Life Cycle Inventory Analysis of Fossil Energies in Japan

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Introduction

A spate of measures is going to be unrolled in an attempt to implement the Framework Convention on Global Climate Change. Yet, to be successful, correct understanding of energy itself is essential.

Under an agreement reached at COP3, industrialized countries have to achieve country-specific greenhouse gas (GHG) reduction targets. Japan on her part is making utmost efforts to reduce GHG emissions that result from fossil energy use at home. But, because warming is a global problem inherently, and because Japan imports almost all of her energy needs from abroad, to grasp life-cycle GHG emissions, from production abroad to transportation and consumption at home, as exactly as possible is a matter of crucial importance even for the imp1orted fossil energies to Japan.

Particularly, when we calculate environmental loads of fossil energy use in the industrial, commercial or residential sectors from global warming aspects, carbon intensity of individual fossil energies becomes a key point.

Based on past works of this kind, this study was designed to make a life cycle inventory (LCI) analysis of major fossil energies (coal, oil, LPG, LNG) imported to Japan pursuant to the concept of ISO 14040 provided by the International Standardization Organization (ISO). The scope of the analysis basically spans mining, liquefaction, overseas transportation, refining, domestic transportation, combustion and equipment construction. While organizing available data under the LCA concept, we also endeavored for new data collection.

1. Inventory Analysis

1-1 Life cycle inventory analysis

"Life cycle assessment (LCA)" is under examination at home and abroad. It is a method to assess an environmental impact of industrial product by calculating waste matters generating from a life cycle of a product, from the moment any raw materials involved in its manufacturing are extracted to the instant the product is discarded. LCA is designed to assess a product, not from conventional standpoints like economics and convenience, but based on the degree of load put on the global environment by the product. LCA is a method to assess, quantitatively and objectively, resource inputs or outputs, as well as resultant environmental loads on the earth or the ecological system, through all stages involved in a product life, from resource mining to manufacturing, use, disposal and transportation.

LCA is not a well-established method yet. But, ISO 14040 (Life Cycle Assessment - Principles and Framework) specifies that LCA consists of six stages (Table 1-1). This study centered on a "life cycle inventory analysis" of fossil energies that were subject to LCA.

1-2 Base of assessment

Environmental loads incurring in individual processes of an energy flow are assessed in terms of intensity of greenhouse gases (CO_2, CH_4) (g-C/Mcal) by taking the final consumption stage as the base (Fig. 1-1). Namely, losses resulting from in-plant consumption, etc. at some stage are assessed. This is called $LCCO_2$ in this study.

1-3 Heat value

In converting the original units of different energies into heat quantity terms, Japan's General Energy Statistics employs the calorie of a gross heat value, while the IEA (International Energy Agency) does that of a net heat value in preparing its World Energy Statistics. A gross heat value includes vapor latent heat of water produced within the exhaust when burning, but a net heat value does not include the vapor latent heat. Latent heat is a heat value spent in vaporization (taking place after rising temperatures and evaporation) of total moisture content and water, the latter produced when fuel's hydrogen content gets compounded with oxygen, in the combustion process of a boiler, etc.

Under this study, we did not conclude which of gross or net heat values was better. Instead, we decided to express our calculation results, gained in heat quantity terms, in both gross and net heat values. Conversion factors from gross to net heat values were put at 0.96 for coal, 0.93 for oil, 0.90 for LNG, and 0.92 for LPG.

1-4 Carbon intensity of purchased electricity

When we need to assess CO_2 emissions resulting from "consumption" of purchased electricity in manufacturing industrial products, to make an assessment at the "sending end," instead of the "generating end," appears more reasonable. However, our concerns were that the targets of this study were large industrial consumers (who perhaps conclude extra-high tension contracts), such as refineries and LNG terminals. The "sending end" features considerable low-tension losses incurring in residential use, etc. Namely, making an assessment at the receiving end should result in overestimated losses, which, in turn, leads to an overestimation of carbon intensity.

Given that most of the study targets were extra-high tension consumers free from low-tension losses and that making an assessment at the "sending end" was risky for the aforementioned reasons, we made the assessment at the "generating end" by taking just in-plant consumption of power plants into consideration. Meanwhile, carbon intensity was calculated of not merely "all-power-plant average" but "all-thermal-power-plant average."

In specific terms, these carbon intensities were calculated back from the Electricity Supply and Demand Statistics based on 89g-C/kWh (all-power-source average, at generating end), FY1977 records of carbon intensity of commercial power services (purchased electricity) released by the Federation of Electric Power Companies (Table 1-2).

1-5 Assessment method of methane emission factor

Methane is a greenhouse gas that has a stronger greenhouse effect than carbon oxides. The magni-

Table 1-1 Component Stages of LCA

Stage	Contents
① Setting objective and scope of analysis	This is the stage to clarify why LCA is made and specify the scope of analysis.
② Life cycle inventory analysis	This is the stage to collect data on resource & energy inputs into the products & services subject to LCA, as well as data on production or yielded products & emissions (output), and prepare a table of input-output specifications of environmental load-related items.
③ Life cycle impact assessment	At this stage, inventories of environmental load-related items, calculated from the data gained at Stage ②, are classified by environment impact category, then put to analysis to learn the magnitude and importance of environmental impact.
④ Life cycle interpretation	This is the stage to assess and interpret the results gained at Stages② and ② in a way compatible with the objective and analysis scope set at Stage ①.
⑤ Reporting	This is the stage to prepare a report by organizing the results gained from the procedures of Stages ① - ④.
⑥ Critical review	This is the stage to confirm that the methods and data employed were relevant to the objective and that they are rational as well.

(Source) Environment Agency, "White Paper on Environment (General) FY1998"

Fig. 1-1 Inventory of Process

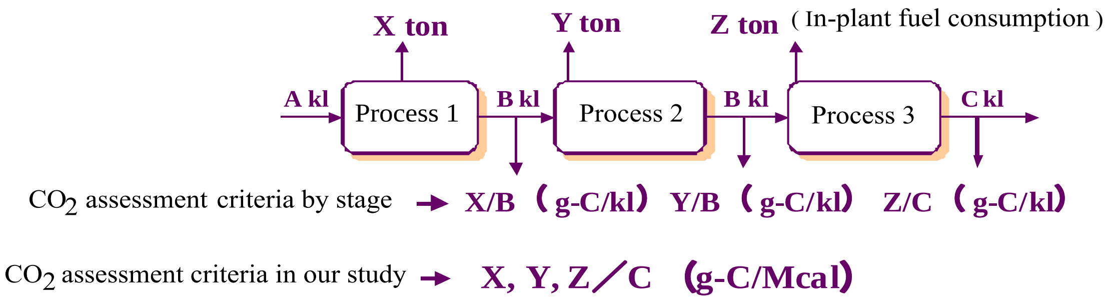


Table 1-2 Carbon Intensity of Commercial Power Services

(Unit: TWh, g-c/kWh)

	Generating end (Gross)		Share of in-plant consumption	Sending end (Net)
	Electrical Energy output	Carbon intensity		Carbon intensity
All-power-plant average	895.0	89	3.8%	93
All-thermal-power-plant average	481.4	165	4.9%	173.5

(Source) Calculated by IEEJ from reference materials of the Federation of Electric Power Companies.

tude of greenhouse effect is assessed with an indicator called global warming potential (GWP). This indicator shows a relative magnitude of greenhouse effect produced when 1kg of a GHG is injected into the atmosphere to the magnitude of greenhouse effect caused by a 1kg-CO_2 injection into the atmosphere. Because GWP is an indicator related to a life of a GHG in the atmosphere, its intensity depends on the number of integrated years into the consideration of greenhouse effect. Generally, global warming problems are considered in an ultra-long time span, say 50 years or 100 years. This time, we assessed methane by putting the number of integrated years into the effect consideration at 100 years, 21 times longer than CO_2 case.

2. Coal

2-1 Outline of assessment

The scope of our coal assessment spans the production, land transport within producing country, marine transport and handling stages and while burning. Data collection centered on existing literature, updated case studies and statistics. As for marine transport, we originally prepared necessary data from actual records furnished by shipping companies and steelmakers. When only collective data were available on all exporting countries, we estimated an environmental load for all imported coals by taking two factors into consideration: mining methods in use and makeup of coal imports.

2-2 Coal supply and demand

In FY1997 a total of 137.28 million tons of coal was sold in Japan. Of it, about 96% were imported. By source, the largest is Australia, followed by Canada, China, Indonesia and the U.S. in this order. Australia, responsible for more than 50% of Japan's coal imports, holds by far heaviest weight (Table 2-1). This time, we calculated an environmental load of all imported coals by producing a weighted average by the shares in the coal import mix.

