Report on Life Cycle Inventory (LCI) Analyses of Refrigerators

June, 2014

The Japan Electrical Manufacturers' Association
The Environmental Technical Expert Committee
The LCA-WG (Life Cycle Assessment – Working Group)

Since September 2010, the LCA-WG of the Environmental Technical Expert Committee of the Japan Electrical Manufacturers' Association has carried out the life cycle inventory analyses of the refrigerators. Thus, the results were compiled in the report. In addition, the contents after "section 1. Introduction" have already been contributed as research materials to *"Journal of Life Cycle Assessment, Japan*" published by the Institute Life Cycle Assessment, Japan.

Table of Contents

1. Introduction

In relation to the LCA of home electric appliances, a case study regarding electric refrigerators (hereafter referred to as refrigerators) was carried out in 1994 as a committee activity of the Japan Environmental Management Association for Industry.[1)] In this study, the Japan Electrical Manufacturers' Association (hereafter referred to as JEMA)also cooperated, and a comparison was made regarding the CO_2 emission amounts in the life cycles of the refrigerators using specified chlorofluorocarbon and the refrigerators using alternative chlorofluorocarbon. In 1996, Tahara et al. compared how differences in basic units of various build-up methods and inter-industry relation table analyses would influence the CO_2 emission amounts.[2)]

JEMA carried out the LCI analyses of refrigerators in the 1999 business year, and compiled the report.[3)] At this time, the CO_2 emission amounts related to the life cycle as a whole was 2,833 kg. When the respective life cycle stages were compared, the total amount in the usage stages was the largest, accounting for 96 percent of the whole. However, product specifications and life cycle scenarios have been rapidly changing in recent years as seen in such examples as improving energy saving performances in the usage stages as a result of adopting vacuum insulation panels, highly efficient compressors, and other items. Other examples included recycle plants that have been operated as home appliance recycling laws have come into force, manufacturing bases that have been moved to overseas locations, and criteria for measuring electrical power consumption levels that have been altered.

Thus, appropriate representative models for the 2010 refrigeration year (from October 2009 to September 2010) and life cycle scenarios were decided, and the LCI analyses were carried out for the purpose of re-evaluating the CO_2 emission amounts of the life cycles as a whole and the percentages of the respective life cycle stages.

In addition, it was assumed that the products of the 1999 refrigeration year were replaced with the products of the 2010 refrigeration year, and a comparison was made after recalculating the matters related to the products of the 1999 refrigeration year, based on the calculation conditions of the products of the 2010 refrigeration year.

2. The Scope

2.1 The Targeted Products

The specifications of the targeted products are shown in Table 1.

Table 1: The Specifications of the Targeted Products

	The refrigerators in the 1999 Refrigeration Year	The refrigerators in the 2010 Refrigeration Year
The Rated Capacity	About 400 L	501 L
The Number of Doors	4 Doors or 5 Doors	6 Doors
The Method of Measuring the annual Power consumption	JIS C 9801:1999	JIS C 9801:2006*
The Sales Periods	The 1999 Refrigeration Year (from 1998/10 to 1999/9)	The 2010 Refrigeration Year (from 2009/10 to 2010/9)
The Refrigerant	HFC134a (alternative chlorofluorocarbon)	R600a (Isobutane)
The Foaming Agent of Heat Insulator	Cyclopentane	
Heat Insulator	Urethane Foam	Urethane Foam + Vacuum Insulation Panel
The Product Mass (including the Packaging Materials)	85.1 kg (the Average of 5 Companies)	102.5 kg (the Average of 3 Companies)

* Main changed points: Ambient temperatures (changed from 25°C for 365 days to 15°C for 185 days + 30°C for 180 days), an installation condition (the side gap was changed from 30 cm to 5 cm), load inputs in the refrigerators, the number of times of opening and closing the refrigerator doors (from 25 times a day to 35 times a day), and operations of added functions such as an ice making machine.

2.2 The System Boundaries

For the purpose of carrying out the research, the system flow was set as described in Figure1. It was decided that all the matters included in the thick lined frame shown in Figure 1 were within the system boundaries.

