Natural Gas in Japan's Post-Fukushima Energy System and its CO_2 Emissions Reduction Potential

Tomohito Okamura [a], Kaoru Kawamoto [a], Yumi Yoshida [b], Michinobu Furukawa [c], Hiromichi Kameyama [c] and Yasuhiko Urabe [d]

[a] Osaka Gas Co.,Ltd, Information & Communication Systems Dept.
[b] Osaka Gas Co.,Ltd, Technology Planning Dept.
[c] Tokyo Gas Co.,Ltd, Fundamental Technology Dept., Technology Research Institute
[d] Tokyo Gas Co.,Ltd, Technology Planning Dept.

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1. Background

The government of Japan had set an aggressive greenhouse gas emissions reduction target (a 15-25% decrease from the 1990 level in 2020) to address global warming prior to the occurrence of the March 2011 Great East Japan Earthquake. The promotion of nuclear power generation was one of the main policies toward achieving that goal. With the radiation leakage from the Fukushima Daiichi Nuclear Power Station following the earthquake disaster, however, major revisions are expected to Japan's nuclear power policies. Plans for the construction of new and replacement nuclear power facilities may be delayed or cancelled, and the operation of aged nuclear power plants may be suspended.

If the production of electricity from nuclear power declines, then thermal power generation will have to be increased as a substitute. That will increase CO_2 emissions. If Japan simply continues following present policies as they are, the CO_2 emissions will greatly surpass the target, so the government is presently examining policies to restrict the increase in CO_2 emissions.

2. Purpose

The purpose of this paper is to quantitatively evaluate the extent to which further promotion of the use of natural gas toward 2020 can offset the increase in CO_2 emissions from the suspension of nuclear power plant operations. Specifically, the paper evaluates the three policies of natural gas cogeneration (including the spread of SOFCs [solid oxide fuel cells] in the household and business sectors), fuel conversion from oil to natural gas, and the effective use of natural gas in vehicles.

3. Methodology

The estimate was conducted using the following five steps.

Step 1: Estimate present energy demand and CO_2 emissions in fiscal 2005
Energy consumption of each type of energy for the commercial and household sectors was divided into each uses (e.g. heating, cooking, hot-water supply, electricity etc); by industry, use and each type of energy for the industrial sector; and by use of energy and type of vehicle for the transportation sector.

The fiscal 2005 energy consumption estimation methods for the industrial, commercial, household and transportation sectors were as follows.

A. Industrial Sector
The IEEJ Energy Balance Tables[1)] were used for the actual energy consumption by industry, categorized into the eight industries foods, fiber, paper and pulp, chemicals, ceramics, metals (ferrous and non-ferrous), machinery, and others. Amounts consumed for use as raw

materials were subtracted from the actual consumption figures by type of energy. The actual consumption by type of fuel was assumed to be energy consumption for heating use, and the actual electric power consumption was assumed to be energy consumption for power supply use.

Turning next to electric power consumption from independent power generation, the energy balance tables only note the total amount of electric power consumption from independent power generation. So "Yearbook of the current survey of energy consumption" [2] was used to estimate independent power generation by industry by type of power source, and the power generated (from the energy balance tables) was proportionately allocated to estimate the electric power consumption by type of power generation.

In calculating the CO_2 emissions from energy consumption, the calculation of CO_2 emissions from fuel consumption was calculated multiplying the fuel consumption for each type of fuel by the assumed calorific value [3] and by the CO_2 emissions per unit per calorie [3].

The CO_2 emissions from electric power consumption were calculated, for power purchased from electricity utilities, by multiplying the amount of electricity purchased by 0.423 kg-CO_2/kWh, which is the average CO_2 emissions per unit energy for all power sources used by Japanese electricity utilities in fiscal 2005. For electricity consumed from independent power generation, the CO_2 emissions from burning fuel were calculated in a similar manner, assuming electric power generation efficiency of 35% and estimating the fuel consumption volumes.

The means of estimating the CO_2 emissions from the volume of energy consumed in the commercial and household sectors, below, were exactly the same as that used for the industrial sector.

B. Commercial Sector
As with the industrial sector, The IEEJ energy balance tables [1] were used for the actual energy consumption of the commercial sector. The consumption by type of energy arranged according to the industries was estimated using commercial sector energy consumption data by type of energy arranged according to the industries per unit floor space in the Handbook of Energy & Economic Statistics in JAPAN [4]

C. Household Sector
As with the industrial and commercial sectors, The IEEJ energy balance tables [1] were used for the actual energy consumption of the household sector. The consumption by type of energy by applications was estimated using household sector energy consumption data by type of energy by applications per household in the Handbook of Energy & Economic Statistics [5].

D. Transport Sector
The actual energy consumption of the transport sector was calculated based on materials presented in the middle- to long-term roadmap of the Ministry of the Environment Central Environmental Council [6], and multiplied by the energy consumption and CO_2 emissions by use and by type of vehicle.

