Chapter 2
Potential of Urban Mine

Abstract The potential of urban mining is getting greater. From the global view, the potential of urban mining, namely the estimated amount of on-surface stock which has been mine form the geo-sphere into the techno-sphere, is comparative to natural resource which is still in geo-sphere as underground stock. However, practical recycling of metals are still in the stage of developing, and depending on the country. As an example, ultimate potential of urban mine in Japan was estimated. The differences between input of each metal contents and output of it were considered to be accumulated. I/O method was combined to estimate the metal contents in exported products. Japan, which is considered a typical exporter of materials, has great potential of urban mining which comes from domestic demand of products. However, real activity of development of urban mine, namely recycling, is not so effective, especially for minor metals which sometime called rare metals from the viewpoint of the importance in industries. We need to develop the technology and system for urban mining, just now.

Keywords Consumption of metals · On-surface stock · Recycling rate · Life-cycle · End-of life flow · Accumulation of metals

2.1 Background

The urgency of resolving resource issues such as recycling is growing daily. As Halada et al. [1] pointed out, it is estimated that the consumption of metals will be several times higher than the present metal reserves until the year 2050. Estimated cumulative consumption at 2050 was compared with the present reserves, as shown in Fig. 2.1. The downward-extending bars in the figure represents today's reserves. The upper bars indicate the reserve base when reserves are set at one. When an upward-extending bar graph crosses the line of one, it signifies that the amount of current reserves has been depleted; when it passes a bar, it means that even the current reserve base has been depleted. Demand is estimated to exceed

T. Nakamura and K. Halada, *Urban Mining Systems*, SpringerBriefs in Applied Sciences and Technology, DOI 10.1007/978-4-431-55075-4_2

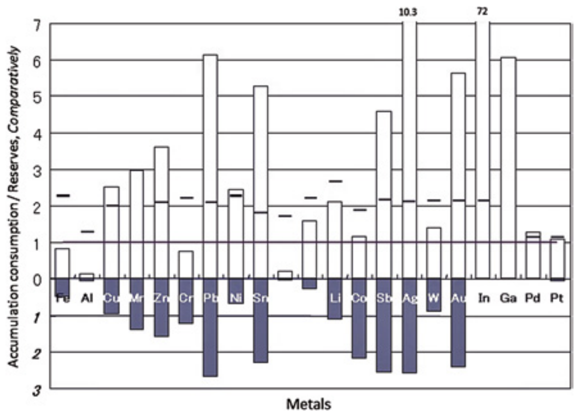

Fig. 2.1 The relation of the accumulation demand and existing reserves by 2050

reserve bases for metals such as gold, silver, copper, lead, zinc, tin, antimony, and indium. In addition, this expectation assumes almost no increase in demand for high-functional rare metals for IT and eco-innovation. Regarding metals for which mines have been developed and exploration is being undertaken on a global scale, dramatic technological innovations like those which were made up to the 20th century are needed to make extremely effective device designs and material designs to match consumption and utilization patterns. The bars which extend down below is the amount of each metal which has already mined. As the amounts of already mined are greater than the amount of reserves in a plenty kinds of metals, the role of recycling is important to reduce the resource issue.

As early as the 1980s, Nanjo [2] noted that the contents of rare earth metals contained in industrial products often exceeded the grades found in raw ores, and they were in the form of refined metals in many cases, so that their reuse did not require the massive amount of energy needed to smelt and refine crude ores. Nanjo called areas of industrial products concentrated on the surface “urban mines.” Around the same time, Nishiyama [3] pointed out that for many metal resources, the amounts that had already been mined exceeded the known reserves. The notion of urban mines has continued since that time, and has recently been developed into the “artificial deposit concept” of Shiratori and Nakamura [4]. Companies and local governments, among others, have started to take an interest in this.

What is the amount of resources can be recycled by opening urban mines? The truth is, this question has not really been addressed. In the case of iron and steel, Japan Ferrous Raw Materials Association, among others, has estimated the amount that has been accumulated, and Japan Oil, Gas and Metals National Corporation (JOGMEC) [5] and the Metal Economics Research Institute of Japan [7] have been preparing information about material flow, but the total amount has not been satisfactorily investigated. Japan has amassed a large amount of resources from overseas and exported some of them in the form of manufactured products. This is one of the main factors that make it difficult to determine the percentage of resources that have stayed in the country. In the case of steel for automobiles, for which product and material have a one-to-one relation, it is possible to estimate the amount of steel exported in automobiles by making simple assumptions. However, estimates are difficult in the case of electronic devices which contain trace amounts of metals such as gold that are used in various applications.

