if their costs are reduced further with their service lives extended. In the commercial sector, the improvement of efficiency for existing gas engine cogeneration systems is expected along with the development and introduction of molten carbonate fuel cell (MCFC) and solid oxide fuel cell (SOFC) cogeneration systems. For example, fuel cells with power generation efficiency of 30% and waste heat utilization efficiency of 40% may be supposed to meet all water heating demand in the residential sector. At present, the residential sector's water hearting demand stands at 17 million tons oil equivalent and its electricity demand at 19 Mtoe. If waste heat from fuel cells is used to cover all water heating demand, fuel required to meet water heating and electricity demand in the residential sector would total 58 Mtoe (=17/0.4+(19-17*0.3/0.4)) with power station thermal efficiency at 40%. If electricity purchases from utilities and boilers (with efficiency at 80%) were to meet the same water heating and electricity demand, fuel requirements would total 69 Mtoe (=17/0.8+19/0.4). Although these estimates could vary depending on preconditions and capacity utilization, the introduction of fuel cells to cover all water heating demand in the residential sector can be expected to reduce energy consumption by about 15% (=(69-58)/69), according to a simple calculation.

Figure 3-4 Assumption for Stationary Household Fuel Cell Systems



Under the reference scenario, Japan is expected to start the introduction of fixed household fuel cell systems in or after 2030 and install 300,000 units (about 300,000 kW) by 2050 (Figure 4-4). Under the technology advance scenario, the reduction of system prices and the extension of systems' service lives are expected to allow Japan to launch the introduction in or after 2020 and install 5 million units (about 5 million kW) by 2050.

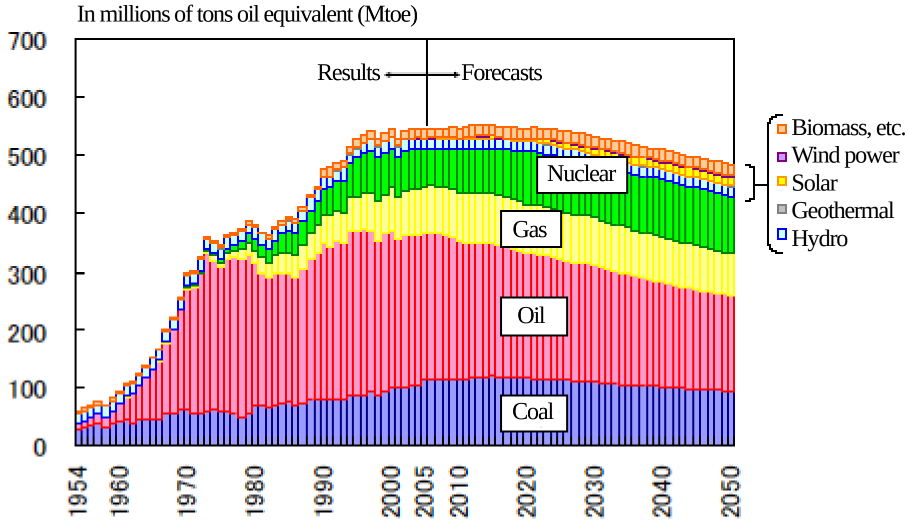
We have assumed the introduction of the E3 gasoline (with a 3% bioethanol content) under the reference scenario and that of the E10 gasoline under the technology advance scenario, considering potential exports from Brazil and other bioethanol producing countries. We have also assumed the introduction of diesel oil with a 5% biodiesel content under the technology advance scenario. Snow/ice heat and other untapped energy sources, though having great supply potentials, feature a lower energy density and, their conversion into energy and transportation infrastructure is estimated to require huge costs. Therefore, their large-scale introduction is not assumed for this analysis.

4. Estimation Results

4-1-1 Primary Energy Supply

Japan's primary energy supply (domestic primary energy supply) grew some 50% slower than the economy in the 1980s as energy conservation efforts made great progress in the wake of the oil crises. In the 1990s, however, primary energy supply per GDP decelerated a decline as the residential, commercial and transportation sectors expanded energy consumption on a lull in energy-saving efforts after the oil crises even amid an economic slump following the burst of the economic bubble. Since around 2000, however, primary energy supply growth has gradually slowed down as energy conservation efforts have been enhanced with interest growing in global environmental problems as well as energy security amid crude oil price spikes. Under the reference scenario, Japan's domestic primary energy supply will slowly decline toward FY 2050 amid sustainable economic growth, energy conservation measures on both the supply and demand sides, economic and industrial structure shifts, and a population decrease (Figure 4-1).

Figure 4-1 Primary Energy Demand (Reference Scenario)



Sources: Estimates by authors

In order to grasp background factors behind energy consumption, we have paid attention to primary energy supply per GDP, per capita GDP and population as factors behind the forecast primary energy supply trend (Table 4-1). The fall in primary energy supply per GDP was limited in the 1990s as energy consumption increased despite economic stagnation. But primary energy supply per GDP will improve toward 2050 at almost the same tempo as in the 1980s thanks to the introduction of energy conservation technologies. Per capita GDP will continue increasing, contributing to expanding primary energy supply. Meanwhile, a population decrease, along with the improvement in primary energy supply per GDP, will contribute to reducing primary energy supply toward 2050. Primary energy supply per GDP in 2050 will be nearly halved from 2005 (Table 4-2)

Table 4-1 Decomposition of Primary Energy Supply Growth (Reference Scenario)

(Unit: % per year)

		1980-1990	1990-2005	2005-2030	2030-2050	2005-2050
Overall change	(⊿TPES)	2.1	1.0	-0.1	-0.5	-0.3
	Primary energy supply per GDP (⊿TPES/GDP)	-1.8	-0.2	-1.7	-1.4	-1.6
	Per capita GDP (⊿GDP/POP)	3.4	1.0	2.1	1.9	2.0
	Population (⊿POP)	0.5	0.2	-0.4	-1.0	-0.7

Sources: Estimates by authors

Of primary energy supply, oil will decline on progress in energy conservation in the auto sector and its falling share of energy consumption in the residential, commercial, industrial and electricity generation sectors (Table 4-2). Demand has already been declining for oil that accounts for about 50% of primary energy supply. As the present trend continues, Japan's dependence on oil in 2030 may slip below 40%. Oil's share of primary energy supply is projected to decline substantially to 37% in 2030 and slip below 35% to 34% in 2050. Factors behind declining demand for oil include a shift from oil to electricity in the industrial, residential and commercial sectors, and a drop in demand for auto fuel. In the industrial sector, oil demand will decrease due particularly to a falling demand for oil for chemical materials. In the residential and commercial sectors, oil demand will decline on a shift to electricity for heating air and water. In the transportation sector, oil demand will shrink on a fall in automobiles in use and fuel efficiency improvements.