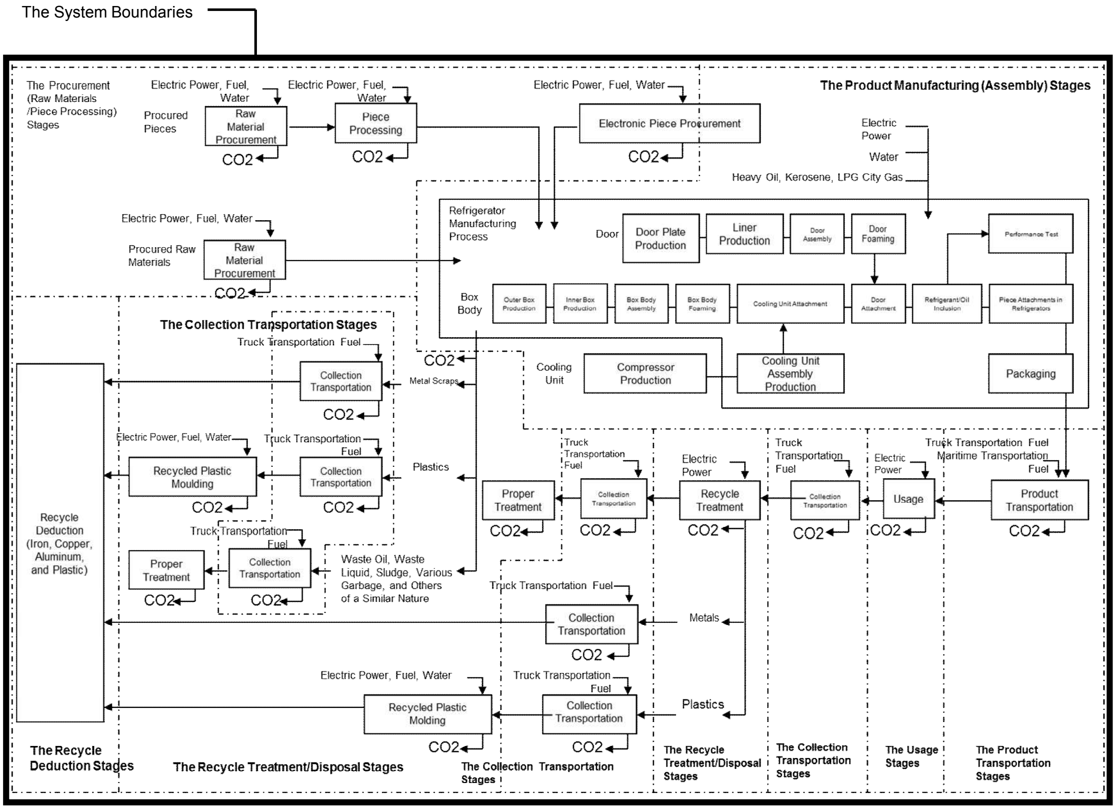

Figure 1: The System Boundaries

3. The Collection Procedures of the Life Cycle Inventory Data

3.1 The Procurement (Raw Material/Parts Processing) Stages

3.1.1 The Collection of the Component Composition Data

Among the six refrigerator manufacturers affiliated with JEMA, data were collected from three manufacturers according to the items listed in Table 2 regarding the component composition (design weight) of the main bodies of the 501 L refrigerators and the packaging materials. Then, the average value was adopted. Figure 2 shows the mass component ratios that were aggregated per component listed in the leftist column of Table 2. In addition, among the six refrigerator manufacturers, data was collected from two manufacturers regarding the iron and plastic materials that were emitted in the product manufacturing (assembly) stages as processing scraps, defective products, and other materials without being used for the products. Then, the average values (0.91 kg for iron and 0.35 kg for plastic) were added as the loads in the procurement stages.

Table 2: The Raw Material Composition List

Large Category	Middle Category	Small Category
Iron and steel	Surface Treated Steel	Precoated Steel Plate（Including Paint)
		Plated Steel Plate
		Polyvinyl Chloride-Plated Steel Plate (Including Polyvinyl Chloride)
	Stainless Steel	Sum of Martensitic, Ferrite, and Austenite Stainless Steel
	Other Iron and Steel	Sum of Surface Untreated General Steel, Special Steel and Other Materials
Copper	Copper	Except for Conducting Wire Materials → See the Separate Item (“Conducting Wire”)
	Copper Alloy	Sum of Brass (Cu-Zn), Bronze (Cu-Sn), Beryllium Copper, and Other Materials
Aluminum	Aluminum	Except for Conducting Wire Materials → See the Separate Item (“Conducting Wire”)
	Aluminum Alloy	Die-Casting (Al-Si-Cu) and Other Materials
Plastics	Plastics	Polyethylene (PE)
		Polypropylene (PP)
		Polystyrene (PS)
		Expanded Polyethylene (EPS)
		Expanded Polyurethane (EPUR)
		ABS
		Polyvinyl Chloride (PVC)
		ASA (Acrylonitrile-Styrene-Acrylate)
		Methacryl (PMMA)
		Polyacetal (POM)
		Polyamide (PA)
		Polyethylene Terephthalate (PET)
		Phenol (PF) Resin
		Other Resin
		Materials (Including Materials Whose Resin Breakdown Is Unknown) Other Than Those Described Above
	Fiber Reinforced Plastic	Glass Fiber Reinforced Plastic
Electronic Circuit Boards	Circuit Boards	Circuit Board with Parts (after Dipping)
Others	Other Alloys	Sum of Titanium Alloy, Zinc Alloy, Brazed and Soldered Alloy, Sintered Alloy, and Other Materials
	Magnet (without Binders)	Sum of Ferrite, Soft Ferrite, Alnico, Cobalt Magnet and Other Materials
	Bond Magnet	Gum Magnets for the Refrigerator Doors and Other Materials Kneaded into Binders
	Rubber	Rubbers Including Chlorine/Bromine (Chloroprene Rubber and Other Rubbers)
		Rubbers Excluding Chlorine/Bromine
	Glass	
	Ceramic	
	Gas	Non Chlorofluocarbonic Refrigerant (Isobutane)
		Thermal Insulating Material Foaming Agent (Cyclopentane)
	Lubricating Oil	Refrigerating Machine Oil
	Conducting Wire	Conducting Material: Copper
		Covering Material: Polyvinyl Chloride (PVC)

		Covering Material: Other Than Polyvinyl Chloride (PVC)
	Packaging and Instruction Manual Materials	Wood Materials
		Cardboard
		Printing Paper (Instruction Manuals and Other Materials)
		Resin Sheets (Polyethylene (PE), Polypropylene (PP))
		Styrene Foam (Expanded Polystyrene (EPS))
		Binding Band (Polypropylene (PP))
	Other Raw Materials	Glass Fiber (Vacuum Insulating Material)
		PET Fiber, Cold Storage Agent
		Items Such as Small Parts That Consist of Multiple Raw Materials and Whose Raw Material Breakdowns Are Unknown

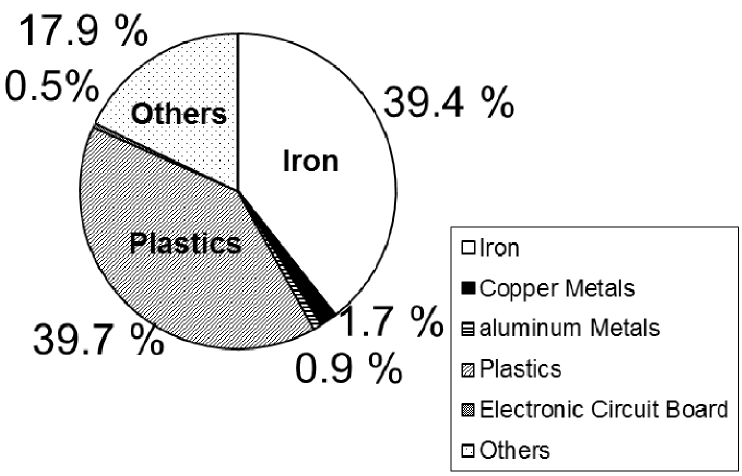

Figure 2: The Component Compositions (Mass) in the Procurement Stages

3.1.2 The Handling of Outsourced Parts

Among the component parts of the refrigerators, plated steel plate s, inner boxes, door liners, expanded polyurethane, and vacuum insulation panels were categorized as in-house parts that were processed and made in the in-house factories (in the refrigerator manufacturing process shown in Figure 1) after purchasing the raw materials and other items. Other parts were categorized as outsourced parts that were processed and made outside the in-house factories and that were input into the refrigerator manufacturing process of the in-house factories. The mass ratio of the in-house parts and the outsourced parts was 36%:64%. Thus, the mass of the outsourced parts was larger than the mass of the in-house parts. In relation to the outsourced parts, the environmental loads of processing the parts were taken into account by using basic units of molding plastic materials (including the packaging materials), press processing for magnet, copper, aluminum, and other alloys, and cold roll processing for iron. However, the yield rates of the outsourced parts were not taken into account.

