

NIMS-EMC Materials Data for the Environment, No.10

Estimation of Total Materials Requirement Energy Resources and Industrial Materials



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March, 2006

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Preface

The 21st century, which is being hailed as the "environment century," is becoming an age where the global environment is being considered from every possible aspect, such as daily and economic activities. Against this backdrop, raw and processed materials are being used to make all types of products. As resources, these materials are being extracted from the earth's environmental sphere, and returned to this sphere as waste, so they are very closely tied with the global environment. Therefore, not only the producers of materials, but also all the people who produce, use, and dispose of the products, have a vested interest in learning about the environmental load and recyclability of these materials to improve productivity and make the right choices for creating a sustainable society for the future.

Unfortunately, there is still relatively little processed information available regarding the environmental load and recyclability of these materials. Sometimes, information that has been "fleshed out" can be found here and there, but it is still often not sufficient to make informed decisions.

To address these issues, the EcoMaterials Center, as a core organization for the acquisition and processing of reliable information on substances and materials, is working hard to issue NIMS-EMC Data as a series. NIMS, it should be noted, is the acronym for the National Institute for Materials Science, and EMC refers to the EcoMaterials Center. While there may be slight differences in procedures for collecting data and creating databases, we would like to use detailed surveys by experts and other vehicles to provide essential material data which can be used to create product materials which cannot be derived from statistical data, and which includes data on such considerations as recyclability and LAC, or Life Cycle Assessment.

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1. Introduction

In recent years, global environmental problems have become increasingly serious, and demand has been rising for a recycling society. In 2000, Japan implemented the Fundamental Law for Establishing a Sound Material-Cycle Society as a first step in achieving this goal. One of the items given special attention in the formation of the recycling society has been the effective promotion of "material recycling." The Japanese Ministry of Environment suggests three material flow indices, and numerical targets are being readied for 2010. The three indices are 1) Resource Productivity (= GDP/natural resource inputs), 2) Recycling Rate (Amount of recycling/(Amount of recycling + Inputs of natural resources)), and 3) Ultimate Disposal Volume. In one idealistic scenario of material recycling, the flow of material becomes a closed loop. A more realizable goal, however, may be to maintain the standard of living at roughly the current level while slowing down the flow of new raw materials coming into the system (enhancing the productivity of resources), and to make a concerted effort to minimize the ultimate disposal amount to put the "recycling loop" within reach.

However, when taking this approach, it is easy to overlook the "hidden flow," which is sometimes called the "ecological rucksack." For example, in the case of copper, the normal grade of ore (pyrites) in Japan is about 0.8%, meaning that about 125 metric ton of copper ore is required to produce 1 ton of copper metal. However, since most Japanese copper is imported in the form of concentrate that has been subjected to intermediate processing at the mine to raise its grade to up to about 40%, only about 2.5 ton of concentrate is needed to produce 1 ton of copper metal. By using enhanced grade concentrate, the energy and resource inputs needed to refine the metal at the domestic smelter can also be reduced, and the resource productivity can theoretically be increased by 50 times or more. However, this improved efficiency is actually a zero-sum because the load is borne by the resource-exporting country.

Research related to this hidden flow is being vigorously pursued both in Japan and overseas. One of the leading overseas research groups in this field is Germany's Wuppertal Institute¹⁾⁻²⁾. In Japan, Halada et al., are currently making rough estimates for Total Materials Requirement (TMR) of metals³⁾. These indices have been gaining attention as indices for evaluating the quality of resources.

2. Purpose of the Research

The purpose of the present research is to 1) calculate the TMR for resources and industrial materials, and 2) address the recycling of end-of-life vehicles (ELVs) by using TMR as a resource index to investigate methods for analyzing cycle flow. The target resources include materials which are essential for industrial activities, including energy sources such as coal, petroleum, and natural gas, biomass materials such as wood and farm products, and non-metallic mineral resources such as limestone. Target materials include aluminum, plastics, paper, and steel. Details of this study's targets are given in Table 2-1 (resources) and Table 2-2 (industrial materials).

Table 2-1 Types of target resources

(a) Energy resources and power generation

Energy resources	Petroleum
	Coal
	Natural gas
	Petroleum (combustion)
	Coal (combustion)
	Natural gas (combustion)
Power generation	Oil-fired
	Coal-fired
	Natural gas-fired
	Nuclear

(b) Non-metallic mineral resources

Non-metallic mineral resources	Silica rock	White silica rock
		Natural silica sand
		Gairome silica sand
	Agalmatolite	
	Limestone	
	Dolomite	
	Refractory clay	Kaolin
		Shale clay
		Kibushi clay
		Gairome clay

(c) Biomass resources

Biomass resources	Rice
	Wheat
	Two-rowed barley
	Six-rowed barley
	Naked barley
	Soybeans
	Azuki beans
	Kidney beans
	Peanuts
	Potatoes
	Sweet potatoes
	Sweet potatoes (starchy substrate)
	Pasture grass
	Early harvested corn
Wood	

Table 2-2 Types of target industrial materials

Type	Industrial materials
Plastics	- Polyethylene (PE): high-density polyethylene particle (HDPE), low-density polyethylene particle (LDPE), linear low-density polyethylene particle (LLDPE)
	- Polypropylene particle (PP)
	- Polystyrene (PS): general polystyrene (GPPS), high-impact polystyrene (HIPS), polystyrene foam (EPS)
	- Polyvinyl chloride powder (PVC)
	- Polyvinylidene chloride powder (PVDC)
	- Polyethylene terephthalate (PET)
Aluminum	- Aluminum oxide, aluminum ingot, aluminum foil, aluminum (recycled)
Glass	- Glass (brown), glass (green), glass (colorless)
Graphic paper	- Paper (non-wood pulp)
	- Paper (wood pulp)
	- Recycled paper
	- Newspaper
Cardboard	- Gray cardboard (GK)
	- Double/triple cardboard (GD/GT)
	- Chromo board (GC)
	- Pulp cardboard (GZ)
	- Liquid packaging cardboard (LPB)
Corrugated board	- Recycled corrugated board (paper)
	- Corrugated board (paper)
	- Recycled corrugated board (fiber)
	- Corrugated board (fiber)
	- Corrugated board (mixture)
Packaging paper	- Kraft (heavy) paper
	- Kraft (heavy) paper (surface treatment)
	- Kraft (heavy) paper (Swiss-made)
	- Bag-made paper
Steel sheet	- Chromium plating sheet (ECCS)
	- Tin plate

3. Total Materials Requirement (TMR)

Total materials requirement (M_{TMR}) is defined as follows:

$$M_{TMR} = \sum M_{DI(i)} + \sum M_{II(i)} + \sum M_{HF(i)} \quad (1)$$

here, $M_{DI(i)}$ is the amount of direct inputs, $M_{II(i)}$ is the amount of indirect inputs, and $M_{HF(i)}$ is the amount of hidden flow materials. It should be noted that the adjunct letter i represents a component of target materials that is included in products and/or materials. Also, the amounts of direct and indirect inputs are the amounts of materials input into the system directly and/or indirectly through economic activities. These indices are also called “economic flow” and represent the amount of economically statistical materials that can be acquired.

The concept of “hidden flow materials” is indispensable in considering TMR. “Hidden flow materials” refers not only to the actual amounts of materials that originate from economic activities, but also to amounts of materials that have been moved or otherwise affected by economic activities. This latter group includes removal of rocks, stones, soil and sand by digging: water required for

logging forests and drilling oil (the water flood method), and the total amount of materials required for restoring lands and protecting landscapes.

It should be noted that the TMR of soil and water are targets of the present evaluation; however, the TMR of air is not, because of the unclear basis for making calculations. In addition, even though the TMR of hydroelectric power is a subject warranting investigation, it is considered to be zero in the present paper.

4. Estimation of TMR

4.1 Method for estimating TMR

Using the example of process flow shown in Figure 4-1, TMR ($TMR_{product}$) of a product in the present study was calculated as follows. "Flow" in the figure refers to the flow of materials or energy, while "process" refers to production, processing, etc. Equation (2) is the TMR of product when $w_{s,jk}$ is the amount of flow s from process j to process k , and t_s is the TMR per unit mass of input flows.

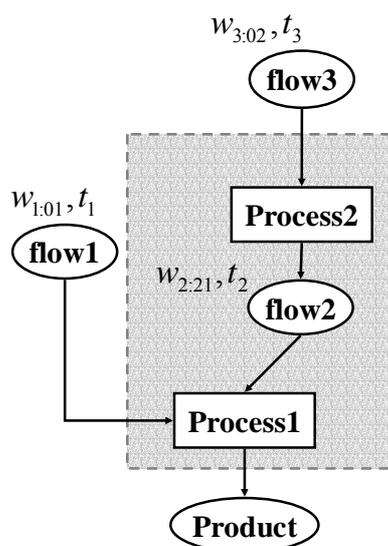
$$TMR_{product} = \sum_{s=1}^n w_{s,jk} t_s \quad (2)$$

$$w_{s,jk} = 0 \quad (j \neq 0)$$

where $j=0$ signifies the external processes beyond the boundary shown by the broken line in Figure 4-1. In other words, we can calculate TMR in the present research by deriving the total TMR of input flow into the product systems that are the object of the evaluation. This is similar to the method which assigns environmental loads to materials and energy input from outside the system boundary in the unit requirement type of LCA.

In the production process, there are sometimes secondary and by-products that are produced in addition to the main product. In such cases, there is no method to clearly handle them in LCA, but LCA is appropriate for system expansion, allocation⁴, etc., to clarify the basis for calculations. On the other hand, it is still not known whether or not the same type of method can be derived in

Figure 4-1 Example of a process flow chart for production



TMR, so this will be an important point for future debate. At any rate, it should be noted that in the present research, allocation of petroleum products was based on production volume, while other materials such as scrap were counted as 0.

4.2 TMR of energy resources

The TMR of energy resources and electrical power has already been calculated⁵⁾ by one of the authors of Halada et al. In the present study, the existing data were refined and some were corrected, and calculations were made again. As with Harada et al.'s study, comprehensive energy statistics (FY 2000 edition)⁷⁾ were used for the energy unit requirement; for the electrical power inventory, reference was made to the data of Uchiyama et al.

(1) TMR of petroleum resources and thermal (oil-based) power generation

In the TMR related to oil resources, there are many cases the peak production period of an oil well where oil is brought to the surface using the earth's natural pressure, so it was determined that there were almost no excess related materials associated with drilling. However, in considering the life cycle of an oil well, when the earth pressure decreases and production declines, water is pumped in to bring out more crude oil. This method is called "water flooding," while using pressure from explosions, etc. to force the oil to the surface is called "fire flooding." In these cases, oil is extracted not as 100% pure petroleum but as a mixture of crude oil and water. The ratio of water to oil is abbreviated as "WOR." The WOR value increases with the age of an oil well, sometimes the WOR value becomes almost 100 when an oil well reaches the end of its useable life. When the lifetime of the oil well is T, the production volume and WOR at the time of t are y(t) and w(t), respectively, and TMR is expressed as follows:

$$TMR_{oil} = \frac{\int_0^T y(t) \cdot (w(t) + 1) dt}{\int_0^T y(t) dt}$$

The relation between the production volume and the WOR value was reviewed by Purvis et al. ("Analysis of production-performance graphs," J. Canadian Petroleum, July-August 1985), but Baker showed the relation between and total production volume based on actual operating data ("Reservoir Management for Water Floods II," J. Canadian Petroleum Technology, Vol. 37 (1998) No. 1, 12-17). Integrating and averaging values on the graph result in a TMR value of 7.4 kg/L. It should be noted that the temporary rise and then primary decline of this WOR curve was due to increased productivity obtained through new methods such as "water flooding." By multiplying the 7.4 kg/L TMR of petroleum extraction obtained in this way by the unit energy requirement of 38.7 MJ/L (2000 Comprehensive Energy Statistics, Planning and Coordination Division, Director-General's Secretariat, Environment Agency), we obtain a TMR of oil combustion of 0.19 kg/MJ. In Halada et al's calculations, there was an error made when transcribing the figures for oil combustion.

Furthermore, in Uchiyama et al's data, 1,448.8 ML of oil was required to produce 6,169 GWh of electrical energy; thus, the TMR for thermal power generation was $7.40 \times 1.4488 / 6.169 = 1.74$ kg/kWh, that is 0.48 kg/MJ.

(2) TMR of coal and coal-powered electrical generation

The combustion of 1 kg of coal produces 32.2 MJ of electrical power. Put another way, it takes 0.03 kg of coal to produce 1 MJ of energy. Previously, in the first stage, a value of 12.4 t/t was derived for coal from actual coal mine data; from that, the TMR per MJ of coal combustion was calculated to be 0.39 kg/MJ. Because Halada et al's calculations contained errors when the TMR for coal was converted into TMR for coal combustion.