Table 4-2 Primary Energy Supply and CO_s Emissions (Reference Scenario)

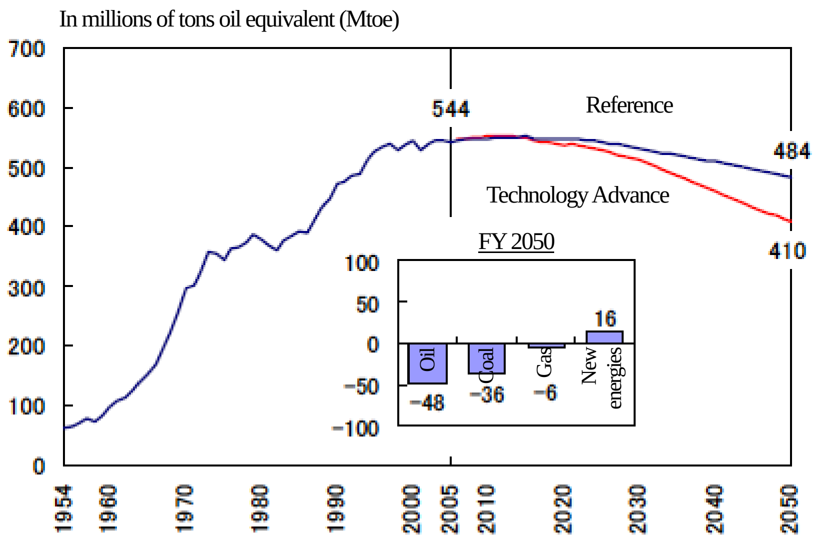
(Mtoe)	Results				Forecasts				Average annual growth (%)			
	FY 1990		FY 2005		FY 2030		FY 2050		2005/ 1990	2030/ 2005	2050/ 2030	2050/ 2005
		%		%		%		%				
Coal	80	17	114	21	110	18	95	20	2.3	-0.1	-0.7	-0.4
Oil	264	57	253	46	200	37	164	34	-0.3	-0.9	-1.0	-1.0
Natural gas	49	11	81	15	82	18	72	15	3.4	0.0	-0.6	-0.3
Nuclear	43	10	64	12	92	20	100	21	2.3	1.5	0.4	1.0
Hydro/geothermal	21	4	17	3	18	4	18	4	-1.5	0.2	0.0	0.1
Renewables	6	1	15	3	31	3	35	7	6.3	2.8	0.6	1.9
Primary energy supply	466	100	543	100	532	100	484	100	1.0	-0.1	-0.5	-0.3
Real GDP (tril. yen)	451		540		815		975		1.2	1.7	0.9	1.3
Primary energy supply per GDP (FY1990=100)	100		97		63		48		-0.2	-1.7	-1.4	-1.6
CO_s emissions (million tons carbon equivalent : Mt-C)	290		328		287		243		0.8	-0.5	-0.8	-0.7
(FY1990=100)	100		113		99		54					

Sources: Estimates by authors

Coal consumption will decline slowly toward 2050 due to a drop in coal thermal power generation, and improvements in the power generation efficiency and in the coke manufacturing efficiency in the industrial sector. In the industrial sector, coal consumption will gradually decrease on falls in steel and cement production. Consumption of coking coal mainly for steelmaking will drop on a decline in blast furnace steel production and energy conservation technology developments including the introduction of pulverized coal injection systems and next-generation coke ovens. Demand for steaming coal for power generation is expected to remain stable due to its stable supply and economic efficiency, although no substantial increase is likely under environmental measures. Therefore, coal's share of primary energy supply in FY 2050 will stand at some 20% close to the present level. Natural gas demand is expected to avoid any decline until 2030 as LNG thermal power generation increases on its convenience and environmental friendliness. From 2030 to 2050, however, natural gas demand will fall slowly because of improvements in LNG thermal power generation efficiency and electricity's rising share of final energy consumption. Natural gas's share of primary energy supply in 2050 will remain at the same level as 15% in 2005. Nuclear energy's share of primary energy supply will increase from 12% in 2005 to about 20% (21%) 2050 under the nuclear development program. The share for solar and other new energy sources will expand from 3% in FY 2005 to 7% in FY 2050. As a result, non-fossil energy sources (nuclear, hydraulic, geothermal and new energy sources) will expand their share of primary energy supply from about 20% (18%) in FY 2005 to about 30% (32%) in FY 2050. Primary energy supply will thus make a gradual shift away from carbon-based energy toward 2050.