2-3 Environmental load of coal production

Coal seams spread like a layer on the ground surface or underground. There are two methods of coal extraction: surface and underground mining. Surface mining is applicable to coals distributed shallow underground, while underground mining to those lying deep underground. After extracted, coals are moved by large truck or belt conveyor to a coal preparation plant, where they are grouped by size and quality. Saleable coals of uniform qualities are stored in a stockyard for a while. To count environmental load of electricity & fuel consumption at this stage, we employed the average of reported figures in two studies. One is an Australian report, "Coal for Development" (Table 2-2 Example (1)). The other is "Environment-affecting Substances Induced Overseas As A Result of Domestic Consumption of Fossil Fuels" (Table 2-2 Example (2)). These study reports alike offer Australian coal data alone. Therefore, we calculated an environmental load at the production stage of all imported coals first by seeking CO_2 emission

Table 2-1 Japan's Coal Imports by Source (FY1997)

	Total coal imports (incl. anthracite)		Steam coal		Coking coal	
Australia	71,947	(54.3)	38,296	(61.3)	33,650	(51.1)
Canada	18,080	(13.7)	2,010	(3.2)	16,070	(24.4)
China	11,981	(9.0)	6,607	(10.6)	2,984	(4.5)
Indonesia	11,574	(8.7)	8,418	(13.5)	3,156	(4.8)
USA	7,417	(5.6)	2,526	(4.0)	4,890	(7.4)
South Africa	4,659	(3.5)	2,685	(4.3)	1,973	(3.0)
Russia	4,310	(3.3)	1,836	(2.9)	2,474	(3.8)
Vietnam	1,316	(1.0)				(0.0)
Columbia	415	(0.3)			415	(0.6)
New Zealand	364	(0.3)	61	(0.1)	303	(0.5)
North Korea	356	(0.3)				(0.0)
Total	132,419	(100.0)	62,439	(100.0)	65,915	(100.0)

(Note) The figures in parenthesis are shares.
(Source) MITI, "Energy Production, Supply and Demand Statistics"

factor in reference to the surface and underground mining ratios (Table 2-3), then producing a weighted average by import volume.

2-4 Environmental load of coal transport

2-4-1 Calculation of CO_2 emission factor of land transport in producing country

From mines to shipping terminals, exportable coals can be transported by various means, such as railway, road and belt conveyor. Yet, we assumed all coals were moved by railway. We also assumed a diesel locomotive, fueled by diesel, was in use. For fuel intensity, we borrowed the figures reported in "Environment-affecting Substances Induced Overseas As A Result of Domestic Consumption of Fossil Fuels" (Table 2-4). The reported figures were based on the data furnished by JR Freight Services in "Transport Energy Handbook." Average railway transport distances from mines to shipping terminals were based on country-specific figures reported in "Environment-affecting Substances Induced Overseas As A Result of Domestic Consumption of Fossil Fuels" (Table 2-5).

2-4-2 Calculation of environmental load of marine transport

The size of vessel to be used in marine transport of coals depends on the amount of cargoes, the capacity of berth and the sea route, among others. By size, vessels are roughly divided into the Cape size (110,000 - 150,000 DWT), the Panamax size (50,000 - 70,000 DWT), and the Handy size (20,000 - 30,000 DWT). Vessels that move coking coals to Japan average about 100,000 DWT in size. It means coking coals bound for Japan are generally transported by large vessel. As for steam coals, the size of vessels averages about 50,000 DWT, and many cargoes are transported by Handy- or Panamax-size vessel. Therefore, we calculated an environmental load of marine transport in two ways by separating Cape-size vessels, popularly in service when moving coking coals, from Panamax-size ones generally used in steam coal transport.

As in the case of land transport in producing country, the figures for average sea-route distances from overseas shipping terminals to Japan's unloading terminals were based on "Environment-affecting Substances Induced Overseas As A Result of Domes-

Table 2-2 Reported Environmental Load at Production Stage (Examples)

	Mine	Location	Mining method	Carbon intensity (g-C/Mcal)
Example (1)	Hunter Valley	Australia (NSW)	Surface mining	0.83
	Macquarie	Australia (NSW)	Underground mining	0.68
Example (2)	Not disclosed	Australia (NSW)	Surface mining	0.86
			Underground mining	0.64

(Source) (1) R.M. Gordon & K.M. Sullivan, "Coal for Development," Coal Allied Industries Ltd., Australia (London, The Second World Coal Institute Conference 1993)
(2) Hiroki Hondo, Yoji Uchiyama et al., "Environment-affecting Substances Induced Overseas As A Result of Domestic Consumption of Fossil Fuels," CRIEPT, (Report contributed to the Energy Resources Academy, 1999)

Table 2-3 Surface & Underground Mining Ratios by Country

(Unit: %)

	Surface mining	Underground mining
Australia	67.5	32.5
Canada	100.0	0.0
China	8.2	91.8
Indonesia	100.0	0.0
USA	58.8	41.2
South Africa	39.8	60.2
Russia	48.7	51.3
Columbia	100.0	0.0
Imported coals from others	29.6	70.4

(Source) Hiroki Hondo, Yoji Uchiyama et al., "Environment-affecting Substances Induced Overseas As A Result of Domestic Consumption of Fossil Fuels," CRIEPT, (Report contributed to the Energy Resources Academy, 1999)

Table 2-4 Fuel Intensity by Type of Carrier

	Carrier	C heavy fuel oil (l/t・km)	A heavy fuel oil (l/t・km)	Diesel (l/t・km)
Land transport in producing country (railway)	Diesel locomotive	—	—	0.0126
Ocean-going transport	Cape-size vessels	0.000615	—	—
Ocean-going transport	Panamax-size vessels	0.000935 (0.231667)	0.000030 (0.231667)	—

(Note) The figures in parenthesis are fuel intensity while mooring and expressed in l/t terms.
(Source) Hiroki Hondo, Yoji Uchiyama et al., "Environment-affecting Substances Induced Overseas As A Result of Domestic Consumption of Fossil Fuels," CRIEPT, (Report contributed to the Energy Resources Academy, 1999), among others.

tic Consumption of Fossil Fuels" (Table 2-5).

(1) Transportation by Cape size (110,000 - 150,000 DWT) vessel

As many steelworks have a berth capable of accommodating a large vessel, coking coals are generally transported by a large vessel and unloaded directly from the vessel to a berth provided at steelworks. Accordingly, we assumed a Cape size vessel was in service for coking coal transportation for a round trip.

We also assumed the vessel was fueled by C heavy fuel oil. Fuel intensity was calculated based on the results of our interview survey made to the Japan Iron and Steel Federation (Table 2-4).

(2) Transportation by Panamax size (50,000 - 70,000 DWT) vessel

Because few coal-fired power plants, the principal steam coal consumers, are equipped with a berth capable of accommodating a large vessel, we assumed a Panamax size (60,000 DWT) vessel was in service for a round trip. In fact, used largely in power production, most of steam coals are brought in by an even smaller vessel than Panamax size. Fuel intensity (kg/t•km) was calculated based on the data provided by major shipping companies of Japan. The furnished data included daily fuel consumption of C and A heavy fuel oils, respectively, while sailing and during mooring, the number of sailing days, sailing distances and tonnage of cargoes. Meanwhile, fuel intensity during mooring was calculated in kg/t terms because it did not influenced by a sailing distance (Table 2-4).

2-4-3 Environmental load of secondary transportation

Because only a limited number of ports are capable of receiving large ocean-going vessels, and because coal consumers scatter across Japan, imported coals are often forwarded from a receiving port to individual power plants, cement works, paper/pulp mills and other coal consumers nationwide. In stricter terms, we have to count this secondary

Table 2-5 Transport Distances of Imported Coals

(Unit: km)

	Land transport in producing country	Marine transport
Australia	187	733
Canada	1,132	7,970
China	455	2,339
Indonesia	23	4,821
USA	1,125	8,886
South Africa	534	14,344
Russia	2,996	1,659
Columbia	284	14,975
New Zealand	23	8,845

(Source) Hiroki Hondo, Yoji Uchiyama et al., "Environment-affecting Substances Induced Overseas As A Result of Domestic Consumption of Fossil Fuels," CRIEPT, (Report contributed to the Energy Resources Academy, 1999)

transportation to end users in our calculation of a life-cycle environmental load of imported coals. Regretfully, we were unable to do so this time due to lack of data.

2-4-4 Calculation of environmental load at handling stage

As coals are generally transported in bulk, their handling proves energy-intensive whenever a different type of carrier is in service. Representative handling equipment at a stockyard are stackers and reclaimers, the former to stack in the yard the coals forwarded by a belt conveyer, and the latter to ship the coals stored in the yard onto a belt conveyor. Most of the handling works are powered by electricity. Aside from mechanical equipment directly involved in loading and unloading works, the operation of belt conveyors holds by far heaviest weight in energy consumption.

On energy consumption in handling coals, we employed the data contained in "A Demonstration Study Report on Impact of Fossil-Fired Power Plant on the Atmosphere." Namely, we calculated an environmental load attributable to the coal handling works from two data: electricity consumption in unloading a ton of coal (0.95 kWh/t) at Port Tomakomai reported in the report, and country-specific carbon intensity of electricity consumption (Table 2-6). Meanwhile, the calculation was made on the assumption that coals were handled twice, first loaded into an ocean-going vessel and second unloaded.

2-5 Environmental load of equipment construction

2-5-1 Calculation of environmental load incurring in building necessary equipment for mining and in-situ land transport

Data on equipment construction for mining and land transport in producing country were taken from relevant figures reported in "Environment-affecting Substances Induced Overseas As A Result of Domestic Consumption of Fossil Fuels." On coals, this report covered Australian miners, and calculated how many materials were needed for producing and transporting a ton of coal from the data furnished by the Australian mines surveyed. The furnished data included coal output from a mine, necessary amounts of materials for the equipment used at a mine and usable life of such equipment.

The manufacture & construction of equipment involves the emission of environment-affecting substances not merely from the process of materials manufacturing but also during materials processing and parts transportation. Therefore, we calculated the emission of these substances by multiplying the emission from the materials manufacturing process by material-specific shares in the emission. Material-specific carbon intensities and shares in the emission were gained from Japan's input and output table for the year 1990 on the assumption that all the materials were produced within the Japanese industrial structure.