Furthermore, according to the data of Uchiyama et al., in the case of coal-fired power generation, it takes 2.336 Mt of coal to produce 6,084 GWh of electrical power; thus, the TMR of coal-fired power generation is $12.4 \times 2.336 / 6.084 = 4.76$ kg/kWh, or 1.32 kg/MJ.

(3) TMR of natural gas and natural gas power generation

In the case of electrical power produced from natural gas, it is necessary to derive TMR that includes extraction of the crude gas. Because natural gas is extracted in a gaseous state, it is difficult to estimate TMR. However, in the case of Japan and the oil fields with which it does business, natural gas is derived simultaneously from petroleum extraction, so an average value of petroleum volume accompanied with natural gas was derived and multiplied by the TMR of petroleum to approximate a value for natural gas TMR.

From the website⁸⁾ of the Japan Petroleum Exploration Co., Ltd., the natural gas/oil ratio from natural gas fields was weight-averaged with the production volume obtained from the following data. JAPEX U.S., 20.7 kL/d oil, 700 km³/d natural gas; JAPEX Gulf 4.77 kL/d, 868 km³/d; Gebang (Sumatra) 51 kL/d, 364 km³/d; Sanga Sanga 6.3 ML/d, 33.6 Mm³/d; Yufutsu 241.8 kL/d, 256.1 km³/d; Sarukawa 77.8 kL/d, 5.7 km³/d; Yuri 49.4 kL/d, 27.4 km³/d; Iwafune-oki 661.7 kL/d, 306.2 km³/d; Higashi Niigata 240.7 kL/d, 658.5 km³/d; Yoshii 101.0 kL/d, 578.4 km³/d; and Katagai 83.9 kL/d, 813.9 km³/d. The average value was 4.88 m³/L, meaning that 0.2 L/m³ of crude oil was produced at the same time. Assigning a specific gravity of 0.85 and calculating this value by the 7.4 TMR of crude oil, that is, $0.2 \times 0.85 \times 7.4$, gives a TMR of 1.26 kg/m³. Assuming the natural gas to be methane and assigning it a combustion heat value of 9,700 kcal/m³ = 40.6 MJ/m³ gives a TMR value of 0.031 kg per MJ of natural gas.

Furthermore, according to the data of Uchiyama et al., in the case of natural gas-fired power generation, it takes 1.1145 Mt of natural gas to produce 6169 GWh of electrical power; converting into methane gives a value of 63,300 TJ = 1963 Gt-TMR from the volume of $1.1145 \times 22.4/16 = 1.56 \text{ Gm}^3$. Thus, the TMR of natural gas-fired power generation is 0.088 kg/MJ.

(4) TMR of nuclear power generation

In the case of nuclear power generation, according to Uchiyama et al. 127 ton of U in the form of UF₆ is consumed to produce 5868 GWh of electrical power. The TMR of uranium ore is 11,000, so the power generation can be quantified as $127\text{K}/5868\text{G} \times 11000 = 0.238 \text{ kg/kWh}$, meaning the TMR of nuclear power generation is 0.066 kg/MJ. Halada et al's figure is different because of an error they made in the transcription.

It should be noted that the 11,000 value of TMR for uranium was estimated from crustal data because of deficiencies in data on actual mines, deposits, etc. However, according to the Ombudsman Okayama website⁹⁾, information released on the Ningyotoge facilities which were all closed down on March 23, 2001 stated that 55,650 t of uranium were taken from open pit mining operations, which also resulted in the production of about 55,000 m³ of uranium slag and smelter waste; 34,000 m³ of slag was disposed of in a tailing dam, and 251,000 m³ of uranium waste soil was disposed of at the mine facilities.

Assigning a specific gravity of 1 to the slag and waste soil gives a percentage of $(251 + 34 + 55 + 55.65) \text{ kt}/(55.65) \text{ kt} = 7.11$. According to Uchiyama et al.'s "Analysis of Energy Revenues of Electrical Power Plants," 25.4 t/y of UO₂ is used to produce 6347 GWh/y at a 1 GW light-water reactor. Thus from the uranium ore production of 57,800 t/y, and a calculated grade of $25.4 \times (285/317)/57800 = 0.04\%$, results in a value of $7.11/0.04\% = 35,500$ which, even under the relatively bad conditions of Japanese mines is at roughly the same order, and the estimations from the ground data also appear to be reasonable as the first approximation.

Figures 4-2 and 4-3 show, respectively, the calculation results for energy resource TMR and electrical power TMR obtained from the present study. Here, TMR(s) indicates the solid components such as soil and tailings, and TMR(aq) shows the liquid component. In addition, Tables 4-1 and 4-2 list, respectively, energy resource TMR and electrical power TMR obtained from the present study combined with the respective values from previous studies⁵⁾. It should be noted that the electrical power for OECD was calculated based on a power resource structure of 50% oil-fired power generation, 19% coal-fired power generation, 13% natural gas and 16% nuclear power.

Figure 4-2 TMR of energy resources

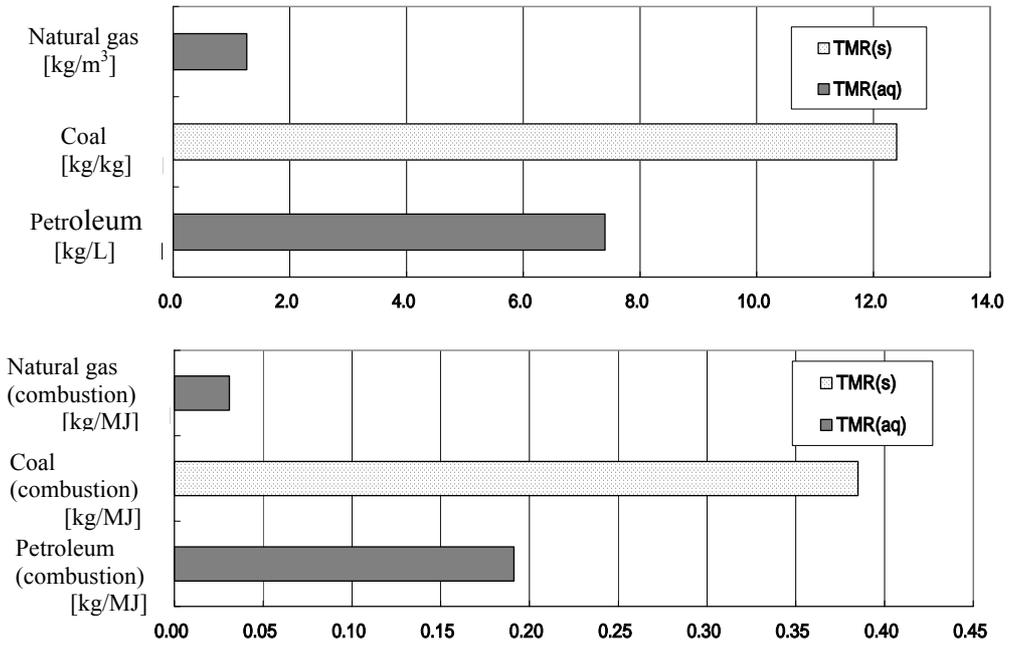


Figure 4-3 TMR of electrical power

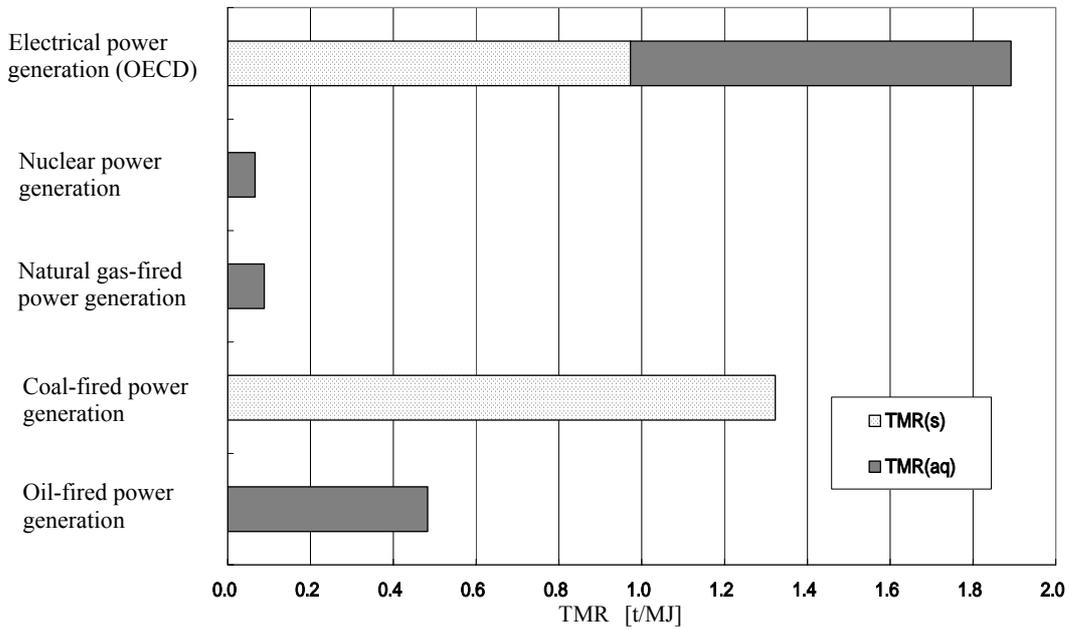


Table 4-1 TMR of energy resources

	Units	TMR (s)	TMR (aq)	TMR (total)	TMR*
Petroleum	Kg/L	-	7.40	7.40	7.40
Coal	kg/kg	12.40	-	12.40	12.40
Natural gas	kg/m ³	-	1.26	1.26	N.A
Petroleum (combustion)	kg/MJ	-	0.19	0.19	0.17
Coal (combustion)	kg/MJ	0.39	-	0.36	0.47
Natural gas (combustion)	kg/MJ	-	0.03	0.03	0.66

*) Calculated by HALADA et al.⁵⁾

Table 4-2 TMR of electrical power

	Units	TMR (s)	TMR (aq)	TMR (total)	TMR*
Oil-fired	kg/MJ	-	0.48	0.48	N.A
Coal-fired	kg/MJ	1.32	-	1.32	N.A
Natural gas-fired	kg/MJ	-	0.09	0.09	N.A
Nuclear	kg/MJ	-	0.07	0.07	0.03
Electrical power (OECD)	kg/kwh	0.97	0.92	1.89	1.76

*) Calculated by HALADA et al.⁵⁾

4.3 TMR of non-metallic mineral resources

Raw ore that is extracted in a natural state from deposits contains impurities such as worthless impurities, so it is subjected to a series of refining processes including dressing, smelting, etc., until a final product is created. Halada et al.³⁾ have already publicly released the TMR of metallic ores. In the present research, estimates were made for the TMR of non-metallic minerals based on the statistical reserve survey¹⁰⁾ released by the Agency for Natural Resources and Energy. Tables 4-3 and 4-4 show data related to reserves of non-metallic minerals.