3.2 The Product Manufacturing (Assembly) Stages

3.2.1 The Collection of Input Energy in the In-House Parts Manufacturing and Product Assembly

Stages

The input energy levels of the product manufacturing (assembly) stages (electric power, city gas, LPG (Liquefied Petroleum Gas), kerosene, heavy oil, water supply and sewerage systems, air, and steam), actual performance data were obtained from the refrigerator manufacturers (five manufacturers including the three manufacturers that submitted the component composition data). For the purpose of calculating the actual performance data, the input amounts corresponding to the manufacturing operations of the refrigerators (501 L) were divided on a pro rata basis according to the ratio of the shipment prices of the respective refrigerators. Then, the arithmetic mean value was adopted.

However, as for the input energy related to the compressor manufacturing operations, the values were cited from the research results of the LCI project of the refrigerators in the 1999 year. This was because the data were difficult to obtain as a result of outsourcing compressors for the products in the 2010 refrigeration year, and it was possible to view that the manufacturing processes in the 2010 refrigeration year were the same as the manufacturing processes in the 1999 year.

In addition, the process of moving the manufacturing bases to overseas locations has been progressing, so the product manufacturing operations in overseas were also taken into account. Thailand and China were selected as the manufacturing countries, both of which have become the actual manufacturing bases of such refrigerators. Basic units of these countries were used only for electrical power. As for basic units related to other energy types, components, and processing, there were no appropriate basic units, so Japan's domestic basic units were used.

3.2.2 The Handling of Waste Materials in the Product (Assembly) Stages

In relation to the emitted materials of the manufacturing factories (metals, plastics, and wastes (such as waste oil, waster liquid, sludge, and various garbage)), data were collected from the refrigerator manufacturers (two manufacturers out of the five manufacturers that were listed in section "3.2.1 The Collection of Input Energy in the In-House Parts Manufacturing and Product Assembly Stages," and the average values were used. It was considered that the metal and the plastic materials were totally recycled and were input in the recycle material manufacturing processes.

It was supposed that scrap metals, which were emitted in the manufacturing processes, were equivalents of chipped materials, iron was as an equivalent of crude steel, copper was as an equivalent of crude copper, and aluminum was an equivalent of aluminum metal. It was also decided that their manufacturing loads were deducted as they were recycled. The loads to make the chipped materials were included in the product manufacturing (assembly) stages. In relation to the plastics, it was considered that the manufacturing loads of polypropylene whose composition percentage was the largest (about 34%) were deducted as the plastics were recycled. The loads required for recycling the collected plastics were taken into account by using basic units of CO_2 emission required to mold such recycled plastics.

3.3 The Transportation Stages

In relation to the product transportation stages, it was decided as shown in Table 3 that the route started from the manufacturing bases, passed through the physical distribution bases and the retail shops, and reached the consumers. It was also considered that 40 refrigerators were loaded onto a 10-ton truck and were carried from the manufacturing bases to the physical distribution bases, and that 25 refrigerators were loaded onto a 4-ton truck and were carried from the physical distribution bases to the retail shops. The respective loading ratios were calculated based on each loaded mass. In relation to the transportation operations from the retail shops to the consumers, the loading ratio was not known. Thus, the average loading ratio of light freight vehicles (for business use) was used based on the "Guideline for Calculating CO_2 Emission Amounts in the Physical Distribution Field" (the Ministry of Economy, Trade and Industry/the Ministry of Land, Infrastructure, Transport and Tourism).[4)]

In relation to the transportation distances, it was decided that the distance from the manufacturing bases to the physical distribution bases was 500 km between Tokyo and Osaka. However, by taking into account of such matters as other packages that were loaded for the return trips in general, only one-way transportation trips were considered.

In addition, it was considered that, in the transportation stages, the manufacturing bases have also moved overseas, as seen in the case of the product manufacturing (assembly) stages. Thus, it was decided that the transportation scenarios included the overseas manufacturing operations that calculated maritime transportation operations by ship and other factors, as well as the domestic manufacturing operations. Table 3 shows the conditions related to the transportation distances, the loading ratios, and the transportation means.

Table 3: The Transportation Means and the Transportation Distances in the Transportation Stages (the Domestic Manufacturing and Overseas Manufacturing Scenarios)

The Manufacturing Bases	The Transportation Categories	The Names of the Transportation Means (Loading Ratios)	The Transportation Distances (km)
The Domestic Manufacture Scenarios	The Manufacturing Bases → The Physical Distribution Bases	10 t Truck (40%)	500
	The Physical Distribution Bases → The Retail Shops	4 t Truck (60%)	15
	The Retail Shops → The Consumers	Lightweight Truck (41%)	5
The Overseas Manufacture Scenarios	The Manufacturing Bases → The Ports	10 t Truck (40%)	100
	The Maritime Transportation Operations	Ships	*
	The Domestic Ports → The Physical Distribution Bases	10 t Truck (40%)	500
	The Physical Distribution Bases → The Retail Shops	4 t Truck (60%)	15
	The Retail Shops → The Consumers	Lightweight Truck (41%)	5

* Thailand: 5,813 km China: 2,111 km

3.4 The Usage Stages

It was decided that the refrigerators were used in Japan.

The annual power consumptions were set to be 287 kWh/year which was the arithmetic mean value of 290 kWh/year (regarding one manufacturer) and 280 kWh/year (regarding two manufacturers) that were the catalogue values (The annual power consumptions) of the refrigerators of each companies (based on the measurement method: JIS C 9801:2006).

The number of usage years of these products was estimated to be 10.4 years based on the "Actual Usage Situations of Home Appliances and Consumers' Awareness Research Report" (the Association for Electric Home Appliances).[5)] This was the result of researching the number of years that the consumers had retained their previously used refrigerators from the date of starting using them to the date of discarding them.

3.5 The Collection/Recycle Treatment and Disposal Stages

3.5.1 The Transport Distances of the Materials to be Collected/Recycled or to be Disposed

Table 4 shows the transportation distances and the transportation means in the collection/recycle treatment and disposal stages. As for the numbers of loading trucks, it was also considered, as seen in the case of the product transportation stages, that 40 refrigerators were loaded onto a 10-ton truck, and that 25 refrigerators were loaded onto a 4-ton truck. Then, the respective loading ratios were calculated based on each loaded mass. In relation to the transportation operations from the consumers to the retail shops, the loading ratio was not known. Thus, the average loading ratio of light freight vehicles (for business use) was utilized, based on the “Guideline for Calculating CO_2 Emission Amounts in the Physical Distribution Field” (the Ministry of Economy, Trade and Industry/the Ministry of Land, Infrastructure, Transport and Tourism).