2-5-2 Calculation of environmental load of shipbuilding

Data on the construction of ocean-going vessels were also gained from the "Environment-affecting Substances Induced Overseas As A Result of Domestic Consumption of Fossil Fuels." This report contains a regression analysis by dead load of vessel and tonnage of cargoes on all ocean-going vessels of 10,000 DWT or larger registered in the "Japan Ship Specifications" (Japan Shipping Assembly, 1998). In calculating the material needs for shipbuilding, tonnage of cargoes was assumed at 112,000 tons for Canada and the U.S. in reflection to heavier weight held by coking coals in the shipments from these countries, and at 90,000 tons for the rest of exporting countries. Then, emission factors were calculated by producing a weighted average by coal imports by country. Among others, it was assumed that only steel was used in shipbuilding, and that a vessel was usable for 20 years.

Table 2-6 Carbon Intensity of Electricity Consumption by Country

(Unit: g-CO_2/kWh)

	Carbon intensity
Australia	736
Canada	175
China	926
Indonesia	561
USA	550
South Africa	647
Russia	782
Columbia	219
New Zealand	73
(Cf.) Japan	326

(Source) Hiroki Hondo, Yoji Uchiyama et al., "Environment-affecting Substances Induced Overseas As A Result of Domestic Consumption of Fossil Fuels," CRIEPT, (Report contributed to the Energy Resources Academy, 1999)

2-6 Environmental load of methane emission

Data on methane emission were borrowed from a report on Australian coals, "Coal for Development," which reported relevant figures to surface-mined Hunter Valley coals and those to underground-mined Macquarie coals (Table 2-7).

Methane emission from coal mining depends on the mining method in use. It is because, at the mines where surface mining is in practice, coal seams are often located shallower than underground-mining mines. Namely, methane is diffused into the atmosphere before mining and the likelihood is that coal seams contain lesser methane than those of underground-mining mines. For this reason, CH_4 emission factor of all imported coals was calculated in reflection to country-specific ratios of surface and underground mining.

2-7 LCI analysis results of coal

Analysis results are summarized in Table 2-8. The results show a considerable environmental load of methane. It was also found that the transportation stage, particularly marine transport, produced a massive environmental load. The gaps in the results be-

Table 2-7 Reported Carbon Intensity at Production Stage (Examples)

Mine	Location	Mining method	Carbon intensity ($kg\text{-}CO_2/GJ$)
Hunter Valley	Australia (N.S.W)	Surface mining	< 0.15
Macquarie	Australia (N.S.W)	Underground mining	< 0.25

(Source) R.M. Gordon & K.M. Sullivan, "Coal for Development," Coal & Allied Industries, Ltd., Australia (London, the Second World Coal Institute Conference 1993)

Table 2-8 LCI Analysis Results of Coal

(Unit: g-C/Mcal)

		High heat value basis			Low heat value basis		
		Steam coal	Coking coal	Average	Steam coal	Coking coal	Average
Production		0.78	0.79	0.79	0.81	0.82	0.82
Transportation	In-situ land	0.53	0.72	0.63	0.55	0.75	0.66
	Ocean-going	1.75	0.96	1.32	1.83	1.00	1.37
	Sub-total	2.28	1.68	1.95	2.38	1.75	2.03
Handling		0.06	0.04	0.05	0.06	0.04	0.05
Equipment construction		0.15	0.12	0.13	0.16	0.13	0.14
Methane		4.39	4.39	4.39	4.57	4.57	4.57
Total		7.66	7.02	7.31	7.98	7.31	7.61
Carbon intensity by fuel		103.44	99.00	101.07	107.75	103.13	105.28
Grand total		111.10	106.02	108.38	115.73	110.44	112.90
Heat value (kcal/kg)		6,200	7,600	6,880	5,952	7,296	6,605

(Source) Prepared by IEEJ from this study results.

tween coking and steam coals are due largely to the differences in their heat values. Among others, coking coals, mass-transported efficiently by large vessel, were found responsible for a lesser environmental load than steam coals while transported.

3. Oil

Focusing on crude oil imported to Japan in FY1997 for refining and non-refining uses, we calculate resultant environmental loads by stage, from production to consumption. Data on FY1997 crude oil imports by area are based on MITI's "Statistical Yearbook of Energy Production, Supply and Demand, 1997" and "Mean Values of Import Records in 1997 (Oil Imports Survey Data Table)."

3-1 Direct energy needs for crude oil production and resultant environmental load

In crude oil production, associated gas provides the basic energy source that drives oil-producing equipment. The associated-gas-powered equipment can roughly be divided into two groups. The first group consists of those directly involved in crude oil production. They include a gas turbine to drive a high-pressure compressor for gas lift or gas injection, a gas turbine to drive a high-pressure pump for water injection, and a heating furnace for demineralization of crude oil. The second group consists of utilities-related equipment, such as a gas turbine to drive a generator, a gas engine, and a general-purpose boiler for tank heating, etc.

Aside from the portion consumed at oil fields, oil-associated gas is sold outside (LNG, LPG and pipelined gas), or re-injected into oil reservoirs. With these portions subtracted from associated gas output, the balance is counted as a surplus and burned in a flare stack. In regard to associated gas consumption at oil fields, our calculations are based on the first-hand data furnished by the PEC (Petroleum Energy Center), which sent a survey mission to the oilfields in Saudi Arabia and the United Arab Emirates, as well as the North Sea oilfields in Norwegian waters.

In specific terms, in-situ gas consumption was put at 60 scf/bbl. Compositions of associated gas and resultant carbon intensity were assumed as shown in Table 3-1. Based on these assumptions, our calculation produced that an environmental load of fuel consumption at crude oil production stage amounted to 0.843 g-C/Mcal.

Table 3-1 Gas Compositions and Resultant CO_2 Emissions

Component	Gas compositions mol%	CO_2 emissions m^3/m^3
H_2S	1.3%	0.000
CO_2	5.8%	0.058
N_2	0.6%	0.000
CH_4	69.3%	0.693
C_2H_6	13.2%	0.264
C_3H_8	6.2%	0.186
C_4H_{10}	2.4%	0.096
C_5H_{12}	0.8%	0.040
C_6H_{14}	0.4%	0.024
Total	100.0%	1.361(0.73kg-C/m^3)

3-2 Environmental load of gas flaring

Gas flaring first requires a gas-oil ratio (GOR) and a flaring rate to be set. In order to calculate the amount of gas associated with crude oil production, we set the ratios (GRO) for the Middle East and Indonesia, as they were responsible for the greater part of oil exports to Japan. In specific terms, GOR, prepared based on the database of the Oil Development Information Center (IRIS21), was put at 720 scf/bbl for the Middle East, and at 350 scf/bbl for Indonesia.

The flaring rates are based on OPEC Yearbook (1998). The flaring rates have been on the decline year by year. The decline reflects successful efforts made by OPEC members, notably Saudi Arabia, for introducing associated gas utilization systems, typically so-called "master gas system."

The average flaring rate was obtained first by seeking an associated gas amount by multiplying country-specific crude oil output by GOR, then multiplying the outcome by the amount of flaring. It was found the flaring rate averaged 6.3% in the Middle East, and 5.9% in Indonesia (Table 3-2). In comparison, Statoil's flaring rate at its North Sea oilfield stays at 1%. We employed these flaring rates as the representative values.

Accordingly, by replacing the rates of 6.3% and 5.9% with their equivalent of 45.36 scf/bbl and 20.65 scf/bbl, respectively, we calculated carbon intensity, which was found at 0.61 g-C/Mcal on weighted average.

To sum up, in terms of weighted average, environmental loads of in-situ gas consumption and flaring at the oil production stage were 0.843 g-C/Mcal and 0.614 g-C/Mcal, respectively.

3-3 Environmental load of methane vent

Our assumption was that basically no methane vent occurred while crude oil production at oil fields, and that methane bent was involved only in associated gas production. The amount of vent was assumed to be the same as in gas fields. In its 1991 report, the Japan Petroleum Mining Federation (Japan Petroleum Development Association) put an average amount of associated gas at 734 scf/bbl. Our calculation was made based on this figure, plus the amount of vent per basic unit at gas fields. As for oil fields, a survey result suggested there was no methane vent at oil fields equipped with flaring units, though it is quite likely that many oil fields are not equipped with such a unit. On this matter, we could not grasp the actual state, and made the calculation based on assumptions (Fig. 3-1).

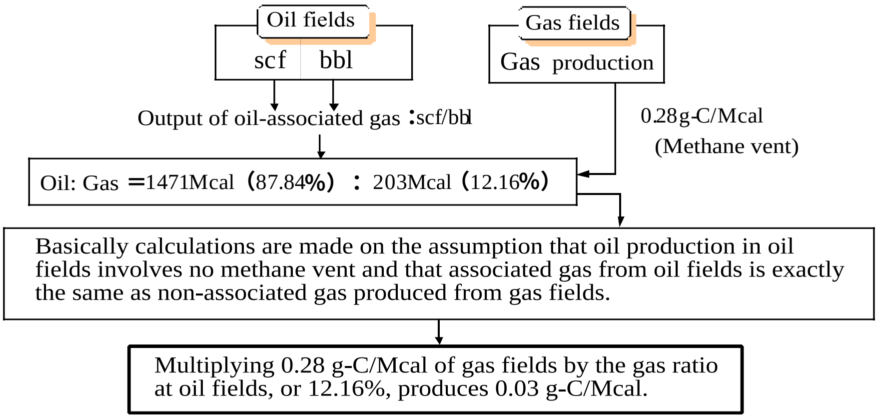
To sum up, our calculation result showed methane vent while crude oil production placed an environmental load of 0.034 g-C/Mcal.