Table 4-3 Reserves of non-metallic (silica rock, agalmatolite and limestone)¹⁰⁾

1. Silica rock

(1) White silica rock (as of April 1, 2004)

Number of surveyed quarries: 30

	Ore reserves		Minable reserves		Percent extractable (%)	Percent of impurities (%)
	Reserves (1000 t)	Grade (%)	Reserves (1000 t)	Grade (%)		
Confirmed value	241,888	88.4	194,819	88.7		
Estimated value	125,738	91.0	90,874	90.6		
Predicted value	332,816	93.9	176,336	93.4		
Total	700,442	91.5	462,028	90.9	58.6	11.1

(2) Natural silica sand (as of April 1, 2004)

Number of surveyed quarries: 40

	Ore reserves		Minable reserves		Percent extractable (%)	Percent of impurities (%)
	Reserves (1000 t)	Grade (%)	Reserves (1000 t)	Grade (%)		
Confirmed value	42,192	80.1	33,846	77.6		
Estimated value	23,836	77.6	18,210	75.4		
Predicted value	26,732	72.7	21,567	73.5		
Total	91,730	77.4	73,623	75.8	73.3	8.7

(3) Gairome silica sand (as of April 1, 2004)					Number of surveyed quarries: 30	
	Ore reserves		Minable reserves		Percent extractable (%)	Percent of impurities (%)
	Reserves (1000 t)	Grade (%)	Reserves (1000 t)	Grade (%)		
Confirmed value	6,445	47.7	5,303	47.9		
Estimated value	3,292	47.8	2,857	48.0		
Predicted value	11,177	53.1	11,004	53.2		
Total	20,914	50.6	19,164	50.9	91.6	9.0

2. Agalmatolite (as of April 1, 2004)				Number of surveyed quarries: 26	
	Ore reserves		Minable reserves Reserves (1000 t)	Percent extractable (%)	Percent of impurities (%)
	Reserves (1000 t)	Grade (%)			
Confirmed value	30,954		21,484		
Estimated value	36,787		19,709		
Predicted value	49,510		18,525		
Total	117,251		59,718	39.7	22.1

3. Limestone (as of April 1, 2004)					Number of surveyed quarries: 277	
	Ore reserves		Minable reserves		Percent extractable (%)	Percent of impurities (%)
	Reserves (1000 t)	Grade (%)	Reserves (1000 t)	Grade (%)		
Confirmed value	11,178,284	54.2	9,182,301	53.8		
Estimated value	10,190,585	54.0	8,179,035	53.8		
Predicted value	39,463,931	54.3	23,010,743	53.6		
Total	60,832,860	54.3	40,372,079	53.7	59.6	11.8

4. Dolomite (as of April 1, 2004)					Number of surveyed quarries: 17	
	Ore reserves		Minable reserves		Percent extractable (%)	Percent of impurities (%)
	Reserves (1000 t)	Grade (%)	Reserves (1000 t)	Grade (%)		
Confirmed value	441,708	17.9	338,568	17.8		
Estimated value	294,133	17.5	217,212	17.7		
Predicted value	683,064	16.7	357,176	16.4		
Total	1,418,905	17.3	912,956	17.2	60.2	6.5

Table 4-4 Reserves of non-metallic (fire resistant) mineral ores¹⁰⁾

5. Refractory clay

(1) Kaolin (As of April 1, 2004)				Number of surveyed quarries: 6	
	Ore reserves		Minable reserves (1000 t)	Percent extractable (%)	Percent of impurities (%)
	Reserves (1000 t)	Grade (%)			
Confirmed value	2,787		2,193		
Estimated value	1,731		1,413		
Predicted value	2,214		1,478		
Total	6,732		5,085	70.9	6.2

(2) Shale clay (As of April 1, 1997)				Number of surveyed quarries: 3	
	Ore reserves		Minable reserves (1000 t)	Percent extractable (%)	Percent of impurities (%)
	Reserves (1000 t)	Grade (%)			
Confirmed value	746.5		435.5		
Estimated value	1,604.0		997.0		
Predicted value	3,185.0		2,107.0		
Total	5,635.5		3,539.5	46.9	26.7

(3) Kibushi clay (As of April 1, 2004)			Number of surveyed quarries: 35	
	Ore reserves (1000 t)	Minable reserves (1000 t)	Percent extractable (%)	Percent of impurities (%)
Confirmed value	3,253	3,084		
Estimated value	1,889	1,772		
Predicted value	8,501	8,193		
Total	13,643	13,049	95.6	0.0

(4) Gairome clay (As of April 1, 2004)			Number of surveyed quarries: 33	
	Ore reserves (1000 t)	Minable reserves (1000 t)	Percent extractable (%)	Percent of impurities (%)
Confirmed value	8,625	6,886		
Estimated value	4,666	4,038		
Predicted value	13,422	12,649		
Total	26,713	23,573	88.2	0.0

Here, “ore reserves” refers to the amount of deposits in the ground, while “minable reserves” refers to the amount of crude that should be recoverable from extracted mineral deposit/ores (that is, this also includes the amount of impurity that is mixed in with the extracted ore reserves). In addition, the percent extractable is derived by the following equation:

$$\text{Percent extractable} = (\text{Minable reserves} \times (1 - \text{mixing rate of impurity}) / \text{ore reserves}) \times 100.$$

Using these data, calculations were made of the TMR of non-metallic minerals. The following is an example of how the TMR of a non-metallic mineral, white silica sand, was calculated. Because the recovery rate of white silica sand is 58.6%, its TMR is $1/0.586 = 1.71$ t/t. Furthermore, the grade of crude sand is 90.9%, so the TMR per component of the raw sand is $1/0.586/0.909 = 1.88$ t/t. The same type of method is used to calculate the TMR of other non-metallic minerals. Table 4-5 shows the TMR values calculated for non-metallic minerals. These calculations do not take into consideration the amount of rock and soil that is removed before extraction begins. Therefore, for greater accuracy it is necessary to consider this in the TMR calculations.

Table 4-5 TMR of non-metallic minerals

		Ore-TMR (t)	
		Per ore (t)	Per component (t)
Silica rock	White silica rock	1.71	1.88
	Natural silica sand	1.36	1.80
	Gairome silica sand	1.09	2.14
Agalmatolite		2.52	-
Limestone		1.71	3.18
Dolomite		1.66	9.66
Refractory clay	Kaolin	1.41	1.99
	Shale clay	2.13	4.55
	Kibushi clay	1.05	1.09
	Gairome clay	1.13	1.29

4.4 TMR of biomass resources

(1) TMR of farm products

Farm products are not only eaten, but also used to make bioplastics, biofuels, various types of industrial materials, and materials for industrial fuels. In the present research, calculations of the TMR agricultural materials (biomass) were made based on the Monthly Statistics of Agriculture, Forestry and Fisheries.¹¹⁾ Table 4-6 shows the area and yield of various types of crops covered in these statistics.

Table 4-6 Area and yield of farm crops (2004)

	Planted area	Yield per 10a	Production
	ha	kg	t
Rice	1,701,000	513	8,730,000
Wheat	212,600	405	860,300
Two-rowed barley	37,200	355	131,900
Six-rowed barley	17,600	291	51,200
Naked barley	5,060	306	15,500
Soybeans	136,800	119	163,200
Azuki beans	42,600	212	90,500
Kidney beans	11,800	231	27,300
Peanuts	9,110	234	21,300
Potatoes	-	4,504	-
Sweet potatoes	40,300	2,500	1,009,000
Sweet potatoes (starchy substrate)	5,510	3,110	171,500
Pasture grass	788,300	3,897	30,723,000
Early harvested corn	87,400	5,330	4,659,000

Using the above data and the TMR of soil, the TMR of farm crops was calculated. Soil TMR was calculated based as follows: Assuming an apparent specific gravity of 1.2 and depth of plowing of 5 cm of soil used for vegetable cultivation, the value was 60 t/a; for an apparent specific gravity of 1.6 and depth of plowing of 12 cm, a value of 192 t/10a was obtained. The following is an example of TMR calculated for a farm crop, in this case rice. Assuming production of 513 kg per 10 ares, TMR would be $(10/0.513) \times (192/10) = 374.2$ t/t. The same type of method can be used to calculate TMR for other crops. Table 4-7 shows the results of calculations for TMR farm crops.

Table 4-7 TMR of farm products

	TMR (t/t)		TMR (t/t)
Rice	374.1	Kidney beans	259.7
Wheat	148.3	Peanuts	256.4
Two-rowed barley	169.2	Potatoes	13.3
Six-rowed barley	206.3	Sweet potatoes	24.0
Naked barley	195.9	Sweet potatoes (starchy substrate)	19.3
Soybeans	504.2	Pasture grass	15.4
Azuki beans	283.0	Early harvested corn	11.3

(2) TMR of wood

The TMR of wood was calculated based on the website of Thinktank Kyoto¹²⁾ at the Kyoto Civic Activity Center. Table 4-8 shows volumes of production and thinning acquired from the website for Japanese cedar (sugi) and Japanese cypress (hinoki). Here, we can see that the rate of thinned wood is 50%. Furthermore, since the website shows the utilization rate of wood per tree to be 25%, we obtain a wood TMR of $1/0.5/0.25 = 8$ t/t.

Table 4-8 Production and thinning volume of cedar and cypress (FY 2000)⁹⁾

Classification		Southern area of Kyoto	Middle area of Kyoto	Chutan	Tango	Total in Kyoto
Forest area (ha)		27,502	149,109	94,503	60,949	332,064
Resource amount	Material production (m ³)	1,328	60,092	8,357	6,269	76,046
	Thinned wood amount (m ³)	5,825	48,200	16,642	4,204	74,871
	Total (m ³)	7,153	108,292	24,999	10,473	150,917

Area classification is compliance with the Kyoto Forest and Forestry Development Plan.

4.5 TMR of industrial materials

Using the respective TMR (total materials requirement) values of energy resources and electrical power, of non-metallic mineral resources, of biomass resources, and of metallic mineral resources, the TMR of industrial materials was calculated. The following data, etc., were preconditions.

When the TMR was calculated for industrial and related materials that were the objects of this study, reference was made to the SAEFL¹³⁾ for inventory data of the manufacturing process. The TMR of metallic mineral resources that had already been disclosed by Halada et al. is the TMR per unit of each type of metal that is contained in the ore. Therefore, to use this as the TMR of ore that contains impurities or other waste, it is necessary to make some conversions.

Therefore, the following conversion method was used to calculate TMR values of mineral concentrates of iron ore and bauxite, and crude zinc ore. The iron in the iron ore is assumed to be Fe₂O₃. The TMR (per metal) of the iron ore is 5.1 t/t, the atomic weight of Fe₂O₃ is 160, of which Fe₂ accounts for 112. Thus, the TMR of the iron ore concentrate is $5.1 \times 112 / 160 = 3.57$ t/t. In the same way, the TMR of bauxite concentrate is $10 \times 27 / 78 = 3.46$ t/t. Because the zinc is crude ore, a grade of 1.08% is assumed, resulting in a zinc TMR (crude ore) of $81 \times 0.0108 = 0.87$ t/t.

(1) TMR of aluminum materials

Figure 4-4 is a flow chart showing the manufacturing process of primary aluminum granules. Primary aluminum granules come from bauxite which is manufactured into alumina using Beyer's method and then refined using the Hall-Hérout process. On the other hand, recycled ingots are made from scrap. Here, the TMR of recycled aluminum is calculated assuming that all aluminum is manufactured from scrap.

Figure 4-4 Flow chart of the process of primary aluminum ingot manufacturing

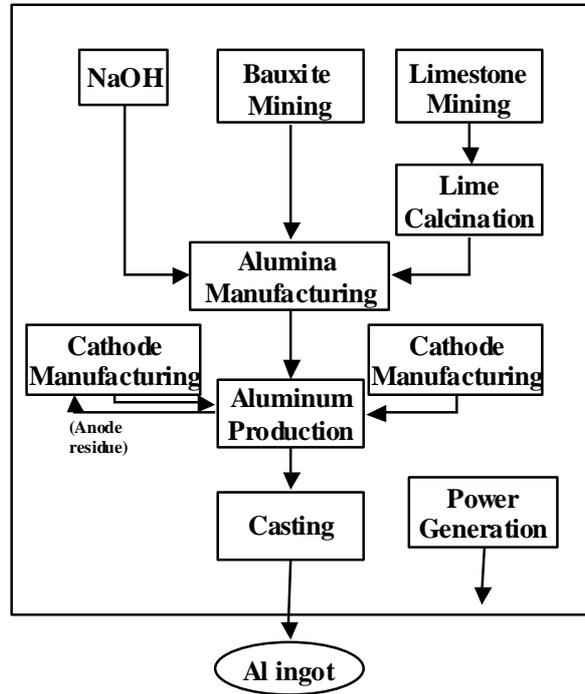


Table 4-9(a) shows the TMR per unit volume of raw materials used in the production of various types of aluminum materials; Table 4-9(b) shows the TMR of aluminum materials that was calculated based on these data. As a result, the following values were derived for the TMR of aluminum materials: Aluminum oxides, 10.24 t/t; aluminum ingots, 47.73 t/t; aluminum foil, 346.23 t/t; recycled aluminum ingots, 2.32 t/t. The primary processing of aluminum ingots requires massive inputs of electrical energy for electrolysis, so the TMR originating from energy resources accounts for a large proportion of this value. In the case of recycled aluminum, however, electrical inputs are reduced because it is manufactured by melting scrap.