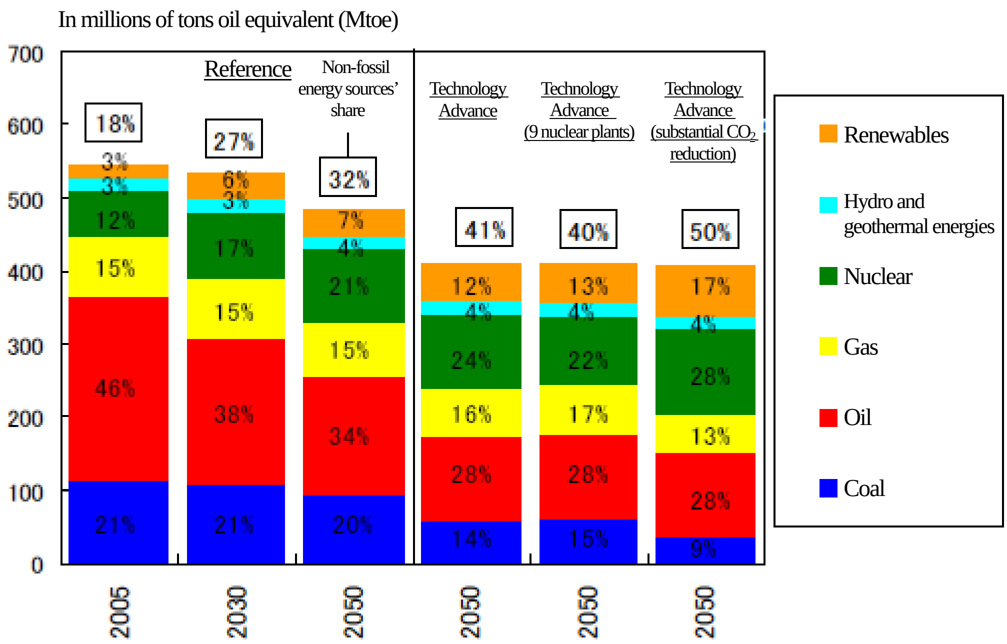
Under the technology advance scenario, primary energy supply will decline toward 2050 on energy conservation effects. In 2050, primary energy supply under the technology advance scenario will be 74 Mtoe less than under the reference scenario (Figure 4-2). The primary energy supply decline covers energy savings in electricity generation and other energy conversion sectors and exceeds a final energy consumption decline of 43 Mtoe as given later. Under the technology advance scenario, oil's share of energy consumption in 2050 will slip below 30% (Figure 4-3), with oil consumption declining 54% from 2005 to levels in the 1960s before the first oil crisis. Contributors to the substantial oil consumption decline will include the growing diffusion of clean energy vehicles such as plug-in hybrids, the introduction of biofuel and the industrial, residential and commercial sectors' further shift from oil to electricity and town gas. Coking coal consumption mainly for steelmaking will decrease on the diffusion of pulverized coal injection systems and next-generation coke ovens. Steaming coal consumption for electricity generation will also fall on improvements in the efficiency of coal thermal power plants. Natural gas consumption will drop on the improved efficiency of LNG thermal power plants and the diffusion of heat pump water heaters in the residential sector. The introduction of new energy sources including solar power will expand substantially. Under the reference scenario, non-fossil energy sources' share of energy supply will increase from about 20% (18%) in 2005 to about 30% (21% for nuclear and 11% for the others) in 2050. Under the technology advance scenario, however, non-fossil energy sources' share will reach about 40% (24% for nuclear and 16% for the others) on the further promotion of energy conservation and the expansion of new energy supply (Figure 4-3). Energy supply will thus make a further shift away from carbon-based energy.

Figure 4-2 Primary Energy Supply (Reference and Technology Advance Scenarios)