Table 3-2 Oil & Gas Shares and Flaring Rates by Country

Area・country	Crude oil imports (1,000 kl/y)	Share (%)	Ratio of associated gas (scf/bbl)	Flaring rate (%)	Flared gas/crude oil (scf/bbl)
Iran	26,617		650	13.80%	89.70
Saudi Arabia	60,082		600	14.10%	84.60
Kuwait	16,019		500	4.60%	23.00
Qatar	19,046		900		
UAE	71,844		950	0.90%	8.55
Oman	13,973		500		
Yemen	1,066		1,250		
Middle East total	224,015	93.28%	720	6.30%	45.36
Indonesia	16,137	6.72%	350	5.90%	20.65
Grand total	240,152	100.00%			

(Note) The flaring rates were calculated based on OPEC Yearbooks.

Fig. 3-1 How Allocation is Made in Calculating Methane Vent



3-4 Environmental load of crude oil transportation

Our assessment covers crude oil for refining and non-refining uses, that is, all crude oil flowing into Japan. Of the data employed in our calculation, those on crude oil imports are 1997 figures, while those for fuel consumption, bunker fuel consumption, etc. are 1995 figures. For this reason, there are some gaps in data compatibility (Table 3-3).

Tankers transport crude oil from producing to consuming areas. If a deep-drafted oil tanker with full of cargoes is bound for Japan from a loading terminal, its sea route depends on the type and size of the tanker, as well as season. The Strait of Malacca•Singapore route, the Strait of Lumbok route, the South China Sea central sea route, the Palawan route and the Okinawa route can be cited as the representative sea routes from the Persian Gulf to Japan.

Tanker-related figures are in terms of mean values of ten tankers of standard size, from one- to 20-year-old in tanker age, actually in service in each of the representative sea routes. With miles/hour taken as the measure, fuel consumption per mile (tons/mile) was obtained by dividing fuel consumption (tons/day) by velocity*24 hours (Table 3-4).

Fuel consumption while sailing was obtained as follows: number of times of navigation (times/year) X a-round-trip distance (miles) X fuel consumption rate (tons/mile). Fuel consumption while mooring was reported as shown in Table 3-5.

Under these assumptions, we made the calculation by putting heat value and carbon intensity of A heavy fuel oil at 9,300 kcal/kg and 79.11 kg-C/Mcal, and those of C heavy fuel oil at 9,800 kcal/kg and 81.8 kg-C/Mcal, respectively. Our calculation result showed that an environmental load of crude oil marine transport was 0.862 g-C/Mcal.

3-5 Energy consumption and environmental load of refinery

Energy consumption and environmental load of refinery, that forms only part of a full-stage oil as-

Table 3-3 Japan's Total Crude Oil Imports and Import Forms

Area・country	Crude oil imports		Share	Crude oil density	Round-trip distance	Standard tanker	Sailing times
	(kl/g)	(t/y)	(%)	(t/kl)	(miles)	(DWT)	(Times/year)
China	12,868,215	11,173,471	4.85	0.8683	2,480	80,000	139.67
South	26,907,029	22,682,625	9.84	0.8430	5,404	100,000	226.83
Middle East	224,015,163	189,830,449	82.36	0.8474	13,192	250,000	759.32
Russia	0	0	0.00	0.8970	1,810	100,000	0.00
Latin America	3,490,437	3,026,558	1.31	0.8671	6,680	250,000	12.11
Africa	1,801,552	1,550,055	0.67	0.8604	13,200	250,000	6.20
USA	512,321	434,243	0.19	0.8476	21,652	100,000	4.34
Australia	2,106,271	1,785,275	0.77	0.8476	6,076	100,000	17.85
Total	271,700,988	230,482,678	100.00		70,494		1,166.32

(Source) Crude oil imports: MITI, "Energy Production, Supply and Demand Statistics," 1997
Crude oil density: "Mean Values of Import Records in 1997(Oil Imports Survey Data Table)"

sessment, can be grasped simply by calculating environmental loads resulting from direct and indirect (purchased electricity) combustion at refinery.

First, a PEC report puts that fuels consumed in direct combustion at refinery amount to 114 million Gcal in heat quantity terms. This portion of oil put to in-plant fuel consumption is part of crude oil imported for refining use. Carbon intensity of this portion is 3.01 g-C/Mcal. Next, indirect fuel consumption at refinery is identical to the amount of purchased electricity, or 23,966.87 TWh. We calculated carbon intensity of the purchased electricity portion from an all-power-plant average (93 g-C/kWh) and an all-thermal-power-plant average (173.5 g-C/kWh) both at sending end. The outcomes were 0.09 g-C/Mcal with the former, and 0.17 g-C/Mcal with the latter.

Thus, adding up these figures for in-plant fuel consumption and purchased electricity produces that an environmental load of refinery is 3.17 g-C/Mcal.

3-6 Environmental load of equipment construction

Environmental load of equipment construction is defined as an environmental load resulting from plant construction at the production stage, shipbuilding for transportation stage and domestic refinery construction. With few data available, our calculations were largely based on the data contained in "Environment-affecting Substances Induced Overseas As A Result of Domestic Consumption of Fossil Fuels (a paper contributed to the Energy Resources Academy, already accepted 990125)." Yet, because this paper focused on overseas alone and offered no calculation about domestic refinery, we made domestic refinery-related calculations in reference to a refinery model constructed after designed values by NIKKI, a plant maker. Our calculation result showed that an environmental load of equipment construction was 0.09 g-C/Mcal.

Table 3-4 Tanker Size and Fuel Consumption

Tanker size (DWT)	Velocity (knots)	Fuel consumption (ton/miles)
250,000	14.9	0.202
100,000	15.1	0.157
80,000	15.1	0.157

3-7 Environmental load at product transportation stage

Our assumptions were that the petroleum products to be transported were gasoline, naphtha, diesel and A and C heavy fuel oils, and that transportation means in use were tank lorries, coastal tankers and tank cars. Trucking and pipelining were omitted this time.

Petroleum products, shipped from a refinery, are supplied to consumers via oil depots and service stations.

In FY1995, coastal tankers moved 40.1% of domestically transported petroleum products to oil depots and large industrial users' plants. Among others, tank lorries moved 49.6% and tank cars did 2.7% from refineries to oil deports or large industrial users' plants.

Including fuel consumption, the data employed in our calculation were the findings of a survey on petroleum product transportation, which was made by the Japan Petroleum Association in its preparing the "Oil Industry's Voluntary Action Program for the Conservation of Global Environment." By putting CO_2 emission factors to combined use with the survey findings, we calculated energy consumption and environmental load involved in product transportation.

3-7-1 Environmental load of land transport by tank lorry

Tank lorry is available in two types: trailer and single-car types. The data employed in our calculation are shown in Table 3-6. Fuel consumption rates (average) were assumed at 2.95 km/l for trailer type, and at 3.67 km/l for single-car type. Heat value of diesel, which fuels the lorries, was assumed at 9,200 kcal.

Based on these data, we calculated energy consumption and environmental load involved in product transportation. Our calculation results showed 0.175 g-C/Mcal for white oils, which was gained by using 8,804 kcal/l, a weighted average of heat value of white oil sales amount. Corresponding figure for black oils was 0.207 g-C/Mcal, which was based on a weighted average of heat value of black oil sales amount, or 9,592 kcal/l.

Table 3-5 Fuel Consumption Rates at Loading and Unloading Terminals and for Cargo Heating

Standard tanker size	Loading terminal		Unloading terminal		Cargo heating
	HFO tons/time	MDO tons/time	HFO tons/time	MDO tons/time	HFO tons/time
80,000	20	3	60	12	114
100,000	20	3	60	12	166
250,000	33	5.4	143	5.7	-

3-7-2 Environmental load of marine transport

Summarized below are major findings of the Japan Petroleum Association's survey on the status quo of white and black oil transportation by coastal tanker. The survey did not distinguish white oils from black oils (Table 3-7).

C heavy fuel oil accounts for 90% of overall fuel consumption by tanker, and the remaining 10% held by A heavy fuel oil used only when entering a port. Given 9,600 kcal/l of C heavy fuel oil and 9,300 kcal/l of A heavy fuel oil, heat value turns to be 9,570 kcal/l on average. Based on these data, our calculation results showed that an environmental load amounted to 0.331 g-C/Mcal for white oils, and 0.361 g-C/Mcal for black oils. Weighted average is 0.338 g-C/Mcal.

3-7-3 Environmental load of land transport by tank car

Petroleum products moved by tank car total 14.74 million kl, including 11.478 million kl of white oils and 3.262 million kl of black oils.

Given that tank cars are in service largely in forwarding the products from the Keihin district to inland areas of Kanto, we assumed that a transport distance averaged 150 km. According to the findings of our interview survey made to a company in charge of oil transportation by tank car, energy intensity of oil transportation is 45 kcal/ton•km. This figure, estimated for a case of transportation within Kanto area, is also on condition that oils are moved by exclusive-use tank cars over flat lands topographically. Because all areas are not flat nationwide, we dropped this figure. Instead, we put it at 50 kcal/ton•km. By source, if calculated from the Railway Statistical Yearbook, electricity occupies 82.4% of energy consumption, and diesel engine does 17.6%. Given that these figures are national average, and that oil transportation by tank car is popular largely in highly electrified Kanto area, we originally assumed the shares at 90% and 10%, respectively. Based on these assumptions, our calculation results showed that environmental loads were 0.0372 g-C/Mcal for heavy fuel oil, 0.0082 g-C/Mcal for diesel, and 0.045 g-C/Mcal when combined. In making the calculations, carbon intensity of electricity was put at 93 g-C/Mcal, an all-power-source average.