Step 2: Estimate the energy demand and CO_2 emissions through 2020 for the BAU case
The energy demand was estimated for the BAU case which assumes no greenhouse gas reduction policies are implemented. The basic estimation method for all sectors was to multiply the fiscal 2005 energy consumption per unit by the projected fiscal 2020 sector activities value.

Specifically, the fiscal 2020 energy demand for each sector was calculated using the following equation.

Fiscal 2020 energy demand by type of energy for each sector = Base year (fiscal 2005) total energy consumption × activity growth × energy consumption per unit × type of energy share

The assumed values for the activity growth through fiscal 2020 in each sector adopt the macro framework in the Central Environmental Council middle- to long-term roadmap[7]. Specifically, the growth from fiscal 2005 in the production volume of each industry for the industrial sector, in total floor space for the commercial sector, in the number of households for the household sector, and in the distance traveled or the volume carried in the transportation sector are reflected in the fiscal 2005 total energy consumption.

Table : The amount of activity in each sector

				2005	2007	2010	2020
Industrial Sector	amount of material production	crude steel	million ton	112.72	121.51	119.07	119.66
		ethylene	million ton	7.55	7.56	7.16	7.06
		cement	million ton	73.93	70.60	68.61	66.99
		paper	million ton	31.07	31.42	31.28	32.44
	Indices of Industrial Production	food industry		99.5	100.0		87.2
		chemistry		99.5	103.5		116.6
		nonferrous metal		100.7	105.0		103.3
		machinery industry		101.5	112.5		136.2
		others		100.0	104.3		94.0
Household Sector	the number of households		million	50.38	51.71	52.86	53.57
Commercial Sector	floor space		million m^2	17.59	17.94	18.42	19.32
Transport Sector	vehicles	passenger	million traveler km	526,788	-	521,113	519,000
		cargo		242,091	-	240,755	237,000
	others	passenger	million man-km	478,495	-	501,697	548,100
		cargo	million t-km	235,465	-	225,110	204,400

Next, as for the energy consumption per unit, for commercial sector power supply and household sector consumer appliances, the increase from fiscal 2005 was estimated with reference to the materials presented in the Central Environmental Council middle- to long-term roadmap[7]. A fixed energy consumption per unit was assumed for other energy consumption from fiscal 2005.

As for the shares for each type of energy, the fiscal 2007 shares were adopted as the most recent shares. Fiscal 2008 and fiscal 2009 data could also have been used for the type of energy shares, but the fiscal 2007 shares were adopted as the most recent data since changes in energy consumption trends because of the global financial crisis were confirmed in the fiscal 2008 and fiscal 2009 data.

The fiscal 2020 CO_2 emissions from energy consumption were calculated using the same method as the fiscal 2005 calculation. On the other hand, for the CO_2 emissions from the consumption of electric power purchased from electricity utilities, the calculation must be conducted using the fiscal 2020 BAU case electric power CO_2 emissions per unit. The analysis here adopts 0.34 kg-CO_2/kWh as the using the fiscal 2020 BAU case electric power CO_2 emissions per unit based on the "Environment Action Plan for Electric Power Companies" [8] published by the Federation of Electric Power Companies of Japan in September 2010, prior to the Great East Japan Earthquake.

Step 3: Estimate the energy demand and CO_2 emissions assuming greenhouse gas measures are implemented

The energy demand and CO_2 emissions in 2020 were estimated assuming that the greenhouse gas reduction policies drafted by the Democratic Party of Japan administration through December 2010 are implemented.

The methods of calculating the energy demand in each sector assuming the greenhouse gas reduction policies implementation were as follows.

A. Industrial Sector

We took the BAU case energy consumption estimated in Step 2 and implemented a) changes in the energy consumption per unit (improved energy consumption efficiency), b) introduction of the maximum possible greenhouse gas reduction policies, and c) changes in type of energy shares (reflecting the effects of fuel conversions).

a) The changes in the energy consumption per unit from fiscal 2005 to fiscal 2010 reflect the improvements in energy consumption efficiency under the targets of the Federation of Economic Organizations Voluntary Action Plan[9] .

b) The introduction of the maximum possible greenhouse gas reduction policies was assumed based on the materials submitted by the Institute of Energy Economics, Japan in 2009[10] for consideration by the Medium Targets Examination Committee

Table : Measures for the Reduction of Greenhouse Gas Emissions in Steel Industry

measures	the amount of energy saving [million kl-oil/year]
Introduction of SCOPE21(Super Coke Oven for Productivity and Environmental enhancement toward the 21st century)	0.30
Improvement in private electric generator efficiency	0.42
Enhancement of energy saving facility	0.51
Promote recycling of waste plastic	0.47
Improvement in electirical facility efficiency	0.12