Table 4-9 TMR of aluminum materials

(a) TMR for input resources

	unit	TMR per unit
Raw brown coal	t/kg	1.2E-02
Crude gas (natural gas)	t/m3	1.3E-03
Raw hard coal	t/kg	1.2E-02
Crude oil from drilling well	t/kg	6.6E-03
Uranium from ore	t/g	1.1E-02
Wood	t/kg	8.0E-03
Pot. energy water	t/MJ	0.0E+00

(b) TMR for products

Resources, commercial fuels		1t Aluminium oxide	1t Aluminium in ingots	1t Aluminium foil	1t recycled aluminium
Raw brown coal	t	0.53	1.50	2.69	0.42
Crude gas (natural gas)	t	0.08	0.43	0.57	0.13
Raw hard coal	t	0.57	19.10	19.96	0.41
Crude oil from drilling well	t	2.15	8.35	8.61	0.21
Uranium from ore	t	0.04	0.83	0.86	0.04
Wood	t	0.00	0.12	0.13	0.00
Pot. energy water	t	0.00	0.00	0.00	0.00
total(Resources, commercial fuels)	t	3.36	30.32	32.82	1.21

	unit	TMR per unit
Bauxite	t/kg	3.5E-03
Iron ore	t/kg	3.6E-03
Limestone	t/kg	1.7E-03
Sand, clay	t/kg	1.2E-03
Rock salt	t/kg	1.5E-03
Coal	t/kg	1.2E-02
SO2 secondary	t/kg	1.0E-03
Aluminium wastes	t/kg	1.0E-03
Salt	t/kg	1.0E-03
Alloys*	t/kg	1.0E-03
Argon*	t/kg	1.0E-03
Chlorine*	t/kg	1.4E-03
CaF2*	t/kg	1.0E-03
Insulating boards*	t/kg	1.0E-03
Insulating stones*	t/kg	1.0E-03
Others (fluxes and gases)*	t/kg	1.0E-03

Resources, feedstock		1t Aluminium oxide	1t Aluminium in ingots	1t Aluminium foil	1t recycled aluminium
Bauxite	t	6.68	12.84	12.84	
Iron ore	t	0.00	0.00	0.00	
Limestone	t	0.15	0.30	0.30	
Sand, clay	t	0.00	0.00	0.00	
Rock salt	t	0.04	0.08	0.08	
Coal	t	0.00	0.13	0.13	
SO2 secondary	t		0.02	0.02	
Aluminium wastes	t				1.08
Salt	t				0.00
Alloys*	t				0.02
Argon*	t				0.00
Chlorine*	t		0.00	0.00	0.00
CaF2*	t		0.03	0.03	
Insulating boards*	t		0.00	0.00	
Insulating stones*	t		0.01	0.01	0.00
Others (fluxes and gases)*	t		0.00	0.00	0.00
total(Resources, feedstock)	t	6.88	13.40	13.40	1.11

TOTAL	t	10.24	43.73	46.23	2.32
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(2) TMR of steel materials

Figures 4-5 (a) and (b) show flow charts of the processes of manufacturing chrome-plated (ECCS) and tin-plated steel sheets, respectively. The processes for making crude steel, the raw material for refined steel, can be roughly divided into the converter/LD method and the electric furnace method. The main material of the electric furnace method is steel scrap, while the main material for the converter/LD method is pig iron that has been produced in blast furnaces from iron ore. In the present study, TMR values were calculated for ECCS steel sheets produced with the converter/LD method and for tin-plated steel sheets.

Figure 4-5 Flow charts of steel manufacturing processes

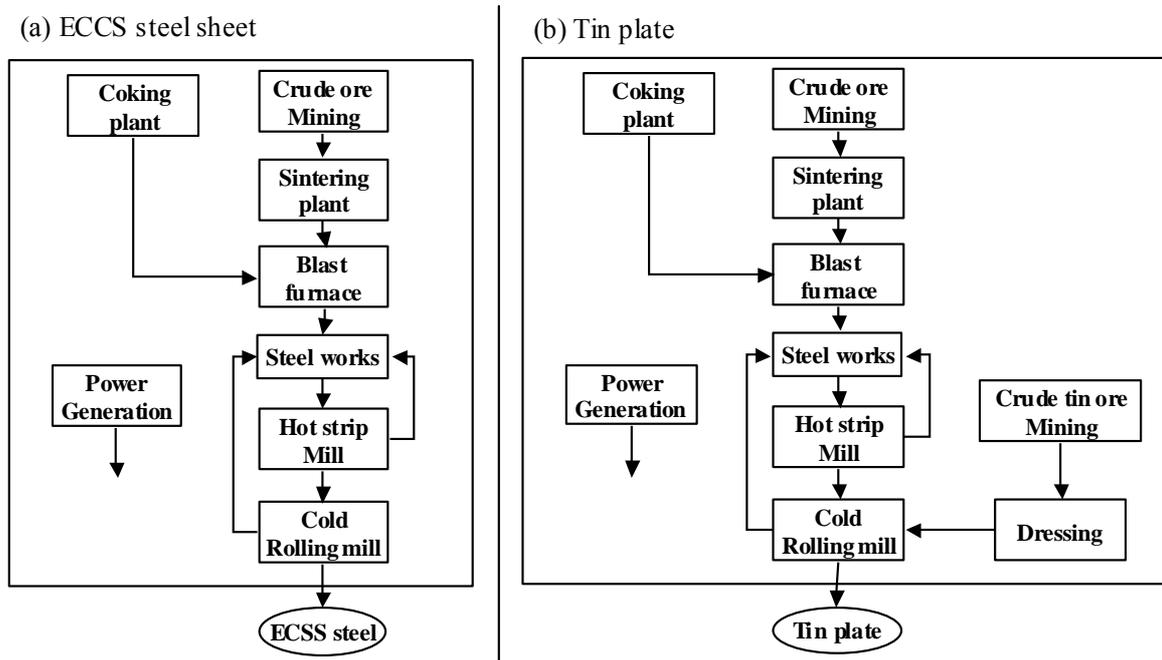


Table 4-10(a) shows the TMR per unit volume of each resource used in the production of various types of steel materials; Table 4-10(b) shows the TMR of steel materials that was calculated based on these data. As a result, the following values were derived for the TMR of steel materials: ECCS steel plate, 26.25 t/t; recycled ECCS steel plate, 7.43 t/t; tin plate, 122.47 t/t; recycled tin plate, 103.34 t/t. Compared with aluminum, the percentage of steel TMR originating from energy resources is low. In addition, the reason for the high value of tin plate compared with ECCS steel plate is that a large amount of materials for the former comes from tin ore.

Table 4-10 TMR of steel materials

(a) TMR for input resources

	unit	TMR per unit
Raw brown coal	t/kg	1.2E-02
Crude gas (natural gas)	t/m3	1.3E-03
Raw hard coal	t/kg	1.2E-02
Crude oil from drilling well	t/kg	6.6E-03
Uranium from ore	t/g	1.1E-02
Wood	t/kg	8.0E-03
Pot. energy water	t/MJ	0.0E+00

	unit	TMR per unit
Iron ore	t/kg	3.6E-03
Limestone	t/kg	1.7E-03
Process water	t/m3	1.0E-03
Alloys*	t/kg	1.0E-03
Scrap external	t/kg	1.0E-03
Chromium compounds*	t/kg	2.6E-02
Degreaser*	t/kg	1.0E-03
Auxiliary material*	t/kg	1.0E-03
Acids*	t/kg	1.0E-03
Crude tin ore	t/kg	8.7E-04
Mill oil*	t/kg	1.0E-03
Additives*	t/kg	1.0E-03

(b) TMR for products

Resources, commercial fuels	unit	ECCS steel sheet	ECCS steel sheet (100% recycled)	Tinplate	Tinplate (100% recycled)
Raw brown coal	t	1.31	3.47	1.31	3.47
Crude gas (natural gas)	t	0.16	0.16	0.16	0.16
Raw hard coal	t	14.76	2.24	14.76	2.26
Crude oil from drilling well	t	0.58	0.16	0.58	0.16
Uranium from ore	t	0.06	0.13	0.06	0.13
Wood	t	0.11	0.01	0.11	0.01
Pot. energy water	t	0.00	0.00	0.00	0.00
total(Resources, commercial fuels)	t	16.98	6.18	16.99	6.20

Resources, feedstock	unit	ECCS steel sheet	ECCS steel sheet (100% recycled)	Tinplate	Tinplate (100% recycled)
Iron ore	t	8.57	0.00	8.57	0.00
Limestone	t	0.48	0.00	0.49	0.00
Process water	t	0.02	0.01	0.02	0.01
Alloys*	t	0.01	0.01	0.01	0.00
Scrap external	t	0.12	1.19	0.12	0.00
Chromium compounds*	t	0.02	0.02	0.00	0.00
Degreaser*	t	0.00	0.00	0.00	0.00
Auxiliary material*	t	0.00	0.01	0.00	0.01
Acids*	t	0.01	0.01	0.01	0.01
Crude tin ore	t	0.00	0.00	96.23	97.10
Mill oil*	t	0.00	0.00	0.00	0.00
Additives*	t	0.03	0.00	0.03	0.00
total(Resources, commercial fuels)	t	9.27	1.26	105.48	97.14

TOTAL	t	26.25	7.43	122.47	103.34
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(3) TMR of plastic materials

Figure 4-6 shows a flow chart for the production process of plastic materials. Plastics are primarily high polymer compounds made of carbon and hydrogen derived from raw materials such as petroleum and natural gas. In Japan, the raw material is naphtha, which is produced during the petroleum refining process. In the production process, the naphtha that is derived from distilling petroleum is heated and decomposed into low molecular compounds such as ethylene and propylene. Next, the molecules derived in this way are chemically combined in a process called polymerization to produce synthetic resins, polymers, etc., such as polyethylene and polypropylene. Some chemical agents are added to these compounds, which are shaped into pellets, which are used as materials for the manufacture of plastics.

Tables 4-11(a) and 4-12(a) show the TMR per unit volume of each resource used in the production of various types of plastics; Tables 4-11(b) and 4-12(b) show the TMR of plastics that was calculated based on these data.

Figure 4-6 Flow chart of the plastic production process

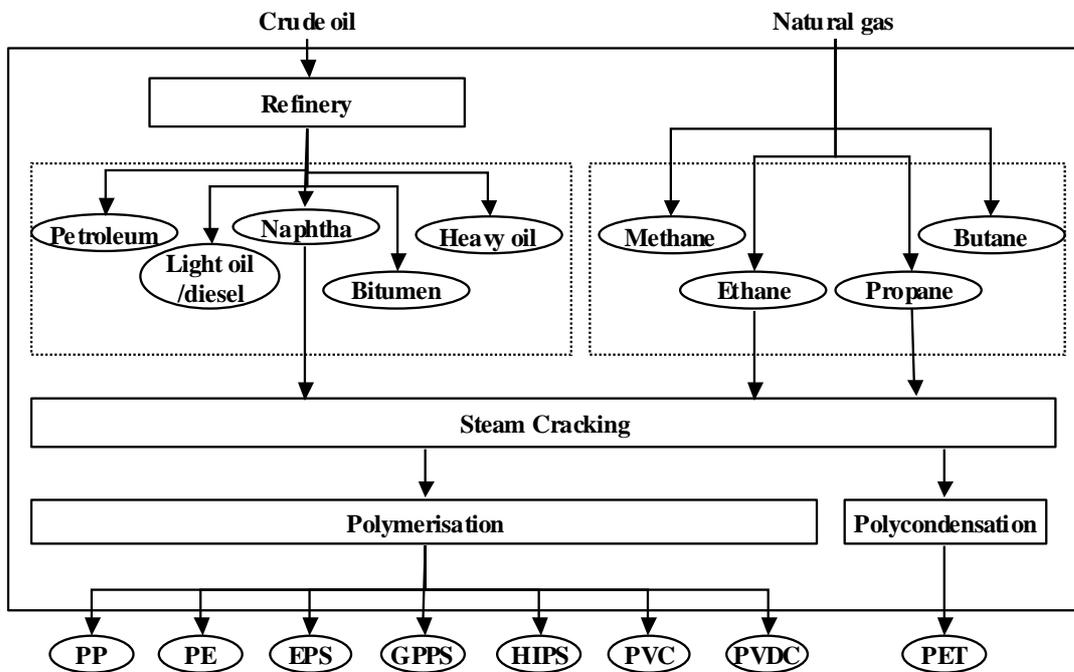


Table 4-11 TMR of plastics (1)

(a) TMR for input resources

		TMR per unit
Raw brown coal	t/kg	1.2E-02
Crude gas (natural gas)	t/m3	1.3E-03
Raw hard coal	t/kg	1.2E-02
Crude oil from drilling well	t/kg	6.6E-03
Uranium from ore	t/g	1.1E-02
Pot. energy water	t/MJ	0.0E+00

		TMR per unit
Crude gas (as feedstock)	t/m3	1.3E-03
Crude oil (as feedstock)	t/kg	7.4E-03
Bauxite	t/kg	3.5E-03
Iron ore	t/kg	3.6E-03
Limestone	t/kg	1.7E-03
Calcium sulphate	t/kg	1.0E-03
Sand, clay	t/kg	1.2E-03
Sulphur	t/kg	1.0E-03
Sulphur as SO2	t/kg	1.0E-03
Rock salt	t/kg	1.5E-03
Process water	t/m3	1.0E-03