On these accounts, an environmental load of domestic transportation of petroleum products is 0.255 g-C/Mcal.

Meanwhile, in regard to average transportation distances assumed by type of carrier, it should be noted that, in some cases, cargoes were transshipped at an oil depot while transported from a refinery to a consuming area. In such cases, an average transportation distance was calculated by counting the mileage before and after the transshipment as two independent transportation distances. For this reason, LCI values resulted in a shorter distance to a consuming area than actual.

3-8 LCI analysis results of oil

So far described is how we calculated the loads put on the environment by oil at individual stages of its total life cycle. Our calculation results are shown in Table 3-8.

On a gross heat value basis, it was found that crude oil production was responsible for 1.51 g-C/Mcal, crude oil transportation 0.90 g-C/Mcal, oil refining 3.10 g-C/Mcal, methane vent 0.03 g-C/Mcal, equipment construction 0.09 g-C/Mcal, and domes-

Table 3-6 Data Used in Calculating Environmental Load of Land Transport

Category	White oils	Black oils	Total
Total amount of transport	114.176 mil. kl/year	1.332 mil. kl/year	115.508 mil. kl/year
Average tonnage of freight	16.9kl	12.5kl	
Average delivery distance	58.3km	61.4km	
Average mileage	116.6km	122.8km	
Trailer ratio	60%	13%	

Table 3-7 Data on Crude Oil Marine Transport

Total amount of transport (white & black oils)	170.196 mil. kl/year (132.422 mil. kl/year: 37.774 mil. kl/year)
Average bottoms	2,000 kl (representative value)
Average tonnage	1,900kl
Average delivery distance	358km
Fuel consumption	46.27 km/kl for a standard delivery distance

(Note) Calculated based on the "Coastal Tanker Freight Agreement."

Table 3-8 LCI Analysis Results of Oil

Category		Carbon intensity (g-C/Mcal)	
		High heat value	Low heat value
Crude oil production	In-situ consumption	0.87	0.94
	Flaring	0.64	0.69
	Sub-total	1.51	1.63
Overseas transport		0.90	0.97
Oil refining		3.10	3.33
Methane vent		0.03	0.03
Equipment		0.09	0.10
Total		5.63	6.06
Carbon intensity by fuel		78.01	83.88
Domestic transport		0.26	0.28

tic transportation 0.26 g-C/Mcal. Carbon intensity was found at 78.01 g-C/Mcal.

On a net heat value basis, crude oil production was found responsible for 1.63 g-C/Mcal, crude oil transportation 0.97 g-C/Mcal, oil refining 3.33 g-C/Mcal, methane vent 0.03 g-C/Mcal, equipment construction 0.10 g-C/Mcal, and domestic transportation 0.28 g-C/Mcal. Carbon intensity turned to be 83.88 g-C/Mcal.

Our calculation results show a case where the differences in heat value and in-plant consumption are taken into account. To take in-plant consumption (losses of 4.15%) into account means to recognize that in-plant consumption by domestic refinery is equivalent to 4.15% of its total throughputs. Namely, we made the calculation by returning the 4.15% portion to the crude oil production stage ($LCCO_2$ calculation).

4. LNG

4-1 Calculation of environmental load at production stage

Our assessment covers the whole of LNG imported to Japan. Namely, based on the data on Japan's LNG imports contained in general statistics, we calculated GHG emissions from individual mining•LNG terminals and while marine transport. Data on LNG imports by country were taken from FY1997 Customs Clearance Statistics. We calculated an environmental load at the production stage from the basic data on four countries, Brunei, Australia, Malaysia and Indonesia, which were collected by a survey mission of the Japan Gas Association to these countries. Basic data on Alaska were obtained through an inquiry by letter. The basic data on the four countries covered both mining and liquefaction processes, but those on Alaska did the liquefaction process alone.

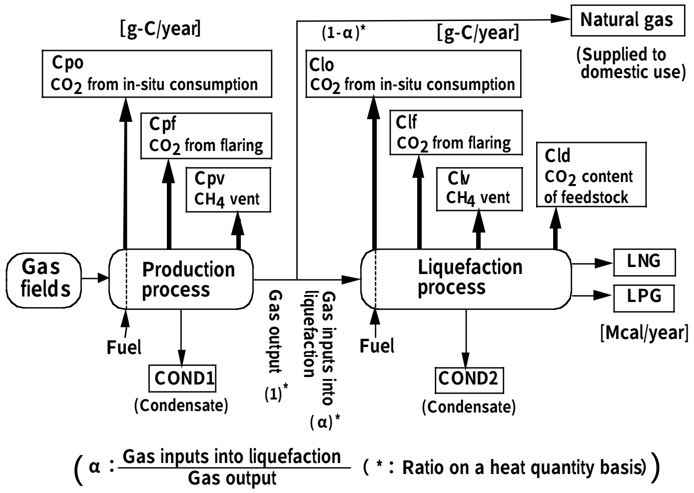
4-4-1 Calculation method of environmental load

On top of LNG, the natural gas production and liquefaction processes also yield condensate, LPG and domestically consumed natural gas as commercial products. Therefore, in order to identify how much of the environmental load of natural gas production & liquefaction was specifically attributable to LNG production, we allocated resultant environmental load also to the co-products in proportion to their outputs. In specific terms, based on the method of proportional division illustrated in Fig. 4-1, the environmental load was allocated to condensate yielded while natural gas production (COND1), condensate yielded while liquefaction (COND2), LPG and LNG in proportion to their heat quantities.

The basic data on fuel consumption while mining, vent and flaring were in terms of a four-country weighted average produced from first-hand information about Brunei, Australia, Malaysia and Badak. The basic data on fuel consumption, vent and flaring at LNG terminals were prepared from the data on the five terminals of Brunei, Australia, Malaysia, Alaska and Badak. They cover 69% of LNG counted in Japan's general statistics. We produced a weighted average by weighing these data by LNG imports from individual terminals. CO_2 content was determined in reflection to the data on Arun, Qatar and Abu Dhabi available from the Japan Petroleum Corporation. All of the first-hand information about the five terminals are 1997 data. Based on these figures and the calculation method in Fig. 4-1, heat quantity-based proportional allocation was made to such products as LPG and condensate. In this connection, when the yield of LNG is taken as 100, the ratios of co-products are 17.0% for COND1, 6.2% for DOMGAS, 4.2% for COND2, and 3.2% for LPG.

Based on these assumptions, we produced the weighted average based on the minimum and maxi-

Fig. 4-1 Proportional Division of CO_2 & CH_4 at Production and Liquefaction Stages



		Equation of proportional division [g-C/Mcal]
Production	Fuel consumption	$\frac{Cpo \times \alpha}{COND1 \times \alpha + COND2 + LPG + LNG}$
	Flaring	$\frac{Cpf \times \alpha}{COND1 \times \alpha + COND2 + LPG + LNG}$
	CH_4 vent	$\frac{Cpv \times \alpha}{COND1 \times \alpha + COND2 + LPG + LNG}$
Liquefaction	Fuel consumption	$\frac{Clo}{COND2 + LPG + LNG}$
	Flaring	$\frac{Clf}{COND2 + LPG + LNG}$
	CH_4 vent	$\frac{Clv}{COND2 + LPG + LNG}$
CO_2 content of feedstock		$\frac{Cld}{COND1 \times \alpha + COND2 + LPG + LNG}$

mum values of carbon intensity of each process as well as LNG imports from individual countries (Table 4-1).

The fuel consumption rate while running a gas turbine, etc. at LNG plant (fuel gas within LNG plant/ input gas into LNG plant) is about 8%. The rates of flaring in the production and liquefaction processes stand at about 0.3% and 0.6%, respectively, of standard heat quantity at the inlet of LNG terminal. Methane vent is about 0.1% in the production (dewatering) process, and about 0.2% in the liquefaction (acid-gas removal) process. CO_2 content averages about 5.3%. The ultimate objective of our assessment is to learn CO_2 emissions per unit heat value of final demand. Environmental load obtained so far is assessed in reference to LNG standards at the outlet of LNG terminal. Our assessment assumes "complete combustion of all LNG imported to Japan" as the standard case. Part of LNG shipped from a LNG terminal is consumed while transported by a LNG tanker as its fuels. For this reason, when calculating CO_2 emissions per Mcal of LNG demand in a consuming area (Japan), any exporting country is required to make an assessment per unit heat quantity by taking such transportation losses into account (Table 4-2).