Table : Measures for the Reduction of Greenhouse Gas Emissions in Cement Industry

measures	the amount of energy saving [million kl-oil/year]
Introduction of energy saving facility	5.2
Promote recycling of waste plastic (for clinker production)	6.2

Table : Measures for the Reduction of Greenhouse Gas Emissions in Chemical Industry

measures	the amount of energy saving [million kl-oil/year]
Introduction of gas turbine	14.4
Improvement in CHP	39.7
Introduction of low-temperature waste heat recovery system	12.9
Introduction of HIDic (Heat Integrated Distillation Column)	19.5
Introduction of catalytic cracking of naphtha	8.8
Promotion of propylene generated from biomass	21.9
Low-Energy Distillation-Membrane Separation Process	35.6
Development of high efficiency CHP	15.9

Table : Measures for the Reduction of Greenhouse Gas Emissions in Papermaking Industry

measures	the amount of energy saving [million kl-oil/year]
Introduction of high efficiency hydrapulpter	5.8
high temperature and pressure type black liquor recovery boiler	8.7
Promote recycling of scrap wood	36

c) The changes in type of energy shares reflect the effects of fuel conversions from fiscal 2005.

B. Commercial Sector

We took the BAU case energy consumption estimated in Step 2 and subtracted the energy conservation case based on the materials presented in the Central Environmental Council middle- to long-term roadmap[6)]. The energy conservation effect calculation method reflects the stock energy efficiency improvement by type of use or is implemented estimating the effect from newly introduced equipment (commercial-use hot water heaters, photovoltaic power generation, BEMS, etc.). The specific contents of the energy conservation effect are as follows.

Table : Improvement of efficiency of air conditioning in commercial sector (stock efficiency)

Item		2005	2020	
			BAU Case	Promotion of energy saving
Cooling	Central electric cooling	4.5	4.5	5.31
	Single packaged electronic cooling	3.04	3.04	4.14
	Absorption cooling	1.2	1.2	1.32
	Gas/Oil heat pump	1.2	1.2	1.29
Heating	Central electric heating	3.0	3.0	3.54
	Single packaged electronic heating	2.03	2.03	2.76
	Absorption heating	0.8	0.8	0.8
	Gas/Oil heat pump	1.2	1.2	1.29
	Boiler	0.8	0.8	0.85

Table : Improvement of efficiency of hot water supply in commercial sector (stock efficiency)

Item	2005	2020	
		BAU Case	Promotion of energy saving
Heat pump water heater	-	0	3.1
latent heat recovery type hot water	-	0	103

Table : Introduction amount of hot water supply in commercial sector (stock capacity)[million kW]

Item	2005	2020	
		BAU Case	Promotion of energy saving
Heat pump water heater	2.4	2.4	3.15
latent heat recovery type hot water	0.95	0.95	0.95

Table : Improvement of efficiency of lighting facility in commercial sector (stock efficiency)

Item	2005	2020	
		BAU Case	Promotion of energy saving
incandescent luminary	0.16	0.16	0.16
fluorescent light	0.9	0.9	1.5

Table : Improvement of efficiency of power instrument in commercial sector (stock efficiency)
The efficiency in 2005 was set to 100.

Item	2005	2020	
		BAU Case	Promotion of energy saving
Average efficiency	100	100	126

Table : Ratio of introduction of BEMS(Building energy management system)

2005	2020	
	BAU Case	Promotion of energy saving
0%	0%	30%

The energy saving ration by introducing BEMS
Air conditioning : 12.5%, Hot water supply : 7.5%, Lighting : 33%, other : 10%

Table : Introduction amount of photovoltaic power system in commercial sector (stock capacity)[million kW]

2005	2020	
	BAU Case	Promotion of energy saving
0.3	1.0	18.5

C. Household Sector

As with the commercial sector, we took the BAU case energy consumption estimated in Step 2 and subtracted the energy conservation case based on the materials presented in the Central Environmental Council middle- to long-term roadmap[6]. The specific contents of the energy conservation effect were as follows.

Table : Improvement of efficiency of air conditioning in household sector (stock efficiency)

項目	2005	2020	
		BAU Case	Promotion of energy saving
Air conditioning (cooling)	3.68	4.74	6.15
Air conditioning (heating)	2.74	3.34	4.27
Combustion-based heating	0.95	0.95	0.95

Table : Improvement of efficiency of hot water supply in household sector (stock efficiency)

Item	2005	2020	
		BAU Case	Promotion of energy saving
Heat pump water heater	2.4	2.7	3.2
latent heat recovery type hot water	0.95	0.95	0.95
Fuel cell			
power generation efficiency	32%	32%	32%
the ratio of waste heat recovery	38%	38%	38%

Table : Introduction demand of hot water supply in household sector (stock capacity)[PJ/year]

項目	2005	2020	
		BAU Case	Promotion of energy saving
Air conditioning (cooling)	5	25	114
Air conditioning (heating)	3	15	162
Fuel cell	0	0	10

Table : Improvement of efficiency of lighting facility in household sector
(stock efficiency)

項目	2005	2020	
		BAU Case	Promotion of energy saving
Air conditioning (cooling)	5	25	114
Air conditioning (heating)	3	15	162
Fuel cell	0	0	10

Table : Improvement of home electrical appliance efficiency
(stock efficiency)
The efficiency in 2005 was set to 100.