(b) TMR for products

Resources, commercial fuels	unit	PE granules (general)	HPDE granules	LPDE granules	LLPDE granules	PP granules
Raw brown coal	t	1.18	0.94	1.36	0.32	0.71
Crude gas (natural gas)	t	0.68	0.59	0.71	0.81	0.39
Raw hard coal	t	1.20	0.95	1.49	0.33	0.73
Crude oil from drilling well	t	1.79	1.59	1.92	1.19	2.45
Uranium from ore	t	0.04	0.03	0.04	0.03	0.02
Pot. energy water	t	0.00	0.00	0.00	0.00	0.00
total(Resources, commercial fuels)	t	4.89	4.11	5.52	2.69	4.31

Resources, feedstock	unit	PE granules (general)	HPDE granules	LPDE granules	LLPDE granules	PP granules
Crude gas (as feedstock)	t	0.78	0.73	0.76	1.08	0.32
Crude oil (as feedstock)	t	3.83	4.05	3.90	2.28	6.11
Bauxite	t	0.00	0.00	0.00	0.00	0.00
Iron ore	t	0.00	0.00	0.00	0.00	0.00
Limestone	t	0.00	0.00	0.00	0.00	0.00
Calcium sulphate	t	0.00	0.00	0.00	0.00	0.00
Sand, clay	t	0.00	0.00	0.00	0.00	0.00
Sulphur	t	0.00	0.00	0.00	0.00	0.00
Sulphur as SO2	t	0.00	0.00	0.00	0.00	0.00
Rock salt	t	0.01	0.01	0.01	0.01	0.01
Process water	t	0.02	0.01	0.02	0.00	0.00
total(Resources, feedstock)	t	4.64	4.80	4.70	3.38	6.44

TOTAL	t	9.53	8.91	10.22	6.07	10.74
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Table 4-12 TMR of plastics (2)

(a) TMR for input resources

		TMR per unit
Raw brown coal	t/kg	1.2E-02
Crude gas (natural gas)	t/m3	1.3E-03
Raw hard coal	t/kg	1.2E-02
Crude oil from drilling well	t/kg	6.6E-03
Uranium from ore	t/g	1.1E-02
Pot. energy water	t/MJ	0.0E+00

		TMR per unit
Crude gas (as feedstock)	t/m3	1.3E-03
Crude oil (as feedstock)	t/kg	7.4E-03
Bauxite	t/kg	3.5E-03
Iron ore	t/kg	3.6E-03
Limestone	t/kg	1.7E-03
Calcium sulphate	t/kg	1.0E-03
Sand, clay	t/kg	1.2E-03
Sulphur	t/kg	1.0E-03
Sulphur as SO2	t/kg	1.0E-03
Rock salt	t/kg	1.5E-03
Process water	t/m3	1.0E-03

(b) TMR for products

Resources, commercial fuels	unit	GPPS moulding compound	HIPS moulding compound	Expandable PS (granules)	PVC powder	PVDC granules	PET granules (amorphous)	PET (partially crystalline)
Raw brown coal	t	0.14	0.14	0.36	0.78	1.86	1.36	1.61
Crude gas (natural gas)	t	0.55	0.57	0.53	0.50	0.78	0.50	0.54
Raw hard coal	t	0.83	1.39	1.15	4.09	8.06	1.61	1.74
Crude oil from drilling well	t	3.29	3.36	2.43	0.86	1.86	2.25	2.32
Uranium from ore	t	0.04	0.05	0.03	0.19	0.46	0.02	0.02
Pot. energy water	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total(Resources, commercial fuels)	t	4.84	5.51	4.49	6.43	13.02	5.75	6.23

Resources, feedstock	unit	GPPS moulding compound	HIPS moulding compound	Expandable PS (granules)	PVC powder	PVDC granules	PET granules (amorphous)	PET (partially crystalline)
Crude gas (as feedstock)	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crude oil (as feedstock)	t	5.36	5.57	5.22	2.72	2.28	5.37	5.37
Bauxite	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron ore	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Limestone	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Calcium sulphate	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sand, clay	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sulphur	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sulphur as SO2	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rock salt	t	0.00	0.00	0.00	1.04	2.03	0.01	0.01
Process water	t	0.00	0.01	0.01	0.02	0.03	0.02	0.02
total(Resources, feedstock)	t	5.37	5.58	5.23	3.78	4.34	5.40	5.40

TOTAL	t	10.21	11.09	9.72	10.20	17.36	11.15	11.63
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(4) TMR of glass materials

Glass is made from silica sand, soda ash, limestone and cullet. These materials are prepared, then heated in a furnace at about 1500°C to melt them into glass. The temperature is then adjusted so that this glass can be shaped into bottles, jars, and other such products.

Table 4-13(a) shows the TMR per unit volume of raw materials used in the production of various types of glass; Table 4-13(b) shows the TMR of glass that was calculated based on these data.

Table 4-13 TMR of glass materials

(a) TMR for input resources

	unit	TMR per unit
Raw brown coal	t/kg	1.2E-02
Crude gas (natural gas)	t/m3	1.3E-03
Raw hard coal	t/kg	1.2E-02
Crude oil from drilling well	t/kg	6.6E-03
Uranium from ore	t/g	1.1E-02
Wood	t/kg	8.0E-03
Pot. energy water	t/MJ	0.0E+00

	unit	TMR per unit
Iron ore	t/kg	3.5E-03
Limestone	t/kg	1.7E-03
Sand, clay	t/kg	1.2E-03
Rock salt	t/kg	1.5E-03
Process water	t/m3	1.0E-03
SO ₂ secondary	t/kg	1.0E-03
Broken glass scrap	t/kg	1.0E-03
Dolomite	t/kg	1.7E-03
Feldspar	t/kg	1.0E-03
Quartz sand	t/kg	1.0E-03
Calumite *	t/kg	1.0E-03
Portachrome/Portafer *	t/kg	1.0E-03
Spodumen *	t/kg	1.0E-03

(b) TMR for products

Resources, commercial fuels	unit	Green glass	Brown glass	White glass	Glass (GB)
Raw brown coal	t	0.10	0.16	0.16	0.00
Crude gas (natural gas)	t	0.03	0.02	0.02	0.20
Raw hard coal	t	0.15	0.54	0.61	2.05
Crude oil from drilling well	t	1.11	1.25	1.21	0.85
Uranium from ore	t	0.04	0.05	0.05	0.03
Wood	t	0.00	0.00	0.00	0.00
Pot. energy water	t	0.00	0.00	0.00	0.00
total(Resources, commercial fuels)	t	1.44	2.02	2.06	3.14

Resources, commercial fuels	unit	Green glass	Brown glass	White glass	Glass (GB)
Iron ore	t	0.00	0.00	0.00	0.00
Limestone	t	0.01	0.16	0.19	0.47
Sand, clay	t	0.00	0.00	0.00	0.02
Rock salt	t	0.01	0.13	0.16	0.37
Process water	t	0.00	0.00	0.00	0.00
SO ₂ secondary	t	0.00	0.00	0.00	0.00
Broken glass scrap	t	1.05	0.68	0.63	0.00
Dolomite	t	0.00	0.11	0.13	0.06
Feldspar	t	0.00	0.00	0.04	0.00
Quartz sand	t	0.00	0.22	0.25	0.58
Calumite *	t	0.00	0.01	0.01	0.00
Portachrome/Portafer *	t	0.00	0.00	0.00	0.00
Spodumen *	t	0.00	0.03	0.00	0.00
total(Resources, feedstock)	t	1.07	1.34	1.40	1.51

TOTAL	t	2.51	3.36	3.46	4.64
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(5) TMR of pulp

Pulp is generally produced by one of two ways: chemically or mechanically. In the mechanical process, mechanical energy is used to produce pulp from wood. This process leaves nearly all of the resin, so this pulp is used in medium quality paper, newsprint, etc., that do not require a high degree of whiteness. In the chemical process, resins such as lignin are dissolved with chemicals so that only the wood fibers are used to make the pulp.

Tables 4-14(a) and 4-15(a) show the TMR per unit volume of raw materials used in the production of various types of pulp; Tables 4-14(b) and 4-15(b) show the TMR of pulp that was calculated based on these data.

Table 4-14 TMR of pulp (1)

(a) TMR for input resources

	unit	TMR per unit
Steam from WIP	t/MJ	0.0E+00
Raw brown coal	t/kg	1.2E-02
Crude gas (natural gas)	t/m3	1.3E-03
Raw hard coal	t/kg	1.2E-02
Crude oil from drilling well	t/kg	6.6E-03
Uranium from ore	t/g	1.1E-02
Wood	t/kg	8.0E-03
Pot. energy water	t/MJ	0.0E+00

	unit	TMR per unit
Bauxite	t/kg	3.5E-03
Iron ore	t/kg	3.6E-03
Limestone	t/kg	1.7E-03
Sand, clay	t/kg	1.2E-03
Rock salt	t/kg	1.5E-03
SO2 secondary	t/kg	1.0E-03
Wood (as feedstock)	t/kg	8.0E-03
S-containing raw materials (as S)	t/kg	1.0E-03
Defoamer*	t/kg	1.0E-03
Complexing agent*	t/kg	1.0E-03
Artificial fertiliser*	t/kg	1.0E-03
Magnesium sulphate*	t/kg	1.0E-03
Sodium dichromate*	t/kg	1.0E-03
Magnesium oxide*	t/kg	1.0E-03

(b) TMR for products

Resources, commercial fuels	unit	Groundwood pulp	Sulphite pulp bleached	Sulphite pulp unbleached	Sulphite pulp bleached Mg(HSO ₃) ₂
Steam from WIP	t	0.00	0.00	0.00	0.00
Raw brown coal	t	0.37	0.14	0.03	3.05
Crude gas (natural gas)	t	0.01	0.01	0.00	0.02
Raw hard coal	t	0.50	0.18	0.03	1.97
Crude oil from drilling well	t	0.55	0.14	0.11	0.13
Uranium from ore	t	0.20	0.05	0.01	0.11
Wood	t	0.00	9.08	8.34	10.14
Pot. energy water	t	0.00	0.00	0.00	0.00
total(Resources, commercial fuels)	t	1.63	9.59	8.51	15.43

Resources, feedstock	unit	Groundwood pulp	Sulphite pulp bleached	Sulphite pulp unbleached	Sulphite pulp bleached Mg(HSO ₃) ₂
Bauxite	t	0.00	0.00	0.00	0.00
Iron ore	t	0.00	0.00	0.00	0.00
Limestone	t	0.00	0.19	0.19	0.00
Sand	t	0.00	0.00	0.00	0.00
Rock salt	t	0.00	0.02	0.00	0.00
SO2 secondary	t	0.00	0.09	0.09	0.06
Wood (as feedstock)	t	7.62	7.24	6.70	6.66
S-containing raw materials (as S)	t	0.00	0.00	0.00	0.00
Defoamer*	t	0.00	0.00	0.00	0.00
Complexing agent*	t	0.00	0.00	0.00	0.00
Artificial fertiliser*	t	0.00	0.00	0.00	0.00
Magnesium sulphate*	t	0.00	0.00	0.00	0.00
Sodium dichromate*	t	0.00	0.00	0.00	0.00
Magnesium oxide*	t	0.00	0.00	0.00	0.03
total(Resources, commercial fuels)	t	7.62	7.55	6.99	6.75

TOTAL	t	9.26	17.14	15.50	22.18
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Table 4-15 TMR of pulp (2)

(a) TMR for input resources

	unit	TMR per unit
Steam from WIP	t/MJ	0.0E+00
Raw brown coal	t/kg	1.2E-02
Crude gas (natural gas)	t/m3	1.3E-03
Raw hard coal	t/kg	1.2E-02
Crude oil from drilling well	t/kg	6.6E-03
Uranium from ore	t/g	1.1E-02
Wood	t/kg	8.0E-03
Pot. energy water	t/MJ	0.0E+00

	unit	TMR per unit
Bauxite	t/kg	3.5E-03
Iron ore	t/kg	3.6E-03
Limestone	t/kg	1.7E-03
Sand, clay	t/kg	1.2E-03
Rock salt	t/kg	1.5E-03
SO2 secondary	t/kg	1.0E-03
Wood (as feedstock)	t/kg	8.0E-03
S-containing raw materials (as S)	t/kg	1.0E-03
Defoamer*	t/kg	1.0E-03
Complexing agent*	t/kg	1.0E-03
Artificial fertiliser*	t/kg	1.0E-03
Magnesium sulphate*	t/kg	1.0E-03
Sodium dichromate*	t/kg	1.0E-03
Magnesium oxide*	t/kg	1.0E-03