Sources: Estimates by authors

Figure 4-3 Primary Energy Supply by Scenario

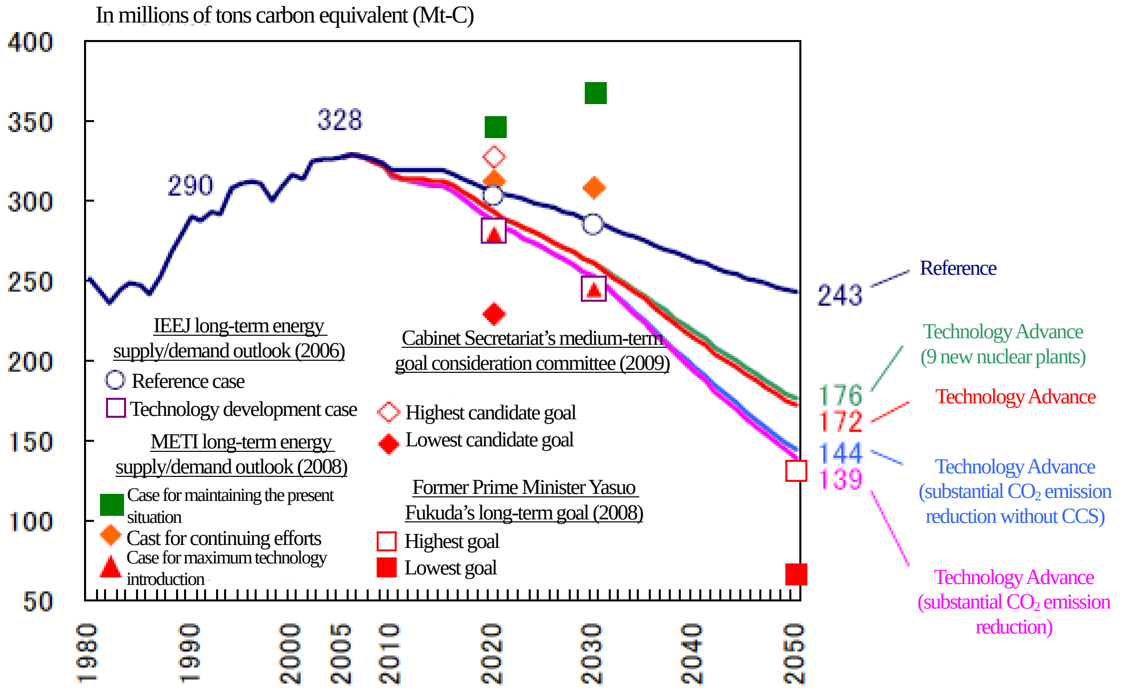


Source: Estimates by authors

4-1-2 CO_2 Emissions

Since 1990, energy-based CO_2 emissions have increased at almost the same pace as energy supply. Energy supply's shift away from carbon-based energy sources has so far made little progress. CO_2 emissions in FY 2005 totaled about 328 million tons carbon equivalent, up 13% from FY 1990. Under the reference scenario, CO_2 emissions in 2030 will decline to almost the same level as in 1990 and those in 2050 will decline by about 16% from FY 1990 (by about 26% from FY 2005) (Figure 4-4). Primary energy supply in 2030 will exceed the FY 1990 level, while non-fossil energy sources' share will expand from the FY 1990 level. As a result, CO_2 emissions in 2030 will be almost the same as in FY 1990. We have looked into three factors behind CO_2 emission changes -- CO_2 emissions (an indicator of primary energy supply's dependence on fossil fuels), primary energy supply per GDP (an indicator of energy conservation) and economic growth (Table 4-3). While the economy will grow at an annual pace of 1.3%, energy conservation will make steady progress after its stagnation in the 1990s. Energy conservation will work to reduce CO_2 emissions at an annual pace of 1.6% to more than offset the economic growth's impact on CO_2 emissions (Table 4-3). A shift away from carbon-based energy sources will work to reduce CO_2 emissions at an annual pace of 0.4%. Under the technology advance scenario, the energy conservation tempo toward 2050 will be 0.3 percentage point faster than under the reference scenario and the tempo of a shift away from carbon-based energy sources will be 0.4 point faster. The tempos of energy conservation and a shift away from carbon-based energy sources under the technology advance scenario will be almost equal to those just after the oil crises. The introduction of renewable energy sources and the shift away from carbon-based fuels under the technology advance scenario will have to make far greater progress than under the reference scenario.

Figure 4-4 CO_2 Emissions by Scenario



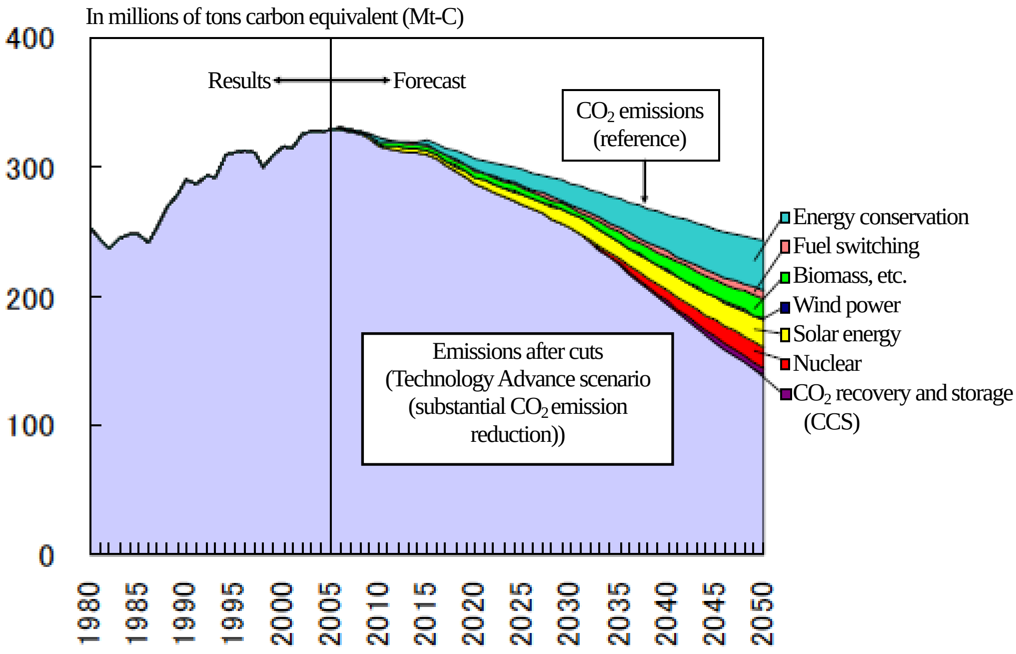
Sources: Estimates by authors

Note: The IEEJ outlook is from "Japan's Long-term Energy Supply/Demand Outlook through 2030 – Under Environmental Constraints and Changing Energy Markets," Institute of Energy Economics, Japan, 2006. The METI outlook is from Reference No. 8. The candidate goal of the medium-term goal consideration committee is from the seventh paper at the Cabinet Secretariat's panel on global warming in 2009. Former Prime Minister Yasuo Fukuda's goal is from his speech titled "In Pursuit of Japan as a Low-Carbon Society" in 2008.

Energy-based CO_2 emissions in 2050 under the technology advance scenario will be 71 Mtce less than under the reference scenario (Figure 4-4). From 2005, CO_2 emissions in 2050 will be cut by about 50% (about 48%) under the technology advance scenario. From 1990, emissions in 2050 will be reduced by about 40% (about 41%). Under the technology advance scenario (nine new nuclear plants) where the number of new nuclear plants is four fewer than under the regular technology advance scenario, CO_2 emissions will increase by 4 Mtce. Under the technology advance scenario (substantial CO_2 emission reduction), CO_2 emissions in 2050 will be cut by 60% (58%) from 2005. Even without CCS (carbon capture and storage) technology taken into account, the cut will be about 60% (56%). From 1990, emissions will be cut by about 50% (52%). Even without CCS technology taken into account, the cut will be about 50% (50%). Under the technology advance scenario (substantial CO_2 emission reduction), CO_2 capture and storage is assumed to start in 2030. In 2040, 10 million tons in CO_2 emissions (about 0.7% of Japan's annual present CO_2 emissions) will be captured from LNG and coal thermal power plants for storage. CCS operations will cover about 19 million tons in CO_2 (about 1.5%) in 2050. Accumulated storage will total 200 million tons in CO_2 in 2050, accounting for about 6% of Japan's existing stable CO_2 isolation capacity (3.5 billion tons).

Under the technology advance scenario (substantial CO_2 emission reduction), energy conservation will make the largest contribution to the CO_2 emission reduction, accounting for 37% of the cut (Figure 4-5), followed by 20% for solar energy, 16% for nuclear and 15% for biomass and other renewable energy sources. The fuel shift will account for 6% and CO_2 recovery and storage for 5%. Among the factors behind CO_2 emissions (Table 4-3), the tempo of energy conservation through 2050 under the technology advance scenario (substantial CO_2 emission reduction) will be 0.3 point faster than under the reference scenario and that of the shift away from carbon-based energy sources will be 0.9 point faster. The shift away from carbon-based energy sources will thus be unprecedentedly faster under the technology advance scenario (substantial CO_2 emission reduction). As a result, primary energy consumption per GDP in 2050 will be about 60% less than in 2005 under the technology advance scenario (substantial CO_2 emission reduction). CO_2 emissions per primary energy consumption in 2050 will be about 40% less than in 2005.