Table 4: The Transportation Means and the Transportation Distances in the Collection Transportation Operations

The Transportation Categories	The Names of the Transportation Means (the Loading Ratios)	The Transportation Distances (km)
The Consumers → The Retail Shops	Lightweight Trucks (41%)	5
The Retail Shops → The Designated Collection Locations	4 t Trucks (60%)	15
The Designated Collection Locations → The Recycle Plants	10 t Trucks (40%)	80
The Recycle Plants → The Material Recycling Factories (Metal)	20 t Trucks (60%)	40
The Recycle Plants → The Material Recycling Factories (Plastic)	20 t Trucks (60%)	40
The Recycle Plants → The Landfill Sites	10 t Trucks (40%)	10

3.5.2 The Recycling Treatment/Proper Treatment (Landfill Disposal)/Recycle Deduction Stages

It was decided that, in the recycle plants, the raw materials of 95% of the metals (iron, copper, and aluminum) and 20% of the plastics were collected and were recycled, based on the “Report on Criteria of Item Additions, Recycling, and Other Matters in Relation to Specified Home Devices (in September 2008)” (the Ministry of Economy, Trade and Industry).[6)]

In relation to energy that was required to carry out the recycle treatment operations, a research was conducted for the purpose of calculating the electrical power consumption level per 1 kg. In order to obtain this value, the annual electrical power usage amounts in the recycle plants having exclusive refrigerator treatment lines were divided by the mass of the annual treatment operations, and the calculated value was adopted. As for isobutane (R600a) refrigerants and cyclopentane expanded thermal insulating materials, it was decided that they were released into the atmosphere.

As for the collected metals, it was decided that, by shredding them in the recycle plants and then by reusing them, the manufacturing loads were deducted (crude steel for iron, crude copper for copper, and aluminum metal for aluminum).

In relation to the plastics, it was considered that the manufacturing loads of polypropylene whose component percentage was the largest (about 34%) were deducted as the plastics were recycled. The loads that were required for recycling the collected plastics were taken into account by using the basic unit of CO_2 emission to be required to mold such recycled plastics.

It was decided that, other than the collected metals and plastics, all the materials were properly treated (landfill disposal).

4. The Inventory Analysis Results

In relation to the basic units, the research used the LCI database, “IDEA ver. 1.0,” [7] that was mounted on the LCA software “MiLCA.” However, as for the electronic circuit boards, the research used the basic unit that had been obtained in a trial calculation of the Heavy Electric Machinery and Industrial System Machine in the LCA Examination WG ofJEMA.[8] In addition, the CO_2 emission amounts in the transportation stages were calculated based on the “Guideline for Calculating CO_2 Emission Amounts in the Physical Distribution Field” (the Ministry of Economy, Trade and Industry/the Ministry of Land, Infrastructure, Transport and Tourism).

Table 5 and Figure3 show the inventory analysis results. The total amount of CO_2 emission in the whole life cycle of the refrigerators was about 1,709 kg. When the respective life cycle stages were compared, the total amount of the usage stages reached about 1,382 kg and was the largest, accounting for about 81% of the whole. Next, the total of the loads of the procurement (raw material) stages was the second largest and about 326 kg (about 19%). In addition, the total of the loads of the procurement (parts processing) stages (27 kg) was more or less the same as the total of the loads of the manufacturing (assembly) stages (about 26 kg). The total loads from the collection transportation stages reached about 3.2 kg, smaller than those of the other stages.

Table 5: The Results of the LCI Analyses of the Refrigerators in the 2010 Refrigeration Year

The Stages	The CO_2 Emission Amounts (kg)		
	JAPAN	China	Thailand
The Procurement (Raw Material) Stages	325.5	Same as Left	
The Procurement (Parts Processing) Stages	27.1	Same as Left	
The Product Manufacturing (Assembly)Stages	26.1	41.4	26.4
The Product Transportation Stages	11.0	17.8	26.3
The Usage Stages	1,382.0	Same as Left	
The Collection Transportation Stages	3.2	Same as Left	
The Recycle Treatment/Disposal Stages	8.4	Same as Left	
The Recycle Deduction Stages	-74.3	Same as Left	
Total	1,709.0	1,731.2	1,724.7

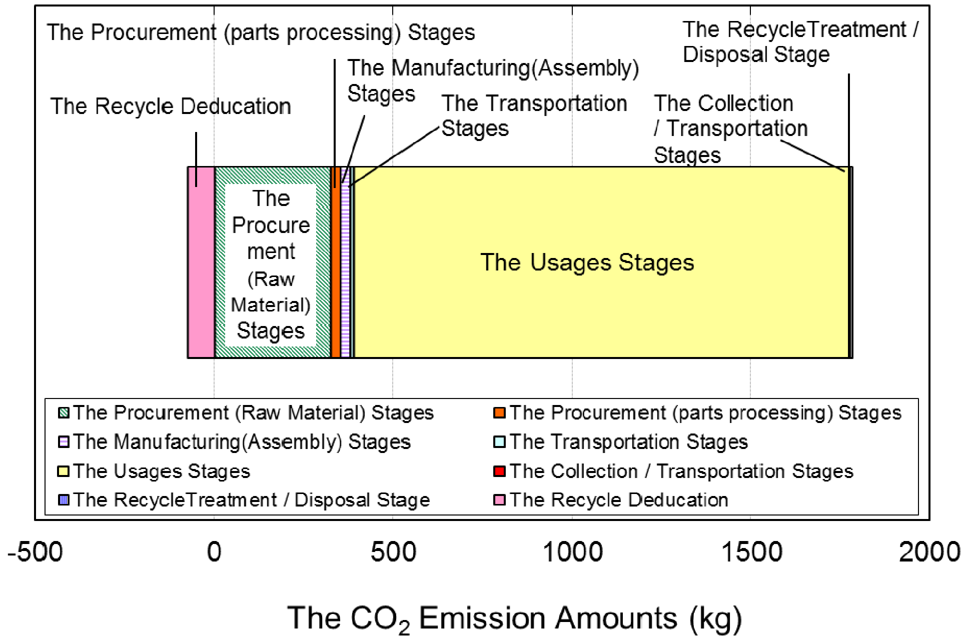

Figure 3: The LCI Analysis Results of the Refrigerators in the 2010 Refrigeration Year (Domestic)

Next, Figure 2 and Figure 4 show the composition ratios of the CO_2 emission amounts and component mass in the procurement stages.