(b) TMR for products

Resources, commercial fuels	unit	Sulphate pulp bleached	Sulphate pulp softwood bl.	Sulphate pulp hardwood bl.	Sulphate pulp unbleached
		Canada	Sweden	Sweden	Sweden
Steam from WIP	t	0.10	0.05	0.05	0.03
Raw brown coal	t	0.02	0.01	0.01	0.12
Crude gas (natural gas)	t	2.07	0.27	0.26	0.08
Raw hard coal	t	0.27	0.37	0.30	0.43
Crude oil from drilling well	t	0.08	0.06	0.05	0.09
Uranium from ore	t	0.48	0.08	0.01	0.00
Wood	t	10.37	10.22	10.84	8.14
Pot. energy water	t	0.00	0.00	0.00	0.00
total(Resources, commercial fuels)	t	13.39	11.06	11.51	8.88
Resources, feedstock	unit	Sulphate pulp bleached	Sulphate pulp softwood bl.	Sulphate pulp hardwood bl.	Sulphate pulp unbleached
		Canada	Sweden	Sweden	Sweden
Bauxite	t	0.00	0.00	0.00	0.00
Iron ore	t	0.00	0.00	0.00	0.00
Limestone	t	0.07	0.06	0.05	0.03
Sand	t	0.00	0.00	0.00	0.00
Rock salt	t	0.10	0.05	0.05	0.01
SO2 secondary	t	0.00	0.02	0.02	0.01
Wood (as feedstock)	t	7.23	7.38	6.94	6.54
S-containing raw materials (as S)	t	0.00	0.01	0.01	0.00
Defoamer*	t	0.00	0.00	0.00	0.00
Complexing agent*	t	0.00	0.00	0.00	0.00
Artificial fertiliser*	t	0.00	0.00	0.00	0.00
Magnesium sulphate*	t	0.00	0.00	0.00	0.00
Sodium dichromate*	t	0.00	0.00	0.00	0.00
Magnesium oxide*	t	0.00	0.00	0.00	0.00
total(Resources, commercial fuels)	t	7.40	7.52	7.07	6.59
TOTAL	t	20.79	18.59	18.58	15.47

(6) TMR of corrugated cardboard

Tables 4-16(a) and 4-17(a) show the TMR per unit volume of raw materials used in the production of various types of corrugated cardboard; Tables 4-16(b) and 4-17(b) show the TMR of corrugated cardboard that was calculated based on these data.

Table 4-16 TMR of corrugated cardboard (1)

(a) TMR for input resources

	unit	TMR per unit
Raw brown coal	t/kg	1.2E-02
Crude gas (natural gas)	t/m3	1.3E-03
Raw hard coal	t/kg	1.2E-02
Crude oil from drilling well	t/kg	6.6E-03
Uranium from ore	t/g	1.1E-02
Biomass	t/kg	2.0E-03
Wood	t/kg	8.0E-03
Pot. energy water	t/MJ	0.0E+00

	unit	TMR per unit
Bauxite	t/kg	3.5E-03
Iron ore	t/kg	3.6E-03
Limestone	t/kg	1.7E-03
Sand, clay	t/kg	1.2E-03
Rock salt	t/kg	1.5E-03
SO2 secondary	t/kg	1.0E-03
Waste paper (as feedstock)	t/kg	1.0E-03
Wood (as feedstock)	t/kg	8.0E-03
Farmyard manure	t/kg	1.0E-03
Potatoes (d100)	t/kg	1.3E-02
Corn (d86)	t/kg	1.1E-02
S-containing raw materials (as S)	t/kg	1.0E-03
Sodium dichromate*	t/kg	1.0E-03
Clay minerals	t/kg	1.0E-03
Urea*	t/kg	1.0E-03
Herbicide*	t/kg	1.0E-03
Artificial fertiliser*	t/kg	1.0E-03
Peroxitan*	t/kg	1.0E-03
Pesticides*	t/kg	1.0E-03
Extruded rod*	t/kg	1.0E-03
Retention agent*	t/kg	1.0E-03
Synth. adhesive*	t/kg	1.0E-03

(b) TMR for products

Resources, commercial fuels	unit	Fluting	Kraft liner brown A	Kraft liner brown B	Kraft liner white	Schrenz	Test liner	Medium
Raw brown coal	t	0.06	0.78	0.03	0.05	0.13	0.16	0.17
Crude gas (natural gas)	t	0.01	0.10	0.01	0.02	0.21	0.17	0.14
Raw hard coal	t	0.12	0.42	0.08	0.24	0.15	0.19	0.19
Crude oil from drilling well	t	0.45	0.68	0.36	0.50	0.16	0.18	0.21
Uranium from ore	t	0.08	0.01	0.09	0.15	0.05	0.12	0.15
Biomass	t	0.10	0.00	0.16	0.09	0.00	0.00	0.00
Wood	t	2.06	4.99	2.78	8.49	0.00	0.00	0.00
Pot. energy water	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total(Resources, commercial fuels)	t	2.87	6.98	3.51	9.54	0.70	0.82	0.86

Resources, feedstock	unit	Fluting	Kraft liner brown A	Kraft liner brown B	Kraft liner white	Schrenz	Test liner	Medium
Bauxite	t	0.00	0.02	0.01	0.01	0.00	0.00	0.00
Iron ore	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Limestone	t	0.00	0.07	0.02	0.05	0.00	0.00	0.00
Sand	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rock salt	t	0.02	0.04	0.00	0.03	0.00	0.00	0.00
SO2 secondary	t	0.03	0.01	0.01	0.01	0.00	0.00	0.00
Waste paper (as feedstock)	t	0.18	0.24	0.28	0.02	1.11	1.07	1.06
Wood (as feedstock)	t	5.66	4.75	5.19	7.00	0.00	0.00	0.00
Farmyard manure	t	0.00	0.05	0.00	0.03	0.00	0.08	0.11
Potatoes (d100)	t	0.00	0.14	0.01	0.07	0.00	0.23	0.30
Corn (d86)	t	0.00	0.18	0.01	0.09	0.00	0.31	0.40
S-containing raw materials (as S)	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium dichromate*	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Clay minerals	t	0.00	0.00	0.02	0.06	0.00	0.00	0.00
Urea*	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Herbicide*	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Artificial fertiliser*	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Peroxitan*	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pesticides*	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Extruded rod*	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Retention agent*	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Synth. adhesive*	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total(Resources, commercial fuels)	t	5.90	5.51	5.54	7.37	1.11	1.70	1.87

TOTAL	t	8.77	12.49	9.05	16.91	1.81	2.52	2.73
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Table 4-17 TMR of corrugated cardboard (2)

(a) TMR for input resources

	unit	TMR per unit
Raw brown coal	t/kg	1.2E-02
Crude gas (natural gas)	t/m3	1.3E-03
Raw hard coal	t/kg	1.2E-02
Crude oil from drilling well	t/kg	6.6E-03
Uranium from ore	t/g	1.1E-02
Biogas	t/m3	1.0E-03
Biomass	t/kg	2.0E-03
Wood	t/kg	8.0E-03
Pot. energy water	t/MJ	0.0E+00

	unit	TMR per unit
Bauxite	t/kg	3.5E-03
Iron ore	t/kg	3.6E-03
Limestone	t/kg	1.7E-03
Sand, clay	t/kg	1.2E-03
Rock salt	t/kg	1.5E-03
SO2 secondary	t/kg	1.0E-03
Crude oil from drilling well (as feedstock)	t/kg	1.0E-03
Waste paper (as feedstock)	t/kg	1.0E-03
Wood (as feedstock)	t/kg	8.0E-03
Farmyard manure	t/kg	1.0E-03
Potatoes (d100)	t/kg	1.3E-02
Corn (d86)	t/kg	1.1E-02
Sodium dichromate*	t/kg	1.0E-03
Clay minerals	t/kg	1.0E-03
Basic brown*	t/kg	1.0E-03
Borax*	t/kg	1.0E-03
Urea*	t/kg	1.0E-03
Herbicide*	t/kg	1.0E-03
Artificial fertiliser*	t/kg	1.0E-03
Bonding agents*	t/kg	1.0E-03
Peroxitan*	t/kg	1.0E-03
Pesticides*	t/kg	1.0E-03
Extruded rod*	t/kg	1.0E-03
Retention agent*	t/kg	1.0E-03
Adhesive*	t/kg	1.0E-03

(b) TMR for products

Resources, feedstock	unit	Corr. board Recycled fibre 1	Corr. board Recycled fibre 2	Corr. board Virgin fibre	Corr. board blended 1	Corr. board blended 2	Corr. board blended 3 Double wall
Raw brown coal	t	0.22	0.20	0.68	0.20	0.21	0.21
Crude gas (natural gas)	t	0.22	0.25	0.12	0.16	0.16	0.19
Raw hard coal	t	0.25	0.22	0.45	0.24	0.30	0.23
Crude oil from drilling well	t	0.28	0.26	0.73	0.35	0.40	0.32
Uranium from ore	t	0.14	0.09	0.05	0.14	0.16	0.13
Biogas	t	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	t	0.00	0.00	0.04	0.06	0.03	0.03
Wood	t	0.00	0.00	4.20	0.98	3.02	0.58
Pot. energy water	t	0.00	0.00	0.00	0.00	0.00	0.00
total(Resources, commercial fuels)	t	1.11	1.03	6.26	2.14	4.28	1.69
Resources, feedstock	unit	Corr. board Recycled fibre 1	Corr. board Recycled fibre 2	Corr. board Virgin fibre	Corr. board blended 1	Corr. board blended 2	Corr. board blended 3 Double wall
Bauxite	t	0.00	0.00	0.02	0.00	0.00	0.00
Iron ore	t	0.00	0.00	0.00	0.00	0.00	0.00
Limestone	t	0.00	0.00	0.05	0.01	0.02	0.00
Sand, clay	t	0.00	0.00	0.00	0.00	0.00	0.00
Rock salt	t	0.00	0.00	0.03	0.00	0.01	0.00
SO2 secondary	t	0.00	0.00	0.02	0.00	0.00	0.00
Crude oil from drilling well (as feedstock)	t	0.00	0.00	0.00	0.00	0.00	0.00
Waste paper (as feedstock)	t	1.11	1.14	0.23	0.83	0.74	0.95
Wood (as feedstock)	t	0.00	0.00	5.28	1.84	2.49	1.09
Farmyard manure	t	0.10	0.04	0.04	0.07	0.08	0.06
Potatoes (d100)	t	0.27	0.10	0.10	0.19	0.21	0.18
Corn (d86)	t	0.84	0.62	0.62	0.73	0.76	0.72
Sodium dichromate*	t	0.00	0.00	0.00	0.00	0.00	0.00
Clay minerals	t	0.00	0.00	0.00	0.01	0.02	0.00
Basic brown*	t	0.00	0.00	0.00	0.00	0.00	0.00
Borax*	t	0.00	0.00	0.00	0.00	0.00	0.00
Urea*	t	0.00	0.00	0.00	0.00	0.00	0.00
Herbicide*	t	0.00	0.00	0.00	0.00	0.00	0.00
Artificial fertiliser*	t	0.01	0.00	0.00	0.01	0.01	0.01
Bonding agents*	t	0.00	0.00	0.00	0.00	0.00	0.00
Peroxitan*	t	0.00	0.00	0.00	0.00	0.00	0.00
Pesticides*	t	0.00	0.00	0.00	0.00	0.00	0.00
Extruded rod*	t	0.00	0.00	0.00	0.00	0.00	0.00
Retention agent*	t	0.00	0.00	0.00	0.00	0.00	0.00
Adhesive*	t	0.00	0.00	0.00	0.00	0.00	0.00
total(Resources, commercial fuels)	t	2.33	1.92	6.38	3.69	4.35	3.03
TOTAL	t	3.44	2.95	12.65	5.83	8.62	4.72

(7) TMR of miscellaneous paper products

Tables 4-18(a), 4-19(a) and 4-20(a) show the TMR per unit volume of resources used in the production of pasteboards, graphic papers, and packaging papers, respectively; Tables 4-18(b), 4-19(b) and 4-20(b) show the TMR of miscellaneous papers that was calculated based on these data.