Figure 4-5 Technology-by-Technology Contributions to CO_2 Emission Reductions (Technology Advance scenario (substantial CO_2 emission reduction))



Sources: Estimates by authors

Table 4-3 Decomposition of Energy-based CO_2 Emission Changes (by scenario)

(Unit: % per year)

	1973-1990	1990-2005	2005-2050			
			Reference	Technology Advance	Technology Advance (nine new nuclear plants)	Technology Advance (substantial CO_2 emission reduction)
CO_s emission changes (⊿CO2)	0.9	0.8	-0.7	-1.4	-1.4	-1.9
Decarbonization (⊿CO2/TPES)	-0.7	-0.2	-0.4	-0.8	-0.8	-1.3
Energy conservation (⊿TPES/GDP)	-2.1	-0.2	-1.6	-1.9	-1.9	-1.9
Economic growth (⊿GDP)	3.8	1.2	1.3	1.3	1.3	1.3

Sources: Estimates by authors

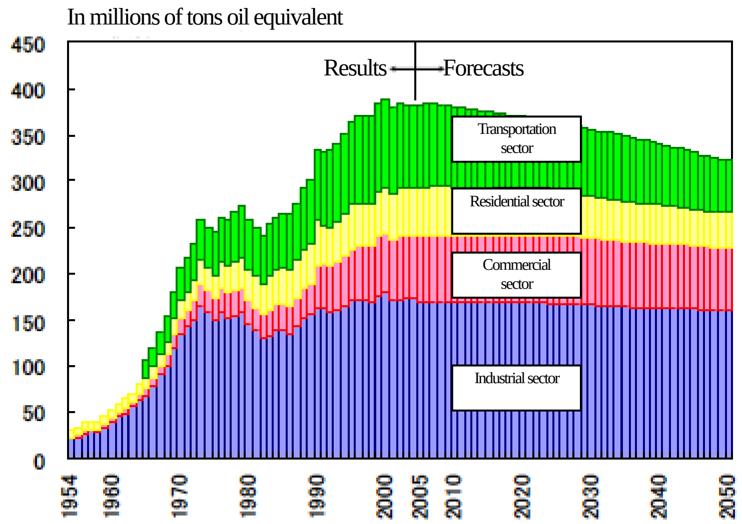
Many challenges may have to be overcome to realize the technology advance scenario and the substantial CO_2 emission reduction scenario. Technological and economic hurdles may be high for the two scenarios.

Under the substantial CO_2 emission reduction scenario, particularly, nuclear power plants will be introduced on a large scale to boost nuclear energy's share of primary energy supply to about 30%. Nuclear power will thus become as important as oil. In this respect, Japan will have to improve the nuclear energy resources utilization efficiency, reduce spent nuclear fuels and other radioactive wastes, secure safe management of plutonium, improve safety and reliability of nuclear power as the most important energy source and increase nuclear energy's economic efficiency for competing with other energy sources. The enhancement of nuclear energy's social acceptability through these efforts will become an even more important goal. As nuclear power is assumed to account for 60% of electricity generation, Japan will have to overcome technological and economic challenges including the development of load-following operation and large-scale electricity storage technologies. In this sense, the large-scale introduction of nuclear plants is still uncertain. As new energy sources are assumed to expand their share of primary energy supply and electricity generation to about 20%, measures will be required to promote the introduction of new energy sources. As capacity increases for solar PV, wind power, home fuel cell and other electricity generation systems whose power generation output is uncontrollable, measures will be required to address problems regarding the quality of electricity and the stabilization of grid networks. Measures to adjust voltage fluctuations at connections to grid networks and ease impacts on grid frequencies will become important.

4-1-3 Final Energy Consumption

Japan's final energy consumption began to increase substantially again around the 1990s as energy conservation measures ran their course. In the 1990s, final energy consumption expanded steadily on an increase in materials production supported by public investment and on a firm rise in the number of automobiles in use despite an economic slump. Since around 2000, however, final energy consumption growth has slowed down on enhanced energy conservation measures. In a long run to fiscal 2050, final energy consumption will decrease on a population decline, enhanced energy conservation measures and the services sector's growing presence in the economy (Figure 4-6).

Figure 4-6 Final Energy Consumption by Sector (Reference Scenario)



Sources: Estimates by authors

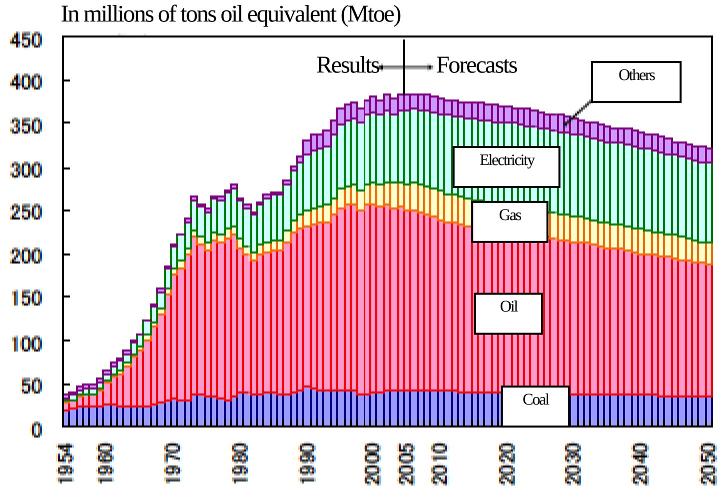
The industrial sector will reduce energy consumption slowly over a long term. The continuation of energy conservation efforts including a voluntary plan of action by the Japan Business Federation, known as Nippon Keidanren, will be coupled with the services sector's growing presence in the economy and rising added values to limit energy consumption growth. The industrial structure shift (the four industrial materials industries' falling share of energy consumption) and each industry's energy conservation progress will limit growth in the industrial sector's energy consumption. The residential and commercial sectors' energy consumption will be limited on improvements of electrical appliance efficiency under energy conservation standards, a decline in population or households and an end to growth in the total floor area of commercial buildings. While the commercial sector alone will continue to expand energy consumption, the residential and commercial sectors' combined energy consumption will turn down in 2010. The transportation sector's energy consumption will continue to fall throughout the projection period as fuel and transportation efficiency are improved amid slowing demand for transportation. The number of passenger cars in use will be capped on the market saturation and falling population. The number of trucks in use has turned down on the increased frequency of truck transportation since a peak in 1990 and will continue the present downward trend. The average mileage of passenger cars has been shortening on an increase in the number of drivers owning multiple vehicles. While trucks' average mileage has tended to lengthen on improvements in the capacity utilization rate, truck transportation demand is expected to level off on the services sector's growing presence in the economy.