Item	2005	2020	
		BAU Case	Promotion of energy saving
Average efficiency	100	107	126

Table : Ratio of introduction of measurement control system

2005	2020	
	BAU Case	Promotion of energy saving
0%	0%	30%

The energy saving ration by introducing measurement control system
Air conditioning : 5%, Lighting : 5%, home electrical appliance : 5%

Table : Introduction amount of photovoltaic power system in household sector
(stock capacity)[million kW]

2005	2020	
	BAU Case	Promotion of energy saving
1.14	1.19	16.5

D. Transport Sector

The calculations were based on materials presented in the middle- to long-term roadmap of the Ministry of the Environment Central Environmental Council[6], considering the effects from fuel efficiency improvements in conventional vehicles, the effects from the introduction of next-generation vehicles such as fuel cell vehicles, hybrids and electric cars, and the effects from modal shift, the use of public transport

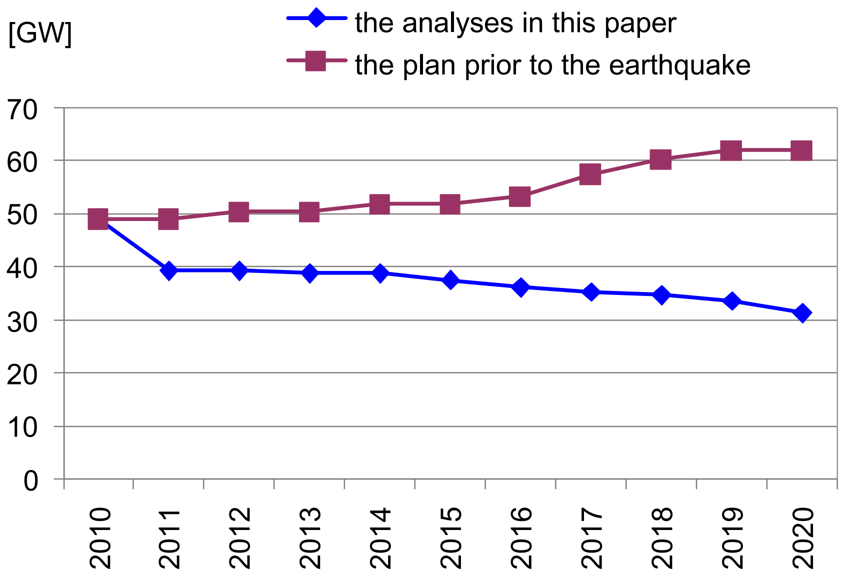
Next, we calculate the CO_2 emissions from the consumption of electric power purchased from electricity utilities in accordance with the following method.

1) Calculate the difference between the purchased electric power consumption for each sector for each use under the BAU case and when the greenhouse gas reduction policies are implemented.
2) Calculate the change in CO_2 emissions from the consumption of electric power purchased from electricity utilities by multiplying the quantity calculated in 1) by 0.6kg-CO_2/kWh, the average CO_2 emissions per unit from thermal power generation (which is likely to be used to meet changes in demand considering Japan's present electric power supply), when the greenhouse gas reduction policies are implemented.
3) Subtract the changes in CO_2 emissions calculated in 2) from the CO_2 emissions from the consumption of electric power purchased from electricity utilities under the BAU case.

Step 4: Estimate the CO_2 emissions after suspension of nuclear power plant operations
Based on Step 3, the CO_2 emissions were estimated for the case where nuclear power plant operations are suspended and thermal power generation is increased as a substitute. The estimate assumes a freeze on new nuclear power plant construction from fiscal 2011 and the decommissioning of existing power plants after 40 years of operation. The breakdown of the substitute thermal power generation (coal, LNG and oil) is estimated using the power generation system operations planning model that we have developed.