As shown in these figures, both the metal and plastic composition ratios accounted for about 40% of the mass of the components in the procurement stages. Meanwhile, of the CO_2 emission amounts, the metals accounted for 33% and the plastics accounted for 40%. In addition, as for the electronic Circuit boards, the mass was about 0.5%, and the total of the CO_2 emission amounts was about 17%. Thus, it was considered that the loads could not be ignored.

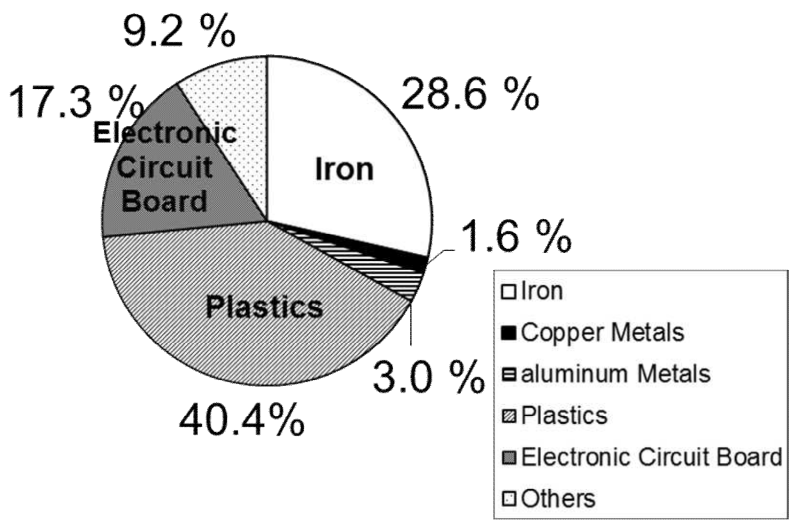

Figure 4: The Component Compositions (the CO_2 Emission Amounts) in the Procurement Stages

Table 5 shows the result of comparing the CO_2 emission amounts in the case when refrigerators were manufactured in China and in Thailand. In the product manufacturing (assembly) stages, the total of the CO_2 emission amounts was + 15.3 kg in the case of manufacturing in China, and the total was + 0.3 kg in the case of manufacturing in Thailand. In the product transportation stages, the total of the CO_2 emission amounts was + 6.8 kg in the case of manufacturing in China, and the total of the CO_2 emission amounts was + 15.3 kg in the case of manufacturing in Thailand. In relation to the life cycles as a whole, the total of the CO_2 emission amounts was 1,709 kg in the case of manufacturing in Japan, while the total of the CO_2 emission amounts was only 1,731 kg (+ 1.3%) in the case of manufacturing in China, and the total was 1,724 kg (+ 0.9%) in the case of manufacturing in Thailand. Thus, the CO_2 emission amounts increased while the percentages themselves remained small.

5. The Comparison with the Products of the 1999 Refrigeration Year

5.1 The Method of Examining about the Comparison and Contrast

Next, the products of the 1999 refrigeration year and the products of the 2010 refrigeration year were compared. Table 1 shows the specifications of the compared targets of the products of the 1999 refrigeration year and the products of the 2010 refrigeration year. The products of the 1999 refrigeration year and the products of the 2010 refrigeration year had the different rated capacity and the different numbers of doors. However, before the replacements of the products were bought, the main products were those of 400 L, but after the replacements were bought, the main products became those of 500 L. Therefore, as for the evaluations in the case of buying the replacements, it was decided that one refrigerator was a function unit, making it possible to mutually compare the respective single refrigerators of the main models of the domestic refrigerator manufacturers in Japan in the respective years. However, as explained in the next section, corrections were carried out in order to make the annual electric power consumption levels have numeric values that had been obtained based on the same measurement method.

5.2 The Corrections

For the purpose of carrying out the comparative examination, the corrections were conducted for the products of the 1999 refrigeration year, based on the calculation conditions of the products of the 2010 refrigeration year.

In relation to the basic units, a change was made by choosing the IDEA database, instead of the database that had been used for the LCA software NIRE-LCA of the National Institute of Advanced Industrial Science and Technology. In addition, the loads of the parts processing and electronic circuit boards, which had not been considered in the report of the 1999 year, were newly taken into account.

The emitted materials in the product manufacturing stages had not been taken into account in the report of the 1999 year. However, this time, it was decided that the emitted materials except for the metals and the plastics were properly treated (landfill). In relation to the metals and the plastics, it was decided that 100% of the materials were collected and recycled, and they were included in the recycle deduction.

In relation to the product transportation routes, the report of the 1999 year had set the transportation scenarios starting from the manufacturing bases reaching to the physical distribution bases. Transportation scenarios were further added, starting from the physical distribution bases, passing through the retail shops, and reaching to the consumers.

As for the annual electric power consumption levels in the usage stages, the measurement methods were changed as a result of the 2006 revision of the "Household Refrigerating Appliance Characteristics and Test Methods" of the Japanese Industrial Standards (JIS C 9801). Thus, from the correction data of the category of refrigerators whose sizes ranged from 401 L to 450 L, which were used by Shinkyusan (http://shinkyusan.com/index.html) and others, the average value (795 kWh/year) of the maximum value (840 kWh/year) and the minimum value (750 kWh/year) was adopted as the corrected value.

The number of usage years was changed from 12 years to 10.4 years.

In relation to the collection transportation stages, the transportation scenario of recycling the plastics was added to the scenarios that had been set in the report of the 1999 year.

As the energy amounts that were required for carrying out the recycle treatment operations, the report of the 1999 year used the electric power levels in the demonstrative plants, and the numeric values were used after researching them in the recycle plants that had actually carried out their treatment operations, based on the Home Appliance Recycling Law, similar to the case of the products of the 2010 refrigeration year.

In addition, in the report of the 1999 year, the loads required for carrying out the recycle treatment operations had been included in the recycle deduction stages. By contrast, based the scenarios related to the products of the 2010 refrigeration year, the loads required for the recycle treatment operations and for the proper treatment (landfill disposal) operations were added and were set for the recycle treatment/disposal stages.

In relation to the recycle deduction operations, it was considered in the report of the 1999 year that all the metals were collected and were recycled, and that the emitted materials from the manufacturing processes and plastics' recycle were not taken into account. By contrast, based on the calculation scenarios of the products of the 2010 refrigeration year, it was considered that, regarding the main bodies, 95% of the metals and 20% of the plastics were collected and were recycled. Then, a recalculation was carried out. In addition, the metals and the plastics emitted from the manufacturing process were also taken into account.