Table 4-4 Final Energy Consumption (Reference Scenario)

Mtoe	Results				Forecasts				Average annual growth (%)			
	FY 1990		FY 2005		FY 2030		FY 2050		2005/ 1990	2030/ 2005	2050/ 2030	2050/ 2005
		%		%		%		%				
Industrial	161	48	168	44	166	48	159	50	0.3	0.0	-0.2	-0.1
Residential/commercial	97	29	124	32	114	30	104	32	1.7	-0.3	-0.4	-0.4
Residential	48	14	52	14	42	15	36	11	0.5	-0.9	-0.7	-0.8
Commercial	48	14	72	19	72	15	68	21	2.7	0.0	-0.3	-0.1
Transportation	77	23	91	24	74	22	57	18	1.1	-0.8	-1.3	-1.0
Final consumption	334	100	382	100	354	100	321	100	0.9	-0.3	-0.5	-0.4

Sources: Estimates by authors

Figure 4-7 Final Energy Consumption by Energy Source (Reference Scenario)

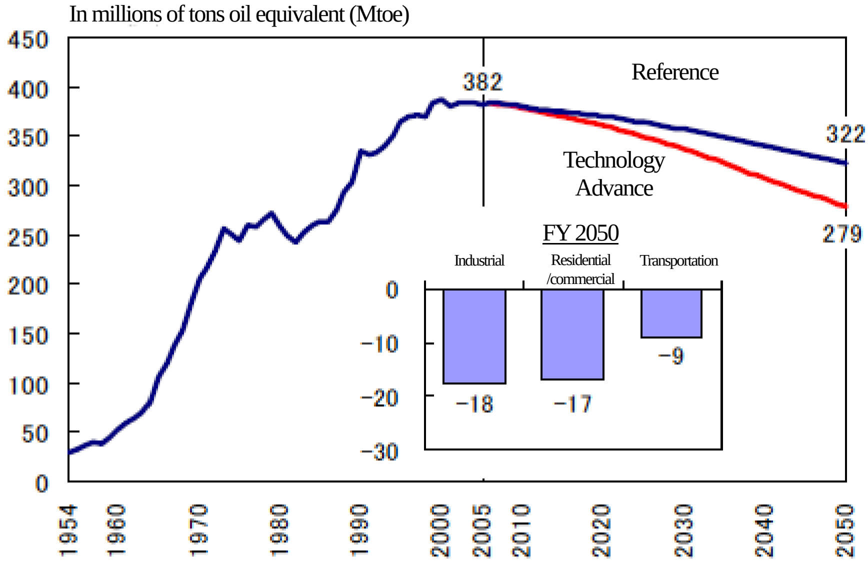


Sources: Estimates by authors

According to a breakdown of final energy consumption by energy source (Figure 4-7), oil consumption will continue to decline. The industrial sector's oil consumption will fall on a fuel shift and falling demand for materials for ethylene production. The residential and commercial sectors' oil consumption will decline on improvements in efficiency of heating and water-heating equipments and a shift to electricity. No major increase in oil consumption is thus expected. The oil consumption decline in the transportation sector is attributable to energy conservation by automobiles that now account for about 80% of energy consumption. Gasoline-electric hybrid vehicles, which have already been commercialized, are expected to diffuse as they have narrowed their price gaps with conventional gasoline-fueled autos. Including passenger cars, hybrid vehicles will make great contributions to energy conservation toward 2050. Biofuels (including bioethanol) have been globally introduced to secure stable energy supply and help prevent global warming. Japan has approved the introduction of the E3 gasoline (with a 3% bioethanol content). As the introduction expands in Japan, oil consumption will continue to decline. Electricity consumption will depend heavily on developments in the residential and commercial sectors. These sectors will growingly shift to electricity that is more convenient and safer as they increase their holdings of home appliances, information technology equipments and other electrical machines and as new electrical equipments diffuse. Given tougher energy conservation standards and measures, however, electricity consumption will slowly grow toward 2050.

Final energy consumption in 2050 under the technology advance scenario will be about 43 Mtoe less than under the reference scenario (Figure 4-8). The industrial sector will repair and improve existing production processes and introduce next-generation coke ovens and other new technologies to dramatically improve its energy efficiency toward 2050, consuming 18 Mtoe less energy than under the reference scenario. Energy consumption in the residential and commercial sectors will be 17 Mtoe less thanks to improvements in air conditioner efficiency, the diffusion and promotion of next-generation lights and the growing share for highly efficient heat pump water heaters. Consumption in the transportation sector will be 9 Mtoe less due to the diffusion of clean-energy vehicles. Under the technology advance scenario (substantial CO_2 emission reduction), nuclear energy's share of primary energy supply in 2050 will increase to about 30% (28%). New energy sources' share will expand to about 20% (17%) on their growing use for electricity generation. If hydraulic and geothermal energies (accounting for 4% of primary energy supply in 2050) are taken into account, non-fossil energy sources' share of primary energy supply in 2050 will reach about 50% (49%), indicating energy supply's further shift away from carbon-based energy sources. Even under the substantial CO_2 emission reduction scenario, however, fossil fuels will still account for about 50% of energy supply. As well as nuclear, oil will be the most important energy source accounting for about 30% (about 28%) of energy supply. Stable energy supply will remain a key energy policy challenge.