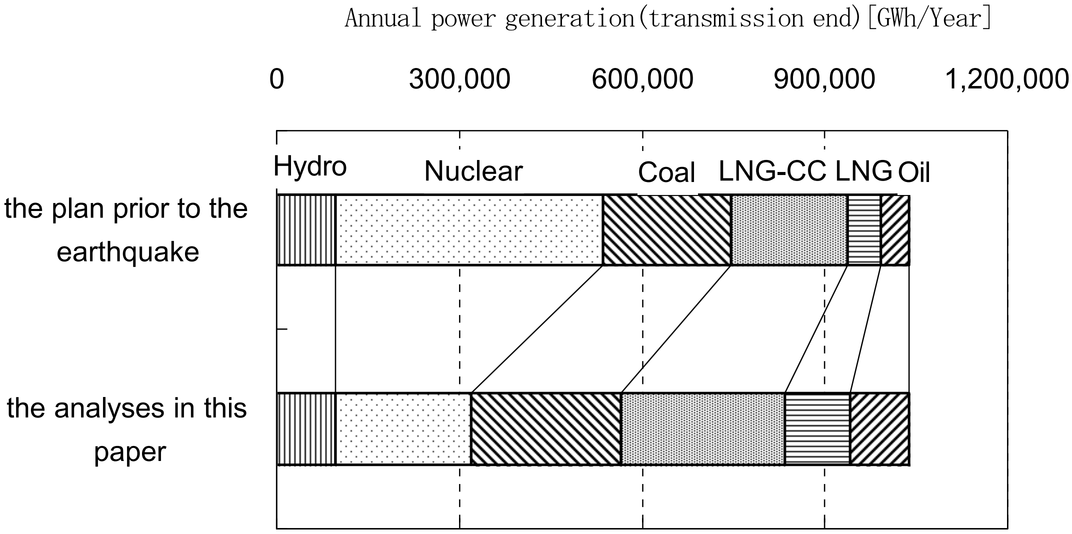
The following figure compares Japan's nuclear power generation from fiscal 2010 to fiscal 2020 under the plan prior to the earthquake, and under the analyses in this paper assuming a freeze on new power plant construction from fiscal 2011 and the decommissioning of existing plants after 40 years of operation.

Figure : Japan's nuclear power generation from fiscal 2010 to fiscal 2020



The following figure compares the power generated by each type of power source in fiscal 2020 before the earthquake, and when thermal power generation is used as a substitute for decommissioned nuclear plants.

Figure : The power generated by each type of power source in fiscal 2020



From the above figure, we calculated that the average CO_2 emissions per unit for all power sources under the power generation structure after the decommissioning of nuclear plants will be 0.45kg-CO_2/kWh. Using this value, we calculated the CO_2 emissions from purchased electric power after the earthquake under the BAU case. We then calculated the CO_2 emissions from purchased electric power when the greenhouse gas reduction policies are implemented by multiplying the changes in purchased electric power consumption when the greenhouse gas reduction policies are implemented by 0.6kg-CO_2/kWh as the average CO_2 emissions per unit of the thermal power generation used to meet changes in demand, and subtracted that product from the CO_2 emissions estimation result under the BAU case.

Step 5: Estimate the CO_2 emissions reduction from promoting the use of natural gas
Based on Step 4, the CO_2 emissions reduction from the spread of natural gas cogeneration, fuel conversion from oil to natural gas, the effective use of natural gas in vehicles and other promotion of the use of natural gas are estimated.

The specific natural gas use promotion policy items, outlines of each policy, assumptions for the calculations, and the CO_2 reduction effects from implementing the policies are presented below by sector and by policy.

A. Industrial Sector

1) Conversion of Oil-fired Private Power Generation to Natural Gas
Convert the fuel for oil-fired private power generation to natural gas.

2) Introduction of New Natural Gas Cogeneration Systems

- Assume introduction of 20 million kW of new natural gas cogeneration systems. The scale of introduction is estimated from the amount of energy consumption for heating use in each industry and the distribution by customer scale, etc.
- The introduced cogeneration systems are assumed to replace existing natural gas heat demand.

- The introduced cogeneration systems are assumed to have a power generation efficiency of 40% and a waste heat use efficiency of 40%, and to operate 5,000 hours per year.

3) Conversion of Oil and LPG Demand for Heating Use to Natural Gas
Convert the remaining oil and LPG demand for heating use to natural gas.

Table : The effect of CO_2 emissions reductions in industry sector

Measuares	The effect of CO2 emissions reduction [million ton-CO2/year]
1) Conversion of Oil-fired Private Power Generation to Natural Gas	5.8
2) Introduction of New Natural Gas Cogeneration Systems	37.2
3) Conversion of Oil and LPG Demand for Heating Use to Natural Gas	16.0

B. Commercial Sector

1) Conversion of Petroleum Product Heating Demand to Natural Gas
Convert the remaining petroleum product and LPG demand for heating use to natural gas.

2) Conversion of Petroleum Product Cooling Demand to Natural Gas
Convert the remaining petroleum product and LPG demand for cooling use to natural gas.

3) Conversion of Petroleum Product Hot Water Demand to Natural Gas
Convert the remaining petroleum product and LPG demand for hot water use to natural gas, and assume introduction of fuel cells with a power generation efficiency of 32% and a waste heat use efficiency of 38%. The introduction scale is equivalent to about 11 million kW. Assume that purchased power can be reduced by the amount of the power generation from operating the fuel cells.