Figure 5 shows the results of comparing the CO2 emission amounts of the products of the 1999 refrigeration year before and after the corrections.

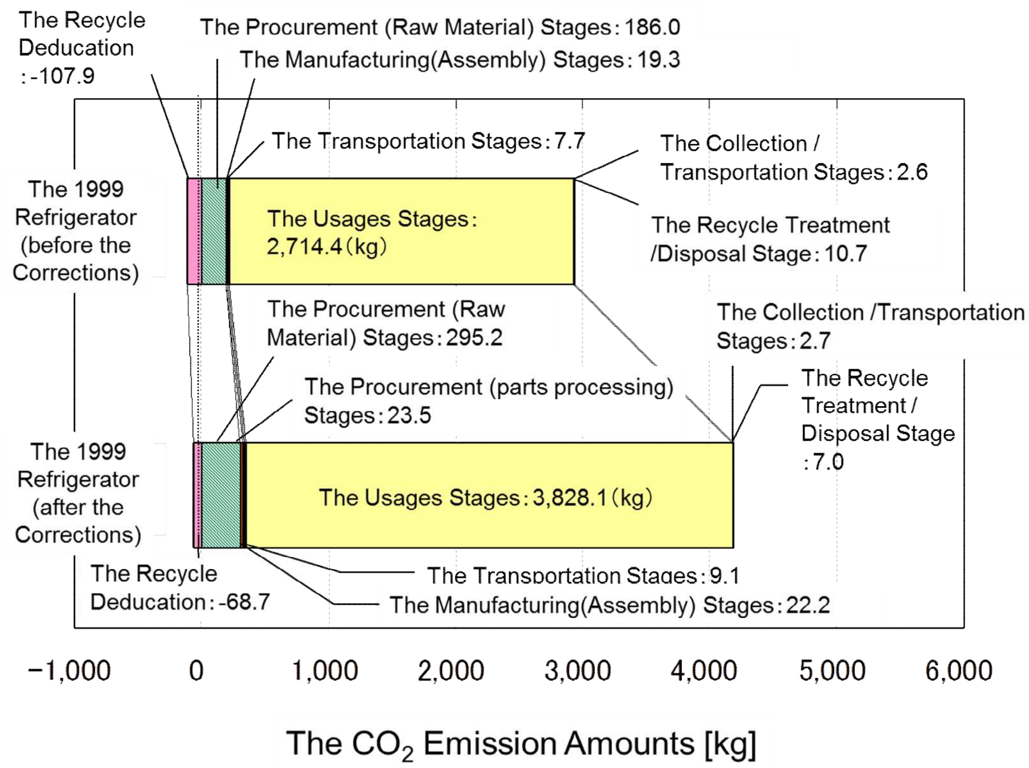

Figure5: The Comparison of the CO_2 Emission Amounts before and after the Corrections of the Products in the 1999 Refrigeration Year

5.3 The Differences between the Products in the 1999 Refrigeration Year (after the Corrections) and the Products in the 2010 Refrigeration Year

Table 6 shows the differences between the products in the 1999 refrigeration year (after the corrections) and the products in the 2010 refrigeration year. The differences were related to the product mass, the annual electric power consumption levels, the energy usage levels, the raw material compositions, and the emitted material amounts of the product manufacturing (assembly) stages. Meanwhile, the collection ratios, the number of usage years, the method of measuring the annual electric power consumption levels, the transportation means/distances, and the basic units remained the same.

Table 7 shows the raw material compositions and the product mass in relation to the products in the 1999 refrigeration year (after the corrections) and in the products in the 2010 refrigeration year.

Table 6: The Differences between the Products in the 1999 Refrigeration Year (after the Corrections) and in the Products in the 2010 Refrigeration Year

The Life Cycle Stages	The Different Items	The Same Items
The Procurement (Raw Material) Stages	The Product Mass, Emitted Material Amounts and Raw Material Compositions in the Product Manufacturing (Assembly)	The Basic Units

The Procurement (Parts Processing) Stages	The Product Mass and Raw Material Compositions	The Basic Units
The Product Manufacturing (Assembly) Stages	The Energy Usage Amounts and Emitted Material Amounts	The Basic Units
The Product Transportation Stages	The Product Mass (Transportation Mass)	The Transportation Means/Distances, and Basic Units
The Usage Stages	The Annual Power Consumption s	The Basic Units, Number of Usage Years, and Measurement Methods of Annual Electric Power Consumption Levels
The Collection Transportation Stages	The Product Mass (Transportation Mass)	The Transportation Means, Distances, and Basic Units
The Recycle Treatment/Disposal Stages	The Product Mass, Emitted Material Amounts and Raw Material Compositions in the Product Manufacturing (Assembly)	The Basic Units
The Recycle Deduction Stages	The Product Mass, Emitted Material Amounts and Raw Material Compositions in the Product Manufacturing (Assembly)	The Collection Ratios and Basic Units

Table 7: The Raw Material Compositions and the Product Mass in Relation to the Refrigerators in the 1999 Refrigeration Year (after the Corrections) and the Refrigerators in the 2010 Refrigeration Year

Components	The Refrigerators in the 1999 Refrigeration Year (after the Corrections)	The Refrigerators in the 2010 Refrigeration Year
	Mass (kg)	
Iron	38.9	40.4
Copper Metals	1.8	1.7
Aluminum Metals	1.3	0.9
Plastics	34.4	40.7
Electronic Circuit Boards	0.5	0.5
Others	8.2	18.4
Total	85.1	102.5

5.4 The Comparison Results

Table 8 and Figure 6 show the results of comparing the products in the 1999 refrigeration year and the products in the 2010 refrigeration year.

When comparing the calculation results in relation to the products in the 1999 refrigeration year (after the corrections) and the products in the 2010 refrigeration year, it was observed that, in the procurement (raw material) stages, the total of the CO_2 emission amounts increased by about 10 percent, compared to that of the products in the 1999 refrigeration year (after the corrections). It was considered that the reason for the increase of the CO_2 emission amounts in the procurement (raw material) stages was largely influenced by the fact that the mass increased by about 20% as a result of the increase of the rated capacity.

Meanwhile, the CO_2 emission amounts in the usage stages decreased by about 64%, showing that the energy saving performances in the usage stages had significantly improved by means of adopting the vacuum insulation panels, and other matters.

When the life cycles as a whole were compared, it was observed that there was a decrease by about 59%.