Figure 4-8 Final Energy Consumption (Reference and Technology Advance Scenarios)



Sources: Estimates by authors

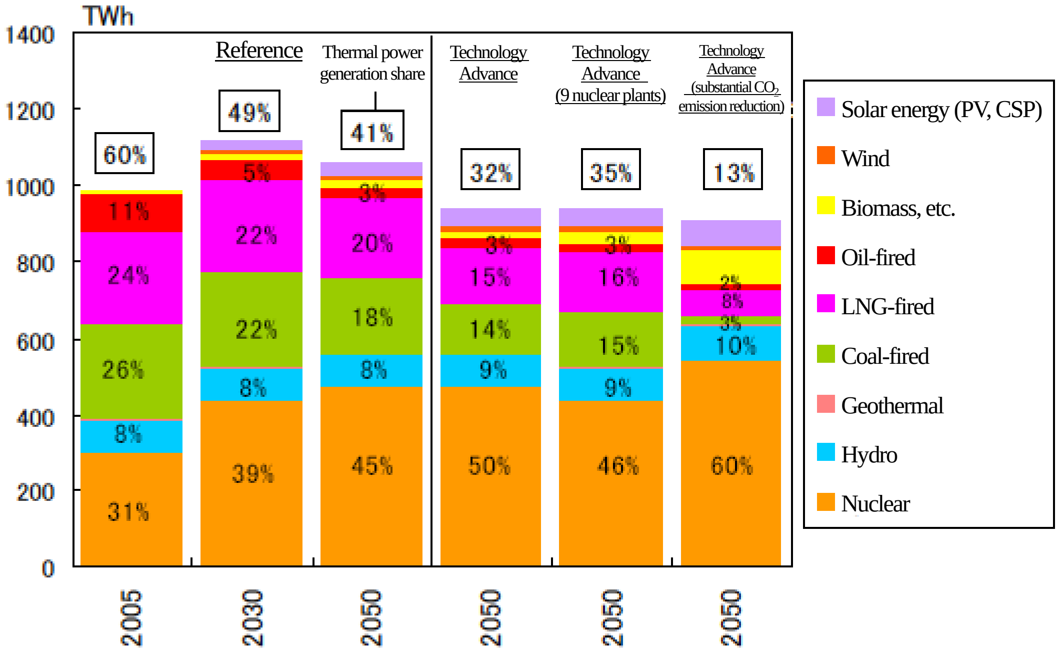
4-2 Technology Advance Scenario

4-2-1 Electricity Generation Mix (Utilities)

Over a long term through 2050, each consumption sector will growingly shift to electricity without growth in overall energy demand. Electricity demand will thus increase steadily. While improvements in the efficiency of electrical equipments will become a factor to reduce electricity demand, electrical products with greater convenience and added values, and industrial structure shifts (including the growing presence of the electrical machinery industry) will work as factors to more than offset the reduction and result in a net increase in electricity demand. In the industrial sector, electricity demand will increase, as much electricity is consumed on growing production of electrical machinery products. In the residential and commercial sectors, electricity demand will increase steadily on an increase in electrical and IT machines and on a shift from oil and gas to electricity, despite energy conservation that will make progress under energy conservation standards. In the residential and commercial sectors where air conditioning, power and lighting demand varies from season to season or from time to time, an increase in electricity demand may contribute to reducing the load factor. For this analysis, we have assumed that pumped storage generation and other existing supply/demand adjustment means will address the load factor change.

Under the reference scenario, electricity demand will increase at an annual rate of 0.2% against the backdrop of energy conservation for electrical equipments and a growing shift to electricity between 2005 and 2050. As about 13 new nuclear plants are constructed toward 2050, nuclear energy's share of total electricity generation will increase to about 40% in 2030 and to about 46% in 2050. Nuclear energy's importance for electricity supply will increase toward 2050 (Figure 4-9). As for hydroelectric generation, Japan has already developed most of its potential hydraulic energy resources. Given considerations to environmental conservation, we cannot expect any substantial increase in hydroelectric generation capacity. As nuclear power generation increases, the share for thermal power generation using fossil resources will shrink to about 50% (49%) in 2030 and to 41% in 2050. Coal thermal power generation, though with a greater environmental load than other thermal power generation means, will continue to serve as an important base-load electricity source because of its stable electricity supply and economic efficiency. LNG thermal power generation features less environmental load than other thermal power generation means and is indispensable for addressing the global environmental problem. LNG thermal power generation efficiency will increase on the introduction of 1,500-degree-Celsius combined cycle plants. Oil thermal power generation will continue to serve as an extra electricity source to address demand peaks or emergencies. But oil thermal power generation will gradually decline as LNG thermal power generation is growingly used for addressing demand peaks.

Figure 4-9 Power Generation Mix by Scenario (Breakdown of Generation)



Sources: Estimates by authors

Under the technology advance scenario, we have assumed the expansion of highly efficient electricity generation technologies and new energy sources. Nuclear energy's share of electricity generation will increase to 50% in 2050 as other electricity generation declines on consumers' energy conservation and their growing introduction of solar PV generation systems. The efficiency of coal thermal power generation will reach about 50% in 2050 on the introduction of ultra-supercritical pressure power generation, 1,700-degree-Celsius gas turbine IGCC (integrated gasification combined cycle) and other highly efficient generation technologies. The efficiency of LNG thermal power generation will rise to 55% toward 2050 on the introduction of 1,700-degree-Celsius combined cycle generation systems. Electric utilities will expand renewable energy power generation technologies including large-scale solar PV and concentrated solar power generation. As a result, the thermal power generation share will decline to about 30% (32%) in 2050. As non-fossil energy sources' share of electricity generation expands under the technology advance scenario, electricity supply's shift away from carbon-based energy sources will make a greater progress than under the reference scenario.

Under the technology advance scenario (nine new nuclear plants), nuclear energy's share of electricity generation in 2050 will be lower at 46%, almost the same as under the reference scenario. But the technology advance scenario (substantial CO_2 emission reduction) envisages the further promotion of nuclear energy and the expansion of new energy uses. Under the substantial CO_2 emission reduction scenario, nuclear energy's share of electricity generation in 2050 will expand to 60%. Renewable energy generation will increase to about 20% of total electricity generation, including solar PV, biomass and waste power generation technologies. As a result, thermal power generation's share will decline to about 10% (13%). Under this scenario, electricity generation using non-fossil fuels will account for the mainstream, making a greater progress in electricity supply's shift away from carbon-based energy sources.