4) Conversion of Natural Gas Hot Water Demand to Fuel Cells
Convert the natural gas demand for hot water use to fuel cells with a power generation efficiency of 32% and a waste heat use efficiency of 38%. Assume that purchased power can be reduced by the amount of the power generation from operating the fuel cells.

5) Conversion of Petroleum Product Commercial Kitchen Demand to Natural Gas
Convert the remaining petroleum product and LPG demand for commercial kitchen use to natural gas.

Table : The effect of CO_2 emissions reductions in commercial sector

Measuares	The effect of CO2 emissions reduction [million ton-CO2/year]
1) Conversion of Petroleum Product Heating Demand to Natural Gas	6.1
2) Conversion of Petroleum Product Cooling Demand to Natural Gas	0.6
3) Conversion of Petroleum Product Hot Water Demand to Natural Gas	10.0
4) Conversion of Natural Gas Hot Water Demand to Fuel Cells	4.0
5) Conversion of Petroleum Product Commercial Kitchen Demand to Natural Gas	0.6

C. Household Sector

1) Conversion of Petroleum Product Heating Demand to Natural Gas
Convert the remaining petroleum product and LPG demand for heating use to natural gas.

2) Conversion of Petroleum Product Hot Water Demand to Natural Gas and Fuel Cells
Convert the remaining petroleum product and LPG demand for hot water use to natural gas, and assume introduction of fuel cells with a power generation efficiency of 32% and a waste heat use efficiency of 38% (a capacity of 0.7kW per unit). The introduction scale is equivalent to about 8 million kW. Assume that purchased power can be reduced by the amount of the power generation from operating the fuel cells.

3) Conversion of Natural Gas Hot Water Demand to Fuel Cells
Convert the natural demand for hot water use to fuel cells with a power generation efficiency of 32% and a waste heat use efficiency of 38%. Assume that purchased power can be reduced by the amount of the power generation from operating the fuel cells.

4) Conversion of Petroleum Product Kitchen Demand to Natural Gas
Convert the remaining petroleum product and LPG demand for kitchen use to natural gas.

Table : The effect of CO_2 emissions reductions in household sector

Measuares	The effect of CO2 emissions reduction [million ton-CO2/year]
1) Conversion of Petroleum Product Heating Demand to Natural Gas	5.1
2) Conversion of Petroleum Product Hot Water Demand to Natural Gas and Fuel Cells	11.0
3) Conversion of Natural Gas Hot Water Demand to Fuel Cells	6.3
4) Conversion of Petroleum Product Kitchen Demand to Natural Gas	0.6

D. Transport Sector

1) Switch to Natural Gas Fuel Cell Passenger Cars
Assume that next-generation passenger cars other than light cars all use natural gas fuel cells.

2) Switch to Natural Gas Fuel Cell Trucks
Assume that next-generation trucks other than light trucks all use natural gas fuel cells.

Table : The effect of CO_2 emissions reductions in transport sector

Measuares	The effect of CO2 emissions reduction [million ton-CO2/year]
1) Switch to Natural Gas Fuel Cell Passenger Cars	6.2
2) Switch to Natural Gas Fuel Cell Trucks	4.3

4. Findings

The Democratic Party of Japan greenhouse gas reduction policies were expected to reduce CO_2 emissions by 15-25% compared with 1990 (a 12% reduction in this paper) under the assumptions prior to the Great East Japan Earthquake. With the likely changes in nuclear power policy following the problems at Fukushima Daiichi that would restrict the construction of new and replacement nuclear plants and suspend operations at aged plants, however, the estimations indicate that CO_2 emissions would revert to around the 1990 level. Next, the estimations assuming the implementation of policies promoting the spread of natural gas cogeneration, fuel conversion from oil to natural gas and the effective use of natural gas in vehicles show the potential for a maximum 12% (approximately 110 million ton) reduction in CO_2 emissions compared with the 1990 level. These reductions are at a level that offsets the increase in CO_2 emissions from the suspension of nuclear power plant operations. The breakdown is some 68 million tons from the spread of natural gas cogeneration, about 35 million tons from fuel conversion from oil to natural gas, and approximately 10 million tons from the effective use of natural gas in vehicles. These are potential figures assuming nationwide expansion of the natural gas pipeline grid.