Table 4-18 TMR of pasteboard

(a) TMR for input resources

	unit	TMR per unit
Raw brown coal	t/kg	1.2E-02
Crude gas (natural gas)	t/m3	1.3E-03
Raw hard coal	t/kg	1.2E-02
Crude oil from drilling well	t/kg	6.6E-03
Uranium from ore	t/g	1.1E-02
Biomass	t/kg	2.0E-03
Wood	t/kg	8.0E-03
Pot. energy water	t/MJ	0.0E+00

	unit	TMR per unit
Bauxite	t/kg	3.5E-03
Iron ore	t/kg	3.6E-03
Limestone	t/kg	1.7E-03
Sand, clay	t/kg	1.2E-03
Rock salt	t/kg	1.5E-03
SO2 secondary	t/kg	1.0E-03
Crude oil from drilling well (as	t/kg	1.0E-03
Waste paper (as feedstock)	t/kg	1.0E-03
Wood (as feedstock)	t/kg	8.0E-03
Farmyard manure	t/kg	1.0E-03
Potatoes (d100)	t/kg	1.3E-02
Corn (d86)	t/kg	1.1E-02
S-containing raw materials (as	t/kg	1.0E-03
Defoamer*	t/kg	1.0E-03
Complexing agent*	t/kg	1.0E-03
Artificial fertiliser*	t/kg	1.0E-03
Magnesium sulphate*	t/kg	1.0E-03
Sodium dichromate*	t/kg	1.0E-03
Magnesium oxide*	t/kg	1.0E-03
Clay minerals	t/kg	1.0E-03
Urea*	t/kg	1.0E-03
Peroxitan*	t/kg	1.0E-03
Pesticides*	t/kg	1.0E-03
Extruded rod*	t/kg	1.0E-03
Rosin size*	t/kg	1.0E-03
Herbicide*	t/kg	1.0E-03

(b) TMR for products

Resources, commercial fuels	unit	Grey board (GK)	Duplex/triplex board (GD/GT)	Chromo board	Pulp board (GZ)	Liquid packaging board (LPB)
Raw brown coal	t	0.14	0.16	1.71	0.09	0.05
Crude gas (natural gas)	t	0.02	0.27	0.12	0.03	0.01
Raw hard coal	t	0.11	0.23	1.55	0.38	0.22
Crude oil from drilling well	t	1.40	0.30	1.99	0.72	0.55
Uranium from ore	t	0.01	0.02	0.19	0.13	0.16
Biomass	t	0.00	0.00	0.06	0.23	0.03
Wood	t	0.63	0.26	3.72	10.99	8.58
Pot. energy water	t	0.00	0.00	0.00	0.00	0.00
total(Resources, commercial fuels)	t	2.31	1.23	9.34	12.56	9.60
Resources, feedstock	unit	Grey board (GK)	Duplex/triplex board (GD/GT)	Chromo board	Pulp board (GZ)	Liquid packaging board (LPB)
Bauxite	t	0.01	0.01	0.00	0.00	0.00
Iron ore	t	0.00	0.00	0.00	0.00	0.00
Limestone	t	0.02	0.09	0.14	0.06	0.03
Sand	t	0.00	0.00	0.00	0.00	0.00
Rock salt	t	0.00	0.00	0.02	0.04	0.01
SO2 secondary	t	0.01	0.01	0.01	0.02	0.01
Crude oil from drilling well (as	t	0.00	0.00	0.01	0.01	0.01
Waste paper (as feedstock)	t	0.96	0.91	0.00	0.00	0.00
Wood (as feedstock)	t	0.51	0.30	6.44	5.74	6.62
Farmyard manure	t	0.00	0.00	0.02	0.06	0.00
Potatoes (d100)	t	0.00	0.00	0.06	0.17	0.00
Corn (d86)	t	0.00	0.00	0.07	0.23	0.00
S-containing raw materials (as S)	t	0.00	0.00	0.00	0.01	0.00
Defoamer*	t	0.00	0.00	0.00	0.00	0.00
Complexing agent*	t	0.00	0.00	0.00	0.00	0.00
Artificial fertiliser*	t	0.00	0.00	0.00	0.00	0.00
Magnesium sulphate*	t	0.00	0.00	0.00	0.00	0.00
Sodium dichromate*	t	0.00	0.00	0.00	0.00	0.00
Magnesium oxide*	t	0.00	0.00	0.00	0.00	0.00
Clay minerals	t	0.00	0.13	0.18	0.43	0.25
Urea*	t	0.00	0.00	0.00	0.00	0.00
Peroxitan*	t	0.00	0.00	0.00	0.00	0.00
Pesticides*	t	0.00	0.00	0.00	0.00	0.00
Extruded rod*	t	0.00	0.00	0.00	0.00	0.00
Rosin size*	t	0.00	0.00	0.01	0.00	0.00
Herbicide*	t	0.00	0.00	0.00	0.00	0.00
total(Resources, feedstock)	t	1.51	1.46	6.96	6.76	6.93
TOTAL	t	3.82	2.70	16.30	19.33	16.53

Table 4-19 TMR of graphic papers

(a) TMR for input resources

	unit	TMR per unit
Steam from WIP	t/MJ	0.0E+00
Raw brown coal	t/kg	1.2E-02
Crude gas (natural gas)	t/m3	1.3E-03
Raw hard coal	t/kg	1.2E-02
Crude oil from drilling well	t/kg	6.6E-03
Uranium from ore	t/g	1.1E-02
Biomass	t/kg	2.0E-03
Wood	t/kg	8.0E-03
Pot. energy water	t/MJ	0.0E+00

	unit	TMR per unit
Bauxite	t/kg	3.5E-03
Iron ore	t/kg	3.6E-03
Limestone	t/kg	1.7E-03
Sand, clay	t/kg	1.2E-03
Rock salt	t/kg	1.5E-03
SO2 secondary	t/kg	1.0E-03
Crude oil from drilling well (as	t/kg	1.0E-03
Wood (as feedstock)	t/kg	8.0E-03
Farmyard manure	t/kg	1.0E-03
Waste paper (as feedstock)	t/kg	1.0E-03
Potatoes (d100)	t/kg	1.3E-02
S-containing raw materials (as S)	t/kg	1.0E-03
Defoamer*	t/kg	1.0E-03
Complexing agent*	t/kg	1.0E-03
Magnesium sulphate*	t/kg	1.0E-03
Sodium dichromate*	t/kg	1.0E-03
Clay minerals	t/kg	1.0E-03
Artificial fertiliser*	t/kg	1.0E-03
Pesticides*	t/kg	1.0E-03
Extruded rod*	t/kg	1.0E-03
Rosin size*	t/kg	1.0E-03
Quartz sand	t/kg	1.0E-03

(b) TMR for products

Resources, commercial fuels	unit	Paper wood-free uncoated	Paper wood-free coated	Paper wood-containing uncoated	Paper wood-containing coated	Recycled paper without deinking	Recycled with deinking	Newsprint
Steam from WIP	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Raw brown coal	t	0.25	0.32	0.67	0.40	0.11	0.33	0.43
Crude gas (natural gas)	t	0.36	0.26	0.03	0.31	0.34	0.03	0.02
Raw hard coal	t	0.58	0.50	1.01	0.63	0.09	0.62	0.67
Crude oil from drilling well	t	0.38	0.32	0.47	0.32	0.06	0.50	0.32
Uranium from ore	t	0.08	0.08	0.38	0.14	0.01	0.15	0.24
Biomass	t	0.07	0.02	1.38	0.02	0.00	1.68	0.97
Wood	t	8.69	5.37	0.42	3.62	0.00	0.42	0.00
Pot. energy water	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total(Resources, commercial fuels)	t	10.40	6.87	4.37	5.45	0.62	3.75	2.65

Resources, feedstock	unit	Paper wood-free uncoated	Paper wood-free coated	Paper wood-containing uncoated	Paper wood-containing coated	Recycled paper without deinking	Recycled with deinking	Newsprint
Bauxite	t	0.00	0.00	0.01	0.00	0.00	0.01	0.01
Iron ore	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Limestone	t	0.40	0.76	0.01	0.46	0.00	0.04	0.03
Sand	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rock salt	t	0.04	0.02	0.00	0.02	0.00	0.05	0.03
SO2 secondary	t	0.02	0.03	0.00	0.01	0.00	0.00	0.00
Crude oil from drilling well (as	t	0.00	0.02	0.00	0.02	0.01	0.00	0.00
Wood (as feedstock)	t	6.02	3.83	7.30	4.57	0.00	0.32	2.98
Farmyard manure	t	0.14	0.10	0.16	0.12	0.15	0.16	0.00
Waste paper (as feedstock)						1.01	1.00	0.79
Potatoes (d100)	t	0.39	0.27	0.45	0.32	0.42	0.44	0.01
S-containing raw materials (as S)	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Defoamer*	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Complexing agent*	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Magnesium sulphate*	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium dichromate*	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Clay minerals	t	0.00	0.25	0.30	0.42	0.00	0.31	0.02
Artificial fertiliser*	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pesticides*	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Extruded rod*	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rosin size*	t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Quartz sand	t	0.00	0.00	0.00	0.00	0.00	0.01	0.01
total(Resources, commercial fuels)	t	7.03	5.28	8.24	5.93	1.59	2.34	3.89

TOTAL	t	17.43	12.16	12.62	11.38	2.21	6.09	6.54
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Table 4-20 TMR of packaging papers

(a) TMR for input resources

	unit	TMR per unit
Raw brown coal	t/kg	1.2E-02
Crude gas (natural gas)	t/m3	1.3E-03
Raw hard coal	t/kg	1.2E-02
Crude oil from drilling well	t/kg	6.6E-03
Uranium from ore	t/g	1.1E-02
Biomass	t/kg	2.0E-03
Wood	t/kg	8.0E-03
Pot. energy water	t/MJ	0.0E+00

	unit	TMR per unit
Bauxite	t/kg	3.5E-03
Iron ore	t/kg	3.6E-03
Limestone	t/kg	1.7E-03
Sand, clay	t/kg	1.2E-03
Rock salt	t/kg	1.5E-03
SO2 secondary	t/kg	1.0E-03
Crude oil from drilling well (as feedstock)	t/kg	1.0E-03
Waste paper (as feedstock)	t/kg	1.0E-03
Wood (as feedstock)	t/kg	8.0E-03
Farmyard manure	t/kg	1.0E-03
Potatoes (d100)	t/kg	1.3E-02
Corn (d86)	t/kg	1.1E-02
S-containing raw materials (as S)	t/kg	1.0E-03
Defoamer*	t/kg	1.0E-03
Complexing agent*	t/kg	1.0E-03
Artificial fertiliser*	t/kg	1.0E-03
Magnesium sulphate*	t/kg	1.0E-03
Sodium dichromate*	t/kg	1.0E-03
Clay minerals	t/kg	1.0E-03
Borax*	t/kg	1.0E-03
Peroxitan*	t/kg	1.0E-03
Pesticides*	t/kg	1.0E-03
Extruded rod*	t/kg	1.0E-03
Rosin size*	t/kg	1.0E-03
Herbicide*	t/kg	1.0E-03

(b) TMR for products

Resources, commercial fuels	unit	Kraft paper single face coated	Kraft paper bleached	Kraft paper unbleached	Swiss kraft	Bag paper integrated Sweden	Bag paper integrated Austria
Raw brown coal	t	0.44	0.38	0.34	0.13	0.04	0.06
Crude gas (natural gas)	t	0.33	0.32	0.43	0.35	0.01	0.06
Raw hard coal	t	0.94	0.95	0.48	0.12	0.13	0.06
Crude oil from drilling well	t	0.47	0.51	0.62	0.11	0.67	0.31
Uranium from ore	t	0.19	0.20	0.24	0.03	0.16	0.00
Biomass	t	0.11	0.14	0.04	0.00	0.00	1.36
Wood	t	7.73	10.78	8.30	1.58	8.50	8.51
Pot. energy water	t	0.00	0.00	0.00	0.00	0.00	0.00
total(Resources, commercial fuels)	t	10.20	13.28	10.46	2.32	9.52	10.37
Resources, feedstock	unit	Kraft paper single face coated	Kraft paper bleached	Kraft paper unbleached	Swiss kraft	Bag paper integrated Sweden	Bag paper integrated Austria
Bauxite	t	0.00	0.00	0.00	0.03	0.01	0.02
Iron ore	t	0.00	0.00	0.00	0.00	0.00	0.00
Limestone	t	0.25	0.06	0.03	0.03	0.03	0.04
Sand, clay	t	0.00	0.00	0.00	0.00	0.00	0.00
Rock salt	t	0.04	0.06	0.01	0.00	0.00	0.01
SO2 secondary	t	0.01	0.02	0.01	0.02	0.01	0.01
Crude oil from drilling well (as feedstock)	t	0.01	0.00	0.00	0.00	0.00	0.00
Waste paper (as feedstock)	t	0.00	0.00	0.00	0.79	0.00	0.00
Wood (as feedstock)	t	5.23	7.31	6.70	1.27	7.24	6.37
Farmyard manure	t	0.02	0.02	0.02	0.03	0.01	0.02
Potatoes (d100)	t	0.05	0.05	0.05	0.08	0.03	0.04
Corn (d86)	t	0.07	0.07	0.07	0.00	0.04	0.06
S-containing raw materials (as S)	t	0.00	0.01	0.00	0.00	0.00	0.00
Defoamer*	t	0.00	0.00	0.00	0.00	0.00	0.00
Complexing agent*	t	0.00	0.00	0.00	0.00	0.00	0.00
Artificial fertiliser*	t	0.00	0.00	0.00	0.00	0.00	0.00
Magnesium sulphate*	t	0.00	0.00	0.00	0.00	0.00	0.00
Sodium dichromate*	t	0.00	0.00	0.00	0.00	0.00	0.00
Clay minerals	t	0.54	0.06	0.06	0.00	0.00	0.02
Borax*	t	0.00	0.00	0.00	0.00	0.00	0.00
Peroxitan*	t	0.00	0.00	0.00	0.00	0.00	0.00
Pesticides*	t	0.00	0.00	0.00	0.00	0.00	0.00
Extruded rod*	t	0.00	0.00	0.00	0.00	0.00	0.00
Rosin size*	t	0.01	0.00	0.00	0.03	0.00	0.00
Herbicide*	t	0.00	0.00	0.00	0.00	0.00	0.00
total(Resources, commercial fuels)	t	6.24	7.65	6.96	2.28	7.39	6.58
TOTAL	t	16.44	20.94	17.41	4.61	16.91	16.95