5. Conclusion

Important for energy and environmental policies contributing to securing future stable energy supply and resolving the global warming problem will be the promotion of energy conservation at all energy consumption sectors, including industrial, residential, commercial, transportation and other final consumption sectors as well as electricity generation and other energy conversion sectors, the expansion of new energy technology introductions and the development of CO_2 capture and storage technology (Figure 5-1). Policy support will be indispensable for the proactive promotion of these measures. Expected to play key roles in these areas are energy efficiency standards and labeling (S&L) programs; tax, trading license, fee and other economic programs; the diffusion of energy and environmental education; and energy and environmental technology development support. Under the technology advance scenario (substantial CO_2 emission reduction), CO_2 emissions in 2050 will be cut by about 60% from the present level. Still, fossil fuels will account for about 50% of energy supply in the year. As well as nuclear energy, oil will be the most important energy source accounting for about 30% of energy supply. Therefore, Japan that depends wholly on foreign countries for fossil energy resources supply will have to secure stable energy supply through such measures as the enhancement of cooperative relations with energy resources producing countries. Regarding international energy supply/demand in 2050, China, India and other developing countries are expected to expand energy consumption substantially. Industrial countries' CO_2 emission cuts alone may fail to address global warming. Asian developing countries that are expected to increase CO_2 emissions fast will be required to cooperate with industrial nations in cutting emissions. Given that these developing countries have great potentials to introduce low-cost and feasible energy conservation technologies and reduce CO_2 emissions, Japan may reportedly be able to take advantage of the Clean Development Mechanism and other Kyoto mechanisms to substantially reduce costs for its energy conservation and CO_2 emission reduction (Reference No. 18). International energy cooperation including technology transfers may grow even more important. Japan's key challenge will be to proactively contribute to securing stable international energy supply and resolving the global warming problem through its international knowledge and know-how transfers, including energy conservation technology cooperation, S&L program development support and technological assistance for nuclear and solar PV power generation.

Figure 5-1 Energy Technologies and Policies of Long-term Importance

Best Mix of Energy and Environmental Policies

S&L (Energy Efficiency Standards and Labeling) Programs

Energy conservation standards (MEPS -- minimum energy performance standards, top-runner systems, etc.), insulation and fuel efficiency standards (CAFE -- corporate average fuel economy -- standards, feebate systems, etc.), LCFS (low carbon fuel standards), energy efficiency standards and labeling programs, etc.

Tax, Trading License, Fee and Other Economic Programs

Environmental taxes (carbon tax, etc.), Kyoto Mechanism (ET -- emission trading, CDM -- clean development mechanism, etc.), green electricity certification, RPS (renewable portfolio standards), carbon offset systems, energy conservation certification, subsidy and other support programs, feed-in tariff systems, electricity pricing programs (green electricity prices, decoupling, etc.), demand response programs, energy conservation rebate programs, ESCO (energy service company) programs, etc.

Others

Energy and environmental technology development support, diffusion of energy and environmental education, introduction of policy assessment methods (enactment of a Government Performance and Results Act, etc.), establishment of voluntary goals, etc.

Promoting Energy Conservation and Expanding Introduction of New Energies and Other Technologies to Reduce Carbon-based Energy Consumption

Industrial Sector

Promoting Three Rs
  Reduce, Reuse, Recycle
Using wastes and waste heat efficiently
Promoting inter-industry cooperation (mutual supply of energy and by-products)
Developing and introducing next-generation industrial furnaces/processes (SCOPE 21 next-generation coke ovens, etc.)

Residential/Commercial Sectors

Energy conservation for buildings
  Enhanced insulation and airproofing to reduce air-conditioning demand
  Introducing passive buildings (using sunlight and natural ventilation)
  Introducing net zero energy buildings
Increased efficiency and more efficient operation of energy-consuming equipments
  Expanding introduction of energy-saving electrical home appliances
  Increasing efficiency of heat pumps (air conditioners and water heaters)
  Increasing efficiency of lights (light emitting diode systems, etc.)
  Increasing efficiency of information equipments (servers, personal computers, etc.)
  Promoting diffusion of energy management (building energy management systems, etc.) and smart meters

Transportation Sector

Expanding diffusion of clean energy vehicles
Diversifying fuels (biofuels, hydrogen, etc.)
Promoting modal shifts (expanding advanced public transportation systems, etc.), car sharing/pooling, and intelligent transportation systems (ITS)

Electricity Sector

Promoting nuclear use
  Advanced operations of light-water reactors, development of next-generation reactors, development of radioactive waste disposal technologies, securement of safe operations
Developing next-generation electricity generation technologies (coal IGCC, highly efficient natural gas power generation)
Developing CO2 recovery and storage technologies
Developing highly efficient electricity distribution equipments (ultra-high voltage transmission lines, superconductive transmission lines, etc.)

New Energy Sources

Developing and introducing solar PV generation, solar thermal power generation, fuel cells, etc.
Developing technology to connect massive distributed power sources
  Developing and introducing electricity storage (storage batteries, etc.)
  Voltage, frequency, current and other controls to stabilize grid networks, smart grid systems
Using untapped energy sources (geo-heat, etc.), biomass and waste energy
Developing fuel liquefaction technologies (GTL, CTL, BTL, etc.)
Developing hydrogen production and storage technologies

Securing Stable Energy Supply

Enhancing cooperative relations with energy resources producing countries (Middle Eastern countries, Russia, etc.)
Diversifying energy resources import sources (Sakhalin, Canada, etc.)
Promoting joint resources development and procurement
Enhancement of oil/gas reserve expansion and other emergency schemes
Utilizing unconventional oil resources (extra-heavy oil, methane hydrate)
Securing safety on sea lanes (Malacca-Singapore Straits, etc.)

International Energy and Environmental Technology Cooperation

Energy conservation technology cooperation (steelmaking, cement and other areas)
Supporting construction of S&L (energy efficiency standards and labeling) programs
Supporting development of technologies for nuclear, solar PV and other new energy sources, and for more efficient coal/natural gas thermal power generation

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