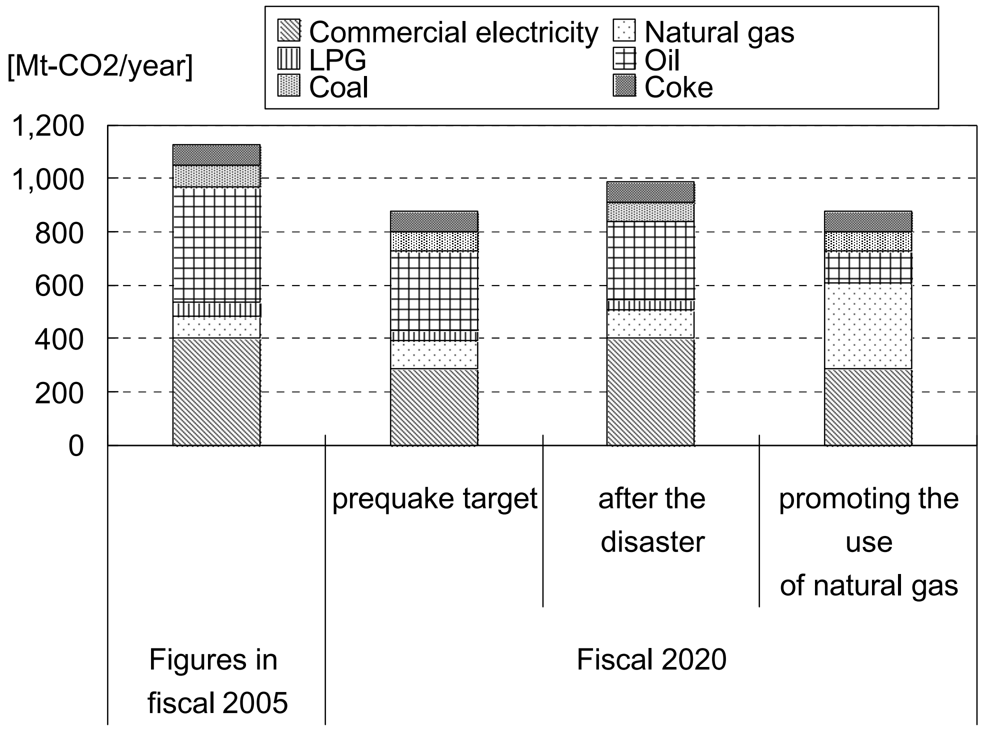


Figure : Post-Fukushima CO_2 Emissions Projection

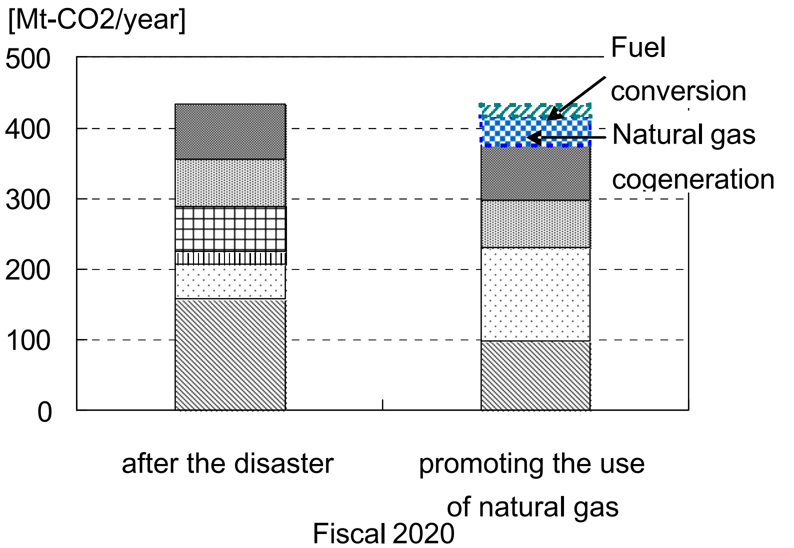


Figure : CO_2 Emissions Projection in the industrial sector

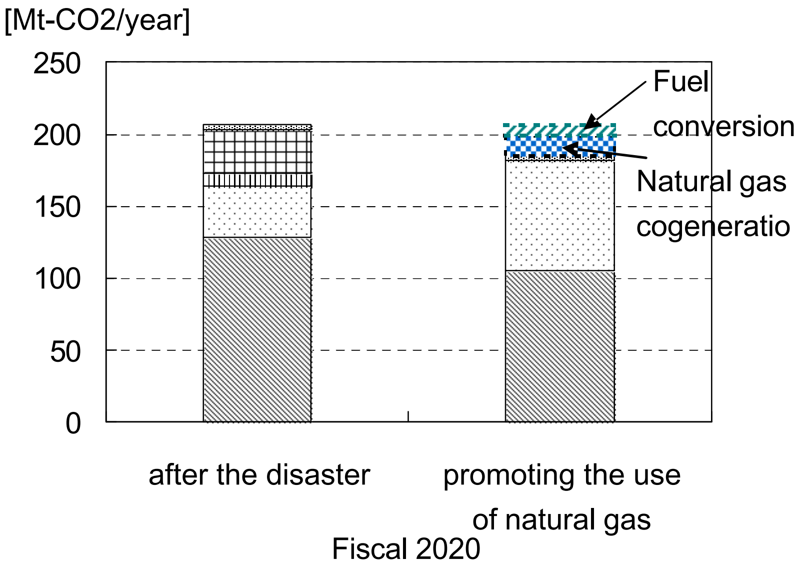


Figure : CO_2 Emissions Projection in the commercial sector

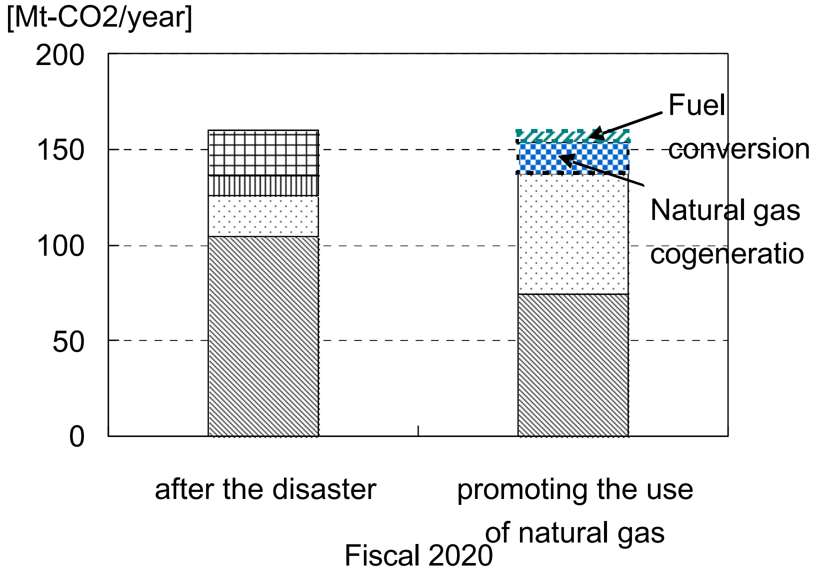


Figure : CO_2 Emissions Projection in the household sector

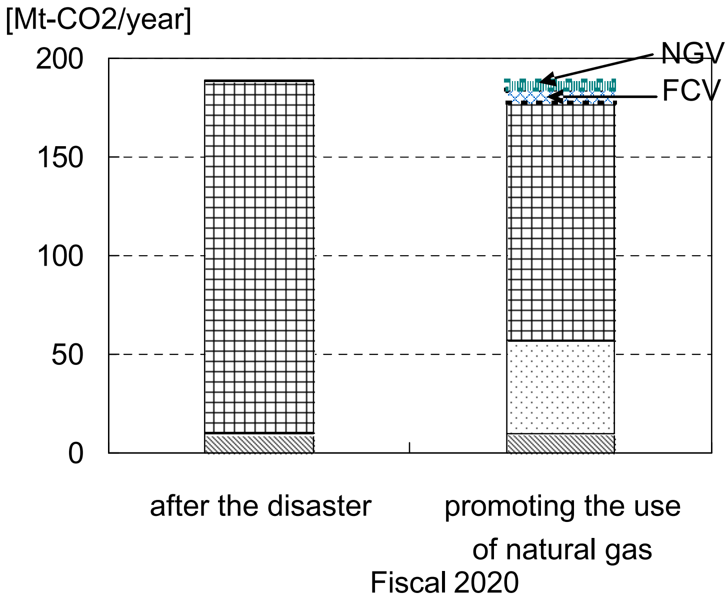


Figure : CO_2 Emissions Projection in the transportation sector

5. Conclusion

Prior to the Great East Japan Earthquake, Japan expected to realize greenhouse gas emissions reductions of 15-25% from the 1990 level in 2020. With likely changes in nuclear power policy following the earthquake disaster from the problems at the Fukushima Daiichi Nuclear Power Station that are expected to restrict the construction of new and replacement nuclear plants and decommission aged plants, however, we estimated the CO_2 emissions in 2020 would increase to the 1990 level. On the other hand, our analyses show that efforts to promote the spread of natural gas cogeneration, fuel conversion from oil to natural gas and the effective use of natural gas in vehicles could offset this increase in CO_2 emissions from the suspension of nuclear power plant operations. Realizing these measures, together with the infrastructure work of expanding the domestic natural gas pipeline grid, will require efforts to further spread natural gas use systems and equipment in the industrial, commercial, household and transport sectors and promote the use of natural gas.

While these analyses have only focused on the CO_2 emissions reduction effect from promoting the use of natural gas, the introduction of natural gas cogeneration and other diverse natural gas use systems and equipment gives end users energy supply redundancy and contributes to boosting energy security. In future examinations on promoting natural gas in Japan’s post-Fukushima energy system, we intend to include the security perspective in addition to the three “Es” of energy, the environment and economics when conducting quantitative evaluations of the social value from the spread of natural gas systems and equipment.

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