4-2 Environmental load of LNG transportation

LNG is transported by LNG tanker for exclusive use. LNG tanker is fueled effectively by boil off gas (BOG) of LNG, the cargo, though C heavy fuel oil is put to combined use. The ratios of BOG and C heavy fuel oil consumption depend on specific elements of tanker in service, such as insulating performance of LNG tanks, engine efficiency, sailing velocity and operation. Naturally CO_2 emissions resulting from burning of these fuels vary. Therefore, in order to learn CO_2 emissions while LNG transportation, we first produced a weighted average by weighing tanker-specific data on BOG consumption, C heavy fuel oil consumption, tonnage of LNG cargoes and transportation distance by route-by-route LNG import records. Then, from the outcomes, we calculated carbon intensity of 1km-transporation of a ton of LNG (g-C/t•km). Subsequently, we calculated an environmental load at the stage of LNG transportation by multiplying resultant carbon intensity by a weighted average of transport distances actu-

Table 4-1 CO_2 and CH_4 Emissions at Natural Gas Production and Liquefaction Stages

		Min.	Max.	Weighted average
Production	Fuel gas	0.02	1.07	0.62
	CH_4 vent	0.00	1.46	0.29
	Flaring	0.10	0.26	0.18
Liquefaction	Fuel gas	5.46	6.57	6.01
	CH_4 vent	0.04	4.83	0.78
	Flaring	0.00	0.76	0.33
	CO_2 content of feedstock	6.50	0.06	2.63

(Note) Standards gained at the outlet of LNG terminal.

Table 4-2 LCCO$_2$ Analysis of Mining & Liquefaction Processes (In-situ Natural Gas Consumption Taken Into Account)

Item		LNG
Mining	Fuel gas	0.64
	Flaring	0.18
	CH_4 vent	0.30
Liquefaction	Fuel gas	6.16
	Flaring	0.34
	CH_4 vent	0.80
CO_2 content of mining gas		2.70

ally recorded in moving the whole of LNG imports to Japan.

We could obtain necessary data on 44 LNG tankers out of a total of 65 regularly in service to Japan. Weighted average of BOG consumption, C heavy fuel oil consumption, tonnage of LNG cargoes and transport distance of the 44 tankers are 1,155 MT, 513 MT, 52,977 MT and 5,540 km (one-way trip), respectively. These put carbon intensity at 2.179 g-C/(t•km). Given Japan's total LNG imports and resultant weighted average of transport distance, or 6,311 km, our calculation result showed that an environmental load incurring in transporting the whole of LNG imports to Japan was 2.116 g-C/Mcal.

4-3 LCI analysis results of LNG

So far considered are environmental loads attributable to LNG at various stages. Environmental load while LNG burning was assumed at 56.39 g-C/Mcal.

Analysis results (Table 4-3) show that, on a gross heat value basis, environmental load amounts to 1.12 g-C/Mcal while mining, 10.00 g-C/Mcal at liquefaction stage, 2.12 g-C/Mcal while transportation, 0.14 g-C/Mcal from equipment construction, and 56.39 g-C/Mcal while burning. On a net heat value basis, corresponding figures are 1.24 g-C/Mcal while mining, 11.00 g-C/Mcal at liquefaction stage, 2.36 g-C/Mcal while transportation, 0.16 g-C/Mcal from equipment construction, and 62.66 g-C/Mcal while burning.

4-4 Life cycle inventory of town gas (13A)

LCCO$_2$ assessment of town gas (13A) is discussed here. While completely identical to LCCO$_2$ of LNG in principle, town gas involves different weighted average values of GHG emissions while mining and liquefaction in producing country and of transportation distance, because the makeup of feedstock LNG supply sources is different from LNG supply mix employed in Japan's general statistics.

Also, the town gas production involves gasification and a heat quantity increase by LPG at domestic plant. To include end users in the assessment, GHG emissions from the secondary transportation to the domestic plant must be assessed as well. In the subsequent sections, LCCO$_2$ assessment of town gas is described mainly in different points from LNG case.

4-4-1 Production & liquefaction processes

The assessment method and the data on producing countries are exactly the same as in LNG assessment. We produced a weighted average by weighing relevant data by Japan's LNG imports specifi-

Table 4-3 LCI Analysis Results of LNG

Item		Carbon intensity (g-C/Mcal)	
		High heat value	Low heat value
Mining	Fuel gas	0.64	0.71
	Flaring	0.18	0.21
	CH_4 vent	0.30	0.33
	Sub-total	1.12	1.24
Liquefaction	Fuel gas	6.16	6.84
	CO_2 content of mining gas	2.70	2.99
	Flaring	0.34	0.38
	CH_4 vent	0.80	0.89
	Sub-total	10.00	11.00
Overseas transport		2.12	2.36
Equipment		0.14	0.16
Total		13.38	14.87
Carbon intensity by fuel		56.39	62.66

cally for town gas production (Table 4-4).

4-4-2 LNG transportation

A weighted average of transport distances from exporting countries of LNG for town gas production was 5,075 km. From this, we calculated an environmental load specifically attributable to town gas feedstock LNG, which was 1.70 g-C/Mcal. The calculation method was the same as employed in LNG case.

4-4-3 Domestic production of town gas

GHG emissions from domestic gas production plants are discussed below. At domestic plants, LNG is given the treatments of pressure boost and gasification, then moved to the burner chip of end users (Fig. 4-2). Namely, because LNG gasifies under atmospheric temperature and pressure, energy used at domestic plants can be regarded as extra energy involved in compressed forwarding (transportation) of LNG, which is required depending on type of demand.

(1) CO_2 emissions resulting from fuel consumption

We first obtained how much energy was consumed in gasification of LNG, boosting of heat quantity, etc. at domestic LNG terminals run by the three gas utilities. Then, we calculated CO_2 emissions that resulted from annual energy consumption involved in the operation of LNG terminals. By dividing the outcome by annual town gas throughputs produced carbon intensity (Table 4-5). With an inventory analysis, an all-power-plant average can be used as carbon intensity of electricity when "static-state amounts" of various inventories are to be assessed. However, when an environmental impact assessment is made on electricity demand fluctuations, energy selection, etc. by using inventory analysis results, such an assessment can be based on the inventory results gained by using carbon intensity of all-fossil-fired average. It is because generated output at fossil-fired power plants fluctuates along with electricity demand fluctuations.

In our calculation, we put carbon intensity of LNG at 56.4 g-C/Mcal. Carbon intensity of electricity is counted in two ways, based on an all-thermal-plant average and an all-power-plant average, the former assumed at 173.5 g-C/kWh and the latter at 93 g-C/kWh in our calculation.

(2) Greenhouse effect of LPG use in boosting heat quantity

LNG-gasified gas (9,600 - 10,800 kcal/Nm^3 or so) has its heat quantity boosted by LPG to 11,000 kcal/ Nm^3 before supplied as town gas 13A. Given this LPG use in the town gas production, we added,

Table 4-4 CO_2 and CH_4 Emissions at Production and Liquefaction Stages of Natural Gas (for Town Gas Production)

Item		Weighted average
Production	Fuel gas	0.62
	CH_4 vent	0.27
	Flaring	0.18
Liquefaction	Fuel gas	6.01
	CH_4 vent	0.61
	Flaring	0.37
CO_2 content of feedstock		2.32

(Note) Standards gained at the outlet of LNG terminal.

Fig. 4-2 Town Gas Manufacturing Processes at Domestic LNG Terminal

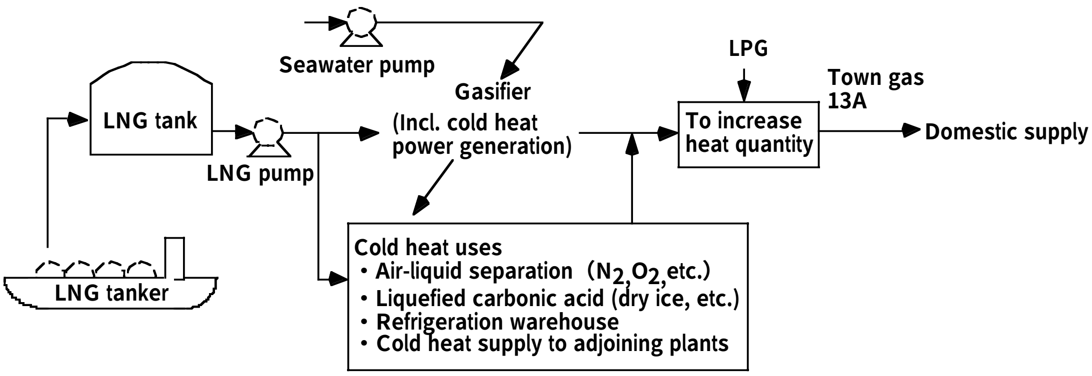


Table 4-5 Energy Consumption at Town Gas Production Stage

Energy consumption	In-plant consumption at LNG terminal	252Tcal
	Commercial power services	184GWh
Annual gas throughputs	166.000Tcal	

(Note) 1996 records of the three gas utilities to our town gas assessment, GHG emissions from LPG cycle, such as resource mining, production and transportation. GHG intensity in LPG cycle was borrowed from our LPG analysis results.

(3) Use of cold heat of LNG

When town gas is produced, cold heat generating from gasification of LNG of -162℃ is recovered. Recovered cold heat of LNG is used in cold-heat power generation and air separation of liquid nitrogen manufacturing, among others. In case of cold-heat power generation (employed in in-plant power generation), its electricity-saving effect was counted in considering energy needs for plant operation. On the other hand, energy-saving effects of cold heat uses in air separation, etc. are not assessed in the life cycle analysis of town gas. Therefore, covering cold-heat projects at domestic LNG terminals run by the three gas utilities, we surveyed electricity needs for such projects in two cases: when cold heat was supplied, and when not supplied (Tables 4-1, 4-6). The gap between the two cases was taken as the electricity-saving amount by the use of cold heat, from which we calculated CO_2 reductions achieved by the use of LNG-derived cold heat. We calculated this CO_2 reduction effect in two ways by using carbon intensity of thermal-power-plant average and of all-power-plant average. The calculation results showed the former led to a reduction of 0.308 g-C/Mcal, and the latter of 0.16 g-C/Mcal.