Table 8: The Comparison of the LCI Analysis Results in Relation to the Refrigerators

The Life Cycle Stages	The CO_2 Emission Amount [kg]	
	The Refrigerators in the 1999 Refrigeration Year (after the Corrections)	The Refrigerators in the 2010 Refrigeration Year
The Procurement (Raw Material) Stages	295.2	325.5
The Procurement (Parts Processing) Stages	23.5	27.1
The Product Manufacturing (Assembly) Stages	22.2	26.1
The Product Transportation Stages	9.1	11.0
The Usage Stages	3,828.1	1,382.0
The Collection Transportation Stages	2.7	3.2
The Recycle Treatment/Disposal Stages	7.0	8.4
The Recycle Deduction Stages	-68.7	-74.3
The Total of the CO_2 Emission Amounts	4,119.1	1,709.0

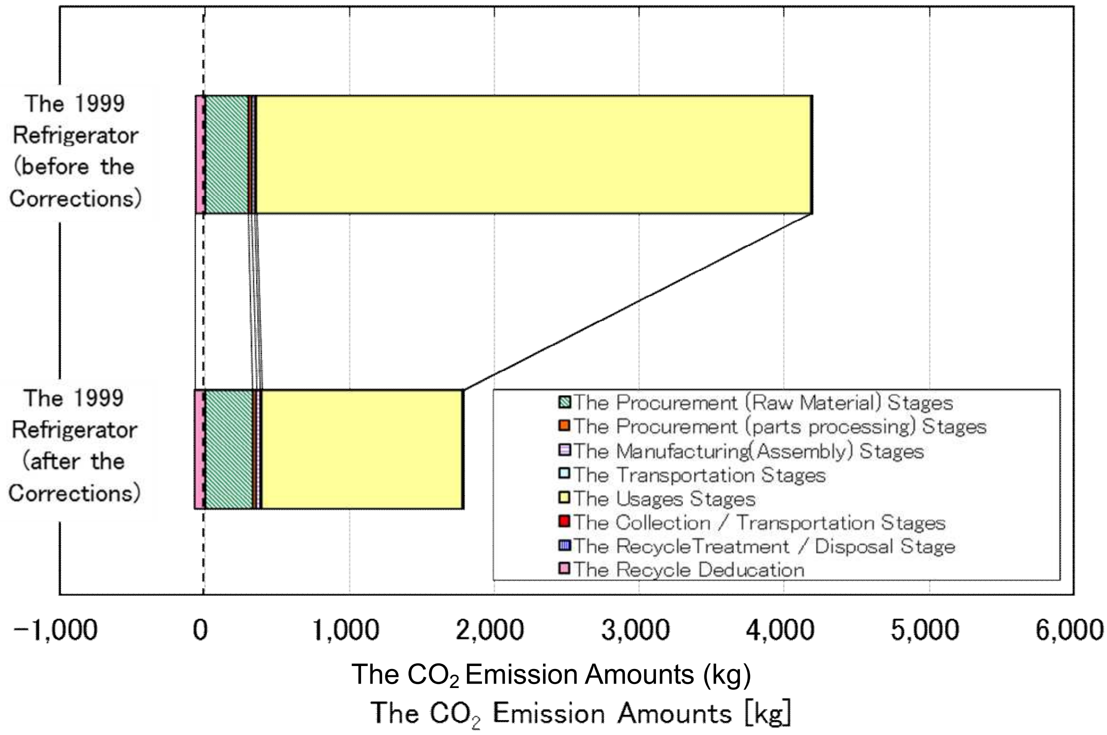

Figure 6: The Comparison of the LCI Analysis Results in Relation to the Refrigerators

5.5 The CO_2 Reduction Effects Produced by Means of Replacements

The CO_2 emission effects produced by means of replacements were examined by making use of the calculation results obtained so far.

Figure 7 shows the results of comparing the CO_2 emission amounts in the case of keeping using the products of the 1999 refrigeration year and in the case of replacements of the products in the 2010 refrigeration year.

In relation to the CO_2 emission amounts, in the case of keeping using the products of the 1999 refrigeration year, the loads only in the usage stages were calculated each year. In the case of replacements of the products in the 2010 refrigeration year, the calculations of the first year included the loads in the recycle treatment/disposal stages and in the collection transportation stages related to the products of the 1999 refrigeration year, as well as the loads in the usage stages, in the product transportation stages, in the product manufacturing (assembly) stages, in the procurement (parts processing) stages, and in the procurement (raw material) stages related to the products of the 2010 refrigeration year. Then, in the second year and in the subsequent years, the loads in the usage stages were annually added to the loads of the first year.

In terms of the first year of replacements, the CO_2 emission amounts were larger in the case of replacements of the products in the 2010 refrigeration year, than in the case of keeping using the products of the 1999 refrigeration year. However, in the following year, the CO_2 emission amounts became smaller in the case of replacements of the products in the 2010 refrigeration year, than in the case of keeping using the products of the 1999 refrigeration year. Then, the total of the CO_2 emission amounts for the five years after the purchases of the replacements was 1,840 kg in the case of keeping using the products of the 1999 refrigeration year, and the total was 1,057 kg in the case of replacements of the products in the 2010 refrigeration year. Thus, it was possible to reduce the levels by 42%.

From these results, it is possible to view that the CO_2 emission reduction effects by means of replacements of the products were large even when the calculations took into account of the loads of the new products in the product transportation stages, in the product manufacturing stages, in the procurement stages, as well as the loads of the old products in the recycle treatment/disposal stages and in the collection transportation stages.