5. Recycling Analysis Using Resource Indices

In this chapter, TMR is used as a resource index in an attempt to analyze the recycling flow. The object of this analysis was a recycling system that uses a shredder to process scrap automobiles. The material composition and recycling flow of end-of-life vehicles (ELVs) are based on the work of Funazaki et al.¹⁴⁾

In conventional material management, which has emphasized “improving the recycling rate” and increasing the amount recycled,” little attention has been paid to trace components such as platinum group metals. It has been the same way with automobile components. Therefore, NIMS-EMC Materials Data¹⁵ were used as a reference for the amount of platinum used in catalytic converters, which was calculated to be 0.8g per vehicle.

Figure 5-1 shows the recycling flow of ELV per vehicle on a weight basis. But, as we can see in Figure 5-2, if this flow incorporates TMR, it can be used to view this information from an entirely different perspective. It should be noted that data on miscellaneous TMR, which includes fibers, rubber, etc., could not be obtained, so it was estimated to be 1 t/t.

From a weight-based recycling perspective, the main process of ELV recycling is a shredding process which involves massive quantities of iron and steel scrap. The main component of the shredder dust (ASR) is plastic. If TMR is used in this case as an indicator of resource quality, the results will differ. That is, from a TMR perspective, the main process is manual dismantling prior to shredding, and many metals with a high TMR, including platinum, are collected. Moreover, the main component of ASR is copper. Consequently, facilities for non-metallic refining are used to collect metallic components from ASR. At the same time, technology for creating alternative fuels from combustible components is effective from a resource utilization perspective, which is indicated by the results of recycling analysis using TMR.

Furthermore, to manage materials effectively for resource recycling, it is necessary to have a firm understanding not only of the massive amounts of conventional data, but also of data related to the effects of small amounts of materials such as platinum group metals.

Figure 5-1 Weight-based recycling flow of end-of-life vehicles (ELVs)

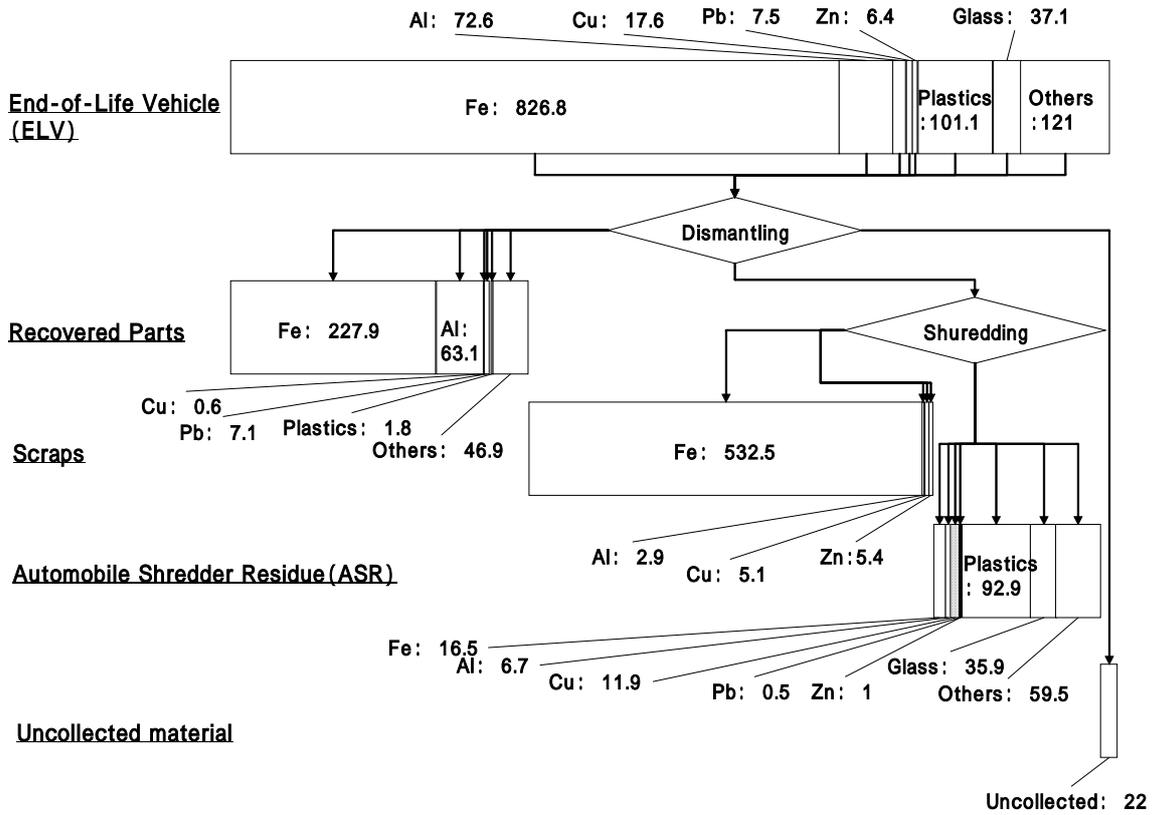
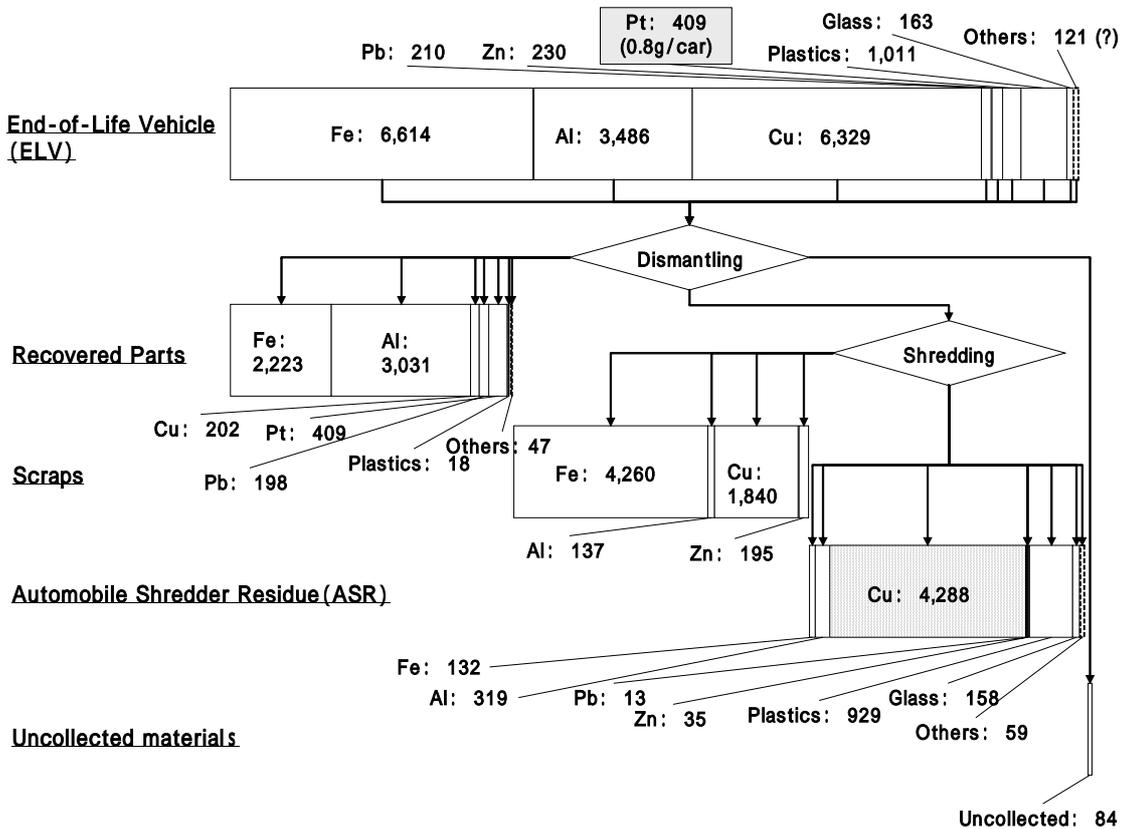


Figure 5-2 TMR-based recycling flow of end-of-life vehicles (ELVs)



6. Discussion

This study has involved calculations of TMR data on energy resources and industrial materials. The following is a discussion about the TMR index, the accuracy of the data, and the analysis of the TMR recycling flow.

First of all, let us consider TMR, TMR is an index to show the amount of flow of materials used in the background of the manufacture of materials and products and, as such, can be expected to be an indicator of environmental impacts that occur with these flows. Consequently, we cannot use TMR to discuss the toxicity or depletability of substances. Presently, there are many other indices besides TMR that can be used to discuss depletion coefficients of resources or the toxicity of substances, so it is necessary to use an index that matches the purpose of the evaluation.

Next is the robustness of the calculated data. There is an awareness of the necessity of TMR, but there are still insufficient basic data available to make the calculations. The results of the present study were based upon data from Uchiyama et al, and SAEFL inventory data. To provide for greater accuracy, these data should be calculated by incorporating with conditions existing in the processes in question.

Finally, let us now look at the TMR-based method of analyzing recycling flow. This method uses TMR as a weighted coefficient for materials. To discuss changes in TMR, the environmental load, etc. in the overall recycling system, it is necessary to make a separate analysis from an LCA perspective.

7. Conclusions

The present study has involved making calculations of the TMR of energy resources, power generation, and packaging and related materials. At the same time, an attempt was made to use TMR to investigate a method for analyzing recycling flow. The main results obtained were as follows:

- There was a total of 98 types of TMR that were compiled in the present study. This included 10 types for energy resources and power generation (6 for energy resources, 3 for power generation, and 1 for electrical power), 15 types for biomass, 10 types for non-metallic mineral resources, and 63 types of TMR for industrial materials.
- A method was proposed that uses resource indices to analyze recycling flow. Analysis of ELV recycling flow showed that from a TMR perspective, manual disassembly was the main process, and that many metals with a high TMR, including platinum group metals, were recovered. Moreover, the main component of copper was found to be ASR.
- By using resource indices to analyze recycling flow, it became possible to consider resource quality, which had not been done in previous analyses.

For future research, plans are being considered to hold international symposia to establish an international method for calculating TMR, conduct a detailed study on basic data, and construct a comprehensive TMR database that encompasses all industrial activities using Interindustry Tables, etc.

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- No. 2 Fundamental Survey for Lead Material Flow in Japan (March, 2004)
- No. 3 Worldwide Supply and Demand of Platinum Group Metals and Trends in the Recycling of Autocatalyst in Japan (March, 2004)
- No. 4 LCA-Based Investigation of Technological Application Scenarios of Surplus Iron Scrap in Converters and Electric Furnaces (March, 2004)
- No. 5 Aluminium Material Flow in Japan (scheduled for publication)
- No. 6 Investigation on the Utilization and Application of Biomass (scheduled for publication)
- No. 7 Current Status of Recycling of Nonferrous Metals in China and Discarded Electric Appliances etc. in Japan (scheduled for publication)
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