Based on these results, we calculated CO_2 reduction effect of the LNG-derived cold heat use by putting carbon intensity of electricity at 93 g-C/Mcal (all-power-plant average) and total town gas throughputs at 166,000 Tcal. The outcome is shown in Table 4-7. When the same was calculated by putting carbon intensity of electricity at 173.5 g-C/Mcal (power plant) and total town gas throughputs at 166,000 Tcal, the outcome turned as shown in Table 4-8.

When calculated by using an all-power-plant average, or 93 g-C/Mcal, carbon intensity of the air separation process is reduced to 0.155 g-C/Mcal, down from 0.290 g-C/Mcal, and that of liquefied carbonic acid & dry ice manufacturing to 0.004 g-C/Mcal, down from 0.008 g-C/Mcal. Carbon intensity of other uses also goes down from 0.01 to 0.006 g-C/Mcal. With all these adding up, carbon intensity is reduced to a total of 0.165 g-C/Mcal, down from 0.308 g-C/Mcal. Accordingly, the gap between the all-thermal-plant and all-power-plant averages is 0.144 g-C/Mcal.

Because results vary depending on selected power source in this way, it is desirable to select ap-

Table 4-6 Energy Savings by LNG Cold Heat Use

Project of LNG cold heat use		Air separation Production of liquefied O_2, N_2	Liquefied carbonic acid Production of dry ice	Others a)
LNG input (1,000 tons/year)		1168	78	53
Product output (output/year)		486 mil. m^3/y	840,000 tons/y	4 mil. RTh/y
Electricity intensity (kWh/unit output)	With LNG cold heat in use	0.43 kWh/Nm^3	0.09 kWh/kg	c)
	Without LNG cold heat in use b)	1.00 kWh/Nm^3	0.19 kWh/kg	
	Reduced electricity intensity	0.57 kWh/Nm^3	0.09 kWh/kg	
Annual consumption of commercial power services		277	8	10

(Notes a) Cold heat supplies to refrigeration warehouses and adjoining plants.
b) Electricity intensity without LNG cold heat use is at-receiving-end standard.
c) Due to plural projects, intensity is not shown here.

Table 4-7 CO_2 Reductions When Calculated with Carbon Intensity of All-Power-Plant Average

Project of LNG cold heat		Air separation Production of liquefied O_2, N_2	Liquefied carbonic acid Production of dry ice	Others
Intensity of CO_2 reduction (g-C/Mcal)	By type of project	-0.155	-0.004	-0.006
	All projects	-0.165		

Table 4-8 CO_2 Reductions When Calculated with Carbon Intensity of All-Thermal-Power-Plant Average

Project of LNG cold heat		Air separation Production of liquefied O_2, N_2	Liquefied carbonic acid Production of dry ice	Others
Intensity of CO_2 reduction (g-C/Mcal)	By type of project	-0.29	-0.008	-0.01
	All projects	-0.308		

Table 4-9 LCI Analysis Results of Town Gas

Item		Carbon intensity (g-C/Mcal)	
		High heat value	Low heat value
Mining	Fuel gas	0.61	0.68
	Flaring	0.17	0.19
	CH_4 vent	0.27	0.30
	Sub-total	1.05	1.17
Liquefaction	Fuel gas	5.90	6.56
	CO_2 content of mining gas	2.29	2.54
	Flaring	0.36	0.40
	CH_4 vent	0.60	0.67
	Sub-total	9.15	10.17
Transportation	Operation	1.64	1.82
Town gas production	Operation	0.29	0.32
	Cold heat use	-0.31	-0.34
	LPG to boost heat quantity	0.30	0.33
	Sub-total	0.28	0.31
Equipment		0.16	0.18
Total		12.28	13.64
Carbon intensity by fuel		58.39	64.88

(Note) The CO_2 reduction effect of lesser amount of purchased electricity, thanks to LNG-derived cold heat use at domestic plants, was calculated by using carbon intensity of all-fossil-fired average. The amount of purchased electricity by plants was also calculated by using all-fossil-fired-average carbon intensity. Domestic supply (gas pipeline construction) is responsible for 0.43 g-C/Mcal on a gross heat value basis, and 0.48 g-C/Mcal on a net heat value basis. Accordingly, with all combined, from the production stage abroad to liquefaction plant, LNG tanker, domestic plant and pipeline construction, the figures are 0.59 g-C/Mcal on a gross heat value basis and 0.66 g-C/Mcal on a net heat value basis.

propriate carbon intensity for a given objective of assessment.

4-4-4 Life cycle inventory of town gas (13A)

Table 4-9 presents the outcomes of life cycle inventory analysis of town gas (13A) at end users, which was made based on the results described in the preceding sections 1-4. Meanwhile, CO_2 emissions per Mcal at the final consumption stage were assessed. The calculation results include LPG used in boosting heat quantity to manufacture town gas of 13A class, which accounts for about 3.9% of the feedstock.

5. LPG

5-1 Status quo of LPG supply and the scope of study

To make an assessment of the whole of LPG supplied to domestic consumers, we calculated GHG emissions from such stages as mining, manufacturing and overseas transportation of LPG supplied from three sources listed in Japan's general energy statistics: LPG produced and imported from gas fields, LPG produced and imported from oil fields, and LPG produced and supplied from domestic refineries (Table 5-1).

We could obtain few detailed data on environmental load of LPG at the production stage. Therefore, we made the basic allocation based on the shares held by oil-associated gas, non-associated gas and domestic production in LPG production mix, from which a weighted average was produced. This way of allocation is acceptable to the mining stage. But, energy consumption at the liquefaction process of LPG production must be calculated from original data. This time, to cover the oil-associated portion, we employed oil figures for mining, then added energy needs for LPG liquefaction. As in the rest of this study, it was better to base our calculation on actual records. But, without relevant data obtained, we had few choices but to depend on simulation results. The figures for LNG and domestic production were obtained in heat quantity terms and in proportion to their shares in the LPG demand-supply mix shown in Table 5-1. With these methods in use, we calculated individual factors of production, flaring, associated gas and methane emission. As for equipment-related data, calculations were made originally for LPG tankers for marine transportation, while a weighted average was obtained for overseas producing-equipment. Energy needs for marine and domestic transportation were calculated from original data on LPG.

5-2 Environmental load of production

5-2-1 Mining

LPG can roughly be divided into two: LPG produced from associated gas that generates when pumping up crude oil and LNG at oil and gas fields, and LPG produced from crude oil processing at refinery. About 99% of domestic LPG supply come from oil-associated, gas-associated and domestic refinery sources. The remaining 1% is produced at domestic chemical plants. In calculating environmental load of LPG production, a weighted average in heat quantity terms was obtained through the basic allocation. The outcomes were taken as the environmental load of LPG at its production stage (Table 5-2).

5-2-2 Liquefaction

Environmental load of LPG at its liquefaction stage was calculated by seeking a weighted average in heat quantity terms through the basic allocation. Yet, while necessary data on LNG liquefaction and LPG production at refinery were gained from refinery and LNG assessment results, respectively, we were able to obtain few data on LPG liquefaction at oil fields. We did have detailed data on a LPG production plant at a domestic oilfield. But, given that the plant size stands no comparison with its overseas counterparts, to take a representative value from the domestic plant was unreasonable. Accordingly, we employed simulation results, which were based on designed values for a plant having an identical capacity to overseas plants.

We describe below the production scale and gas compositions employed in the simulation of the designed plant for oil-associated gas production. Assumptions of the simulation are depicted as well.

Among the data on oil-associated LPG production employed in the assessment, annual operating hours of the plant were put at 8,330 hrs/year, and annual gas throughputs at 1,479,369 tons/year. Compositions and high heat values (HHV) of feed gas/fuel gas were employed as well (Table 5-3).

Fuel gas consumption was assumed at 836,278 tons/year, and annual product output at 140,752 tons/year of propane, 69,713 tons/year of butane and 45,474 tons/year of naphtha. Heat values are 12,023,663 tons/year for propane, 11,818,596 tons/year for butane ad 11,345,823 tons/year for naphtha. Compositions of the products (wt) were assumed as shown in Table 5-4.

Output was designed at 31 tons/hour. Given the compositions and HHV of feed gas/fuel gas, heat value of the product amounts to 364,011,100 kcal/hour. In comparison, in-plant energy consumption includes 9,789,494 kcal/hour by acid-gas separators, 3,436,013 kcal/hour by freezers and 8,811,071 kcal/hour by other units.

Accordingly, carbon intensity from the liquefaction plant of associated gas is 3.53 g-C/Mcal (Table 5-5).

Table 5-1 LPG Supply and Demand Records

(Unit: 1,000 tons)

			Propane	Butane	Total	Share Major classification	Share Minor classification
Supply	Oil refining		2,255	2,071	4,326		22.14
	Petrochemical		83	128	212		1.08
	Imports		-	-	15,004	100	
		Crude-associated	-	-	12,004	80.01	61.43
		Non-associated	-	-	3,000	19.99	15.35
	Grand total		-	-	19,542	-	100

(Source) Prepared from the reference materials of MITI and the Japan LPG Association.