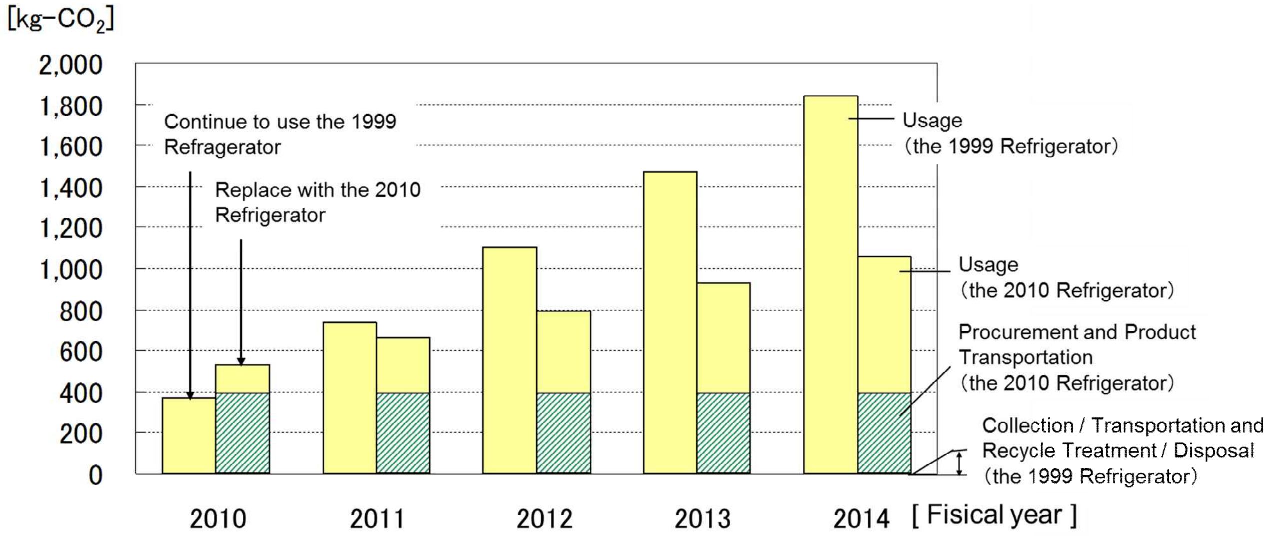

Figure 7: The Results of Comparing the CO_2 Emission Amounts in the Case of Keeping Using the Products of the 1999 Refrigeration Year and in the Case of Replacements of the Products in the 2010 Refrigeration Year (the Cumulative Values in 2010 and after)

6. Conclusions

When the calculation results of the refrigerators in the 1999 refrigeration year (after the corrections) and the refrigerators in the 2010 refrigeration year were compared, the CO_2 emission amounts in the usage stages decreased by about 64%. This finding showed that the energy saving performances in the usage stages had significantly improved by means of adopting the vacuum insulation panels, and other matters. In relation to the life cycles as a whole, it was observed that there was the decrease by about 59%.

When the respective life cycle stages were compared, the total amount of the usage stages was the largest, accounting for about 81% of the whole. Next, the total of the loads of the procurement (raw material) stages was the second largest, accounting for about 19%.

When the CO_2 emission amounts of the respective manufacturing bases were compared, the total amount from the manufacturing operations in China increased by +1.3%, and the total amount from the manufacturing operations in Thailand increased by +0.9%, but the percentages remained small, in contrast to those from the manufacturing operations in Japan.

From these results, it was quantitatively shown that the energy saving effort in the usage stages was the most effective for the purpose of reducing the CO_2 emission amounts in the case of the products in the 2010 refrigeration year, similar to the case of the products in the 1999 refrigeration year.

In relation to the electronic circuit boards, they accounted for the small percentage of the total mass, but accounted for the large percentage of the total of the CO_2 emission amounts. Thus, it was viewed that their loads could not be ignored.

When the products in the 1999 refrigeration year were replaced with the products in the 2010 refrigeration year, the CO_2 emission amounts became larger in the first year when the replacements were bought, compared to the case of not replacements. However, the CO_2 emission amounts became smaller in the second year and in the subsequent years in the case of replacements. Thus, the findings showed that the CO_2 reduction effects by means of the purchases of the replacements were greater in the case when the replacements were used for a long time after the purchases.

Moreover, as the future challenges, it is possible to list the following matters.

For the purpose of calculating the loads of the electronic circuit boards, the secondary data (basic units) were used for the evaluation. Thus, it is necessary to examine a possibility of evaluating by means of the primary data.

In addition, it is necessary to carry out detailed analyses related to energy saving contributions made by the vacuum insulation panels, the high efficiency compressors, and other matters.

Added to these, this time, the analyses were conducted by calculating the representative values, so it is important to arrive at a conclusion by means of carrying out sensibility analyses taking into account of the variation of the product usage conditions, the parts, and other factors.

Reference Materials:

1) The Subcommittee of the International Inquiry of the Methods of the Rationalization of Use of Energy (1995): Environmental Management, the Japan Environmental Management Association for Industry, the Life Cycle Inventory of Refrigerators, 91-97.
2) Kiyotaka Tahara, Kojima Toshinori, and Inaba Atsushi (1996), the Second International Conference on EcoBalance, Proceedings, Ibaraki, 539-542.
3) The Japan Electrical Manufacturers' Association, LCA-WG (2000), the "LCA-WG" Report of the Activities in the 1999 Year of the Japan Electrical Manufacturers' ., the Research Results Related to the Data Collection and Other Matters of the LCI (Life Cycle Inventory) of Home Appliance Products.
4) The Ministry of Economy, Trade and Industry/the Ministry of Land, Infrastructure, Transport and Tourism (2006), the Guideline for Calculating CO_2 Emission Amounts in the Physical Distribution Field.
5) The Association for Electric Home Appliances (2009), the Actual Usage Situations of Home Appliances and Consumers' Awareness Research Report, 19.
6) The Ministry of Economy, Trade and Industry (2008), the Report on Criteria of Item Additions, Recycling, and Other Matters in Relation to Specified Home Devices.
7) The National Institute of Advanced Industrial Science and Technology, the Japan Environmental Management Association for Industry, "LCI Database IDEA ver.1.0."
8) The Japan Electrical Manufacturers' Association, the Heavy Electric Machinery and Industrial System Machine in the LCA Examination WG (2007), the General Meeting of the Institute of

Electrical Engineers of Japan, Lecture and Research Paper Collection, Toyama, 8-9.

Members of the LCA-WG Committee:

Hiroshi Miyake, SANYO Electric Co., Ltd. (until December 2011)
Masao Shimizu, Sharp Corporation (from April 2011 to March 2012)
Shiro Aihara, Sharp Corporation
Setsuko Tsukamoto, Sharp Corporation (until March 2011)
Norio Takeyama, Toshiba Corporation
Sachiko Motoike, Panasonic Corporation
Mitsuo Sato, Hitachi Appliances, Inc.
Masayuki Ichinohe, Hitachi, Ltd.
Tetsuya Takahashi, Mitsubishi Electric Corporation (from April 2012)
Motohiro Tanaka, Mitsubishi Electric Corporation (until March 2012)
Chie Uchiyama, Mitsubishi Electric Corporation (from September 2012)
Kiyoshi Saito, the Japan Electrical Manufacturers’ Association
Koichi Ichimura, the Japan Electrical Manufacturers’ Association
Yu Kuwahara, the Japan Electrical Manufacturers’ Association