Table 5-2 Environmental Load of LPG Production

(Unit: g-C/Mcal)

	Oil-associated (incl. domestic production) Note 1	LNG-associated Note 2	LPG
Fuel gas	0.84	0.62	0.81
Flaring	0.64	0.18	0.57
Associated CO_2	-	2.63	0.39
Vent	0.03	0.29	0.07
Total	1.51	3.72	1.84

(Notes) 1. These figures show environmental loads resulting from crude oil production at oil fields. This type accounts for 85% of total domestic LPG supply.
2. These figures show environmental loads resulting from LNG production at gas fields. This type accounts for 15% of total domestic LPG supply.

With these calculation results summed up, fuel gas in the liquefaction process is responsible for 3.77 g-C/Mcal, the flaring fuel stage 0.05 g-C/Mcal, and methane vent 0.12 g-C/Mcal, or 3.94 g-C/Mcal when combined. Based on these results, environmental loads of LPG production are 1.45 g-C/Mcal while mining and 3.94 g-C/Mcal while liquefaction. CO_2 contents of mining gas were 0.39 g-C/Mcal.

5-3 Environmental load of LPG transportation

Transport fuel consumption was calculated for a tanker of standard type, with a tank capacity put at 77,055m^3 and stowage factor at 98%. Fuel consumption while sailing was gained by adding average fuel needs, 2.25 MT/D, for re-liquefaction units while sailing with and/or without cargoes of 50.45 MT/D. Fuel consumption while mooring was gained by adding 60 MT/D. Cargo weight is put at 0.583 for propane and 0.602 for butane based on the propane & butane import ratios by area. The ratios are 0.589 for the Middle East, 0.591 for Asia and 0.594 for Australia.

With Port Chiba designated as the spot of arrival in Japan, area-by-area sailing distances were calculated back from a weighted average of area-by-area imports. The outcomes are shown in Table 5-6.

Based on these assumptions, our calculation results showed that C heavy fuel oil was responsible for 2.66 g-C/t•km, and A heavy fuel oil for 0.043 g-C/t•km. These put the fuel consumption rate of area-by-area LPG transport at 2.798 g-C/t•km for a round trip, and 1.354 g-C/t•km for a one-way trip.

When calculated with area-specific distances, it turns to be 1.37 g-C/Mcal from the Middle East and 0.55 g-C/Mcal from the South. These put a weighted average by LPG imports mix by area at 2.40 g-C/Mcal.

Given 2.40 g-C/Mcal attributable to direct fuel consumption by LPG import tankers and 0.86 g-C/Mcal specifically attributable to LPG, the latter gained as a weighted average from the environmental load assessed for oil tankers, an environmental load of LPG supply amounts to 2.05 g-C/Mcal.

5-4 Environmental load of equipment construction

We assessed an environmental load of equipment construction in the full range from overseas production to transportation and domestic refining. Because this sort of study is rarely made, and because few updated data are available, we referred to the report of the Central Research Institute of Electric Power Industry (CRIEPI). Yet, as the CRIEPI report made model-based calculations, it is not easy to distinguish

Table 5-3 Compositions and Heat Values of Feedstock•Fuel Gases

Name of gas	Feedstock gas	Fuel gas	Name of gas	Feedstock gas	Fuel gas
	% (mol)	% (mol)		% (mol)	% (mol)
CH_4	61.67	84.03	C_6+	0.76	0.01
C_2H_6	10.18	14.46	H_2+Acid	19.14	0.34
C_3H_8	5.24	1.10	Total	100.00	100.00
i-C_4H_{10}	0.73	0.01			
n-C_4H_{10}	1.26	0.01	HHV(kcal/kg)	9117.00	12928.00
i-C_5H_{12}	0.45	0.02	MW	24.69	18.65
n-C_5H_{12}	0.57	0.02	g-C/Mcal		58.39

Table 5-4 Compositions of Products Produced at Plant

Name of gas	Propane	Butane	Naphtha
CH_4	0	0	0
C_2H_6	1.1	0	0
C_3H_8	98	0.7	0
i-C_4H_{10}	1	35.8	2.2
n-C_4H_{10}	0	63.3	16.4
i-C_5H_{12}	0	0.2	28.1
n-C_5H_{12}	0	0	31.7
C_6+	0	0	21.6

Table 5-5 Environmental Load of LGP Liquefaction Process

(Unit: g-C/Mcal)

	Oil-associated (Note 1)	LNG-associated (Note 2)	Refinery (Note 3)	LPG
Fuel gas	3.53	6.01	3.09	3.77
CH_4 vent	-	0.78	-	0.12
Flaring	-	0.33	-	0.05
Total	3.53	7.12	3.09	3.94

(Notes)
1. The figures are based on a simulation of LPG liquefaction plant at oilfield.
2. The figures are based on an assessment of actual records at LNG liquefaction stage.
3. The figures are based on an assessment of environmental loads (national average) resulting from crude oil processing at refinery.

production and liquefaction plants and overseas transport tankers from each other. The report offered no assessment on domestic refinery, either. Therefore, as shown in the following equation, we counted in our calculation LPG shares in the import mix for covering the production stage, plus the portion transported by LPG tankers.

LPG equipment = (oil-associated - oil transport X supply share) + (LNG-associated - LNG transport X supply share) + (oil-associated X supply share: domestic production) + LPG tanker portion

As a result, an environmental load of LPG production was put at 0.13 g-C/Mcal. Of it, LPG tankers are responsible for 0.06 g-C/Mcal.

5-5 Environmental load of domestic transport

Environmental load of domestic transport is considered by dividing into land and marine transport. First, specifications of the vehicle (tank lorries) subject to land transport assessment are as follows: 10-ton (7.7 - 9.0 tons) lorry in size, freight tonnage of 20 tons, fueled by diesel, fuel economy at 3 km/l, delivery distance at 250 km. On these assumptions, the environmental load was put at 0.505 g-C/Mcal.

Next, specifications of the tanker (coastal tankers) subject to marine transport assessment are as follows: 700 DWT in size, 1,500-horsepower engines mounted, fueled by C heavy fuel oil, fuel consumption rate at 4.6 tons/24 hrs. As the grounds for calculation, hourly horsepower is put at 160g horsepower hour and sailing speed at 1.852 km/knot because the number of knots (velocity) is 12 - 15. Output is assumed at 80% of gross output. Sailing hours are 24 hours. On these assumptions, calculation result showed 0.525 g-C/Mcal. A weighted average gained from these figures for tank lorries and coastal tankers is 0.51 g-C/Mcal.

5-6 LCI analysis results of LPG

Summarizing these results puts that, at the production stage, mining fuel gas is responsible for 4.58 g-C/Mcal, flaring 0.62 g-C/Mcal, associated CO_2 0.39 g-C/Mcal and methane vent 0.19 g-C/Mcal. Corresponding figures are 2.05 g-C/Mcal for the transportation stage and 0.13 g-C/Mcal for equipment construction (Table 5-7).

6. Summary

As described so far, we made a life cycle inventory (LCI) analysis of fossil energies consumed in Japan. As stated in the objective of this study, there are ever-growing concerns over global warming problems. Under such circumstances, we could grasp life-cycle GHG emissions, from production to transportation and consumption, as exactly as possible for the moment. We believe our analysis results can be of some help to studying LCA (life cycle assesment) for many other fields. Our LCI analysis results are summarized in Table 6-1.

We are confident that our calculation results may

Table 5-6 Fuel Consumption in LPG Transport by Area

	Weighted-average transport distance	LPG imports	Cargo tonnage by standard tanker	Number of times of round trip	Fuel consumption
	(Round-trip miles)	(MT/Y)	(MT/round trip)	(Times/Y)	(MT/round trip)
Middle East	13,147	11,958,467	44,478	268.9	1,770
Asia	5,221	2,445,396	44,629	54.8	737
Australia	7,364	671,753	44,855	15.0	1,016

Table 5-7 LCI Analysis Results of LPG

Category		Carbon intensity (g-C/Mcal)	
		High heat value	Low heat value
Production	Fuel consumption	4.43	4.82
	Flaring	0.61	0.66
	CO_2 content of mining gas	0.41	0.45
	Methane vent	0.19	0.21
Overseas transport		2.05	2.23
Equipment		0.13	0.14
Sub-total		7.82	8.51
Carbon intensity by fuel		68.33	74.27
Domestic transport		0.51	0.55

Table 6-1 Comparison of Environmental Loads of Different Fossil Energies

(Unit: g-C/Mcal)

	Coal		Oil		LNG		LPG	
	High heat value	Low heat value	High heat value	Low heat value	High heat value	Low heat value	High heat value	Low heat value
Production	5.23	5.45	4.64	4.99	11.12	12.35	5.89	6.42
Transport	1.95	2.03	0.90	0.97	2.12	2.36	2.05	2.23
Equipment	0.13	0.14	0.09	0.10	0.14	0.16	0.13	0.14
Carbon intensity by fuel	101.07	105.28	78.01	83.88	56.39	62.66	68.33	74.27
Total	108.38	112.90	83.63	89.92	69.77	77.52	76.40	83.04

provide some criteria when considering energy and environmental policies from the global perspective. COP3 set forth country-by-country emissions reduction targets. Yet, warming problem is a global issue. It means to consider the best energy mix, endorsed by LCI analysis results, is essential in successfully advancing global warming abatement efforts.

While specific institutional designs of Kyoto Mechanism are under examination, to consider specific mechanisms of JI and CDM based on the life cycle concept may be an important subject as well.

In the days ahead, it is recommended to consider supply and demand of the right energies in the right uses by gathering and analyzing more detailed data than ever and by making LCA of fossil energies by use.

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