2.2 World Potential

2.2.1 Estimated Potential

We have two different types of stocks of metal. One is the primary stock which is still under the ground to be mined. This can be called as “underground stock”. The other stock is the secondary stock, which has been mined already and accumulated as products or waste in the human’s techno-sphere. The secondary stock is called as “on surface stock”. The basic potential of urban miming is estimating the secondary stock as the global cumulative volume which has been mined.

When calculating the global cumulative volume, there is no need to consider trade since there are no national boundaries to be considered, so it is easier to calculate than the cumulative volume for individual countries. However, when discussing cumulative amounts, certain issues come up such as natural limits, flow limits, and the definition of assets. Natural limits involve ways of dealing with materials that are buried, or corrode over time. Flow limits involve using an understanding of annual statistics to deal with “double counts,” etc., that occur during processing and recycling. Asset definitions involve issues that arise from legal aspects such as fixed assets, useable life, patterns of ownership, and so on. These concepts are still being widely debated, and a standard theory has not yet been established.

In order to avoid such confusion and to emphasize an initial understanding of the rough estimate, this paper treats all resources that are extracted and brought to the surface as cumulative volume. Thus they are treated in an integrated manner without regard to flow or asset definition, and this even includes items on the surface for which management or ownership rights have been lost. In other words, even junk items are considered to be part of the cumulative total. This paper also takes the view that corroded and oxidized items form part of the oxidized resources, in that same way that oxide ores do. Furthermore, items buried in landfills are considered to exist far closer to the ground surface than do underground resources. In order to avoid confusion that might arise from the discussions about the various types of accumulation, it was decided to call this the broadly defined cumulative volume. In other words, the broadly defined cumulative volume corresponds to the amount of material that has been taken into the human economic sphere.

One more point that should be considered is how to deal with intermediate and recycled goods. Because these are goods that are being used, or have been used, it is easy to consider accumulation based on the amount used. However, there are metals that are immediately recycled from used scrap. By using the amount used as a base, recycled volume should be subtracted from the scrap volume. In addition, when using data such as industrial statistics, it should be noted that there exist intermediate products such as semi-processed materials which form intermediate demand. Because the amount linked to accumulation is the final demand, if the intermediate demand is added to this total, it results in a double count. However, most industrial statistics contain data arranged from the production side; the separation of intermediate demand from final demand requires specialized knowledge of the current condition of industries, which is difficult to obtain merely from numerical statistics. However, there is a simple solution to both of these problems, which is to know the amount of resources that have been excavated instead. If we consider the generalized cumulative amount mentioned earlier, even if it is complicated within a system, if recycling is included several times, then the amount of material taken into the system will nothing more than the sum total of the amount of inputted material. In other words, if we use data on the amount of metals that have been extracted over the years, we can calculate the broadly defined cumulative amount by collecting the relevant data.

Data on the amount of extracted metals is compiled into metal statistics, mineral yearbooks by such organizations as the US Geological Survey [8]. These data are further simplified into a database format in the form of the Sekai Koubutu Shigen Databook (World Mineral Resource Databook) edited by MMIJ [9] in Japan. This handbook was used as a base for the calculations, and data from missing years were obtained from other references. In addition, it is necessary to retrace the long history of conventional cumulative data, which include some data that have been estimated based on old data books. However, metals production dramatically increased after World War II, and the way that the data have been compiled since then is better, so the cumulative amount of extracted metal was calculated for the period since the end of the war. It should be noted that these data are in better condition and that old data are lacking for some years, so those missing data were interpolated based on the previous and following years; if that was not possible, then the data were extrapolated.

Figure 2.2a–c shows the results for each metal. Figure 2.2a shows high ratios of cumulative amounts for metals with large markets. The bright areas in the figure show on-surface stock (a broadly defined cumulative amount) that have already been excavated and brought into the economic sphere, while the dark area shows underground stock as reserves of natural resources. The percentage is the ratio of on-surface stock to the total amount of both stocks. In the group shown in Fig. 2.2a, the amount of metals that have already been extracted exceeds the present reserves (except for Cu, which is about the same in both cases). From this figure, we can conclude that an intensive effort must be made to open more natural mines for these resources, and expand the possibilities for recycling them.

Figure 2.2b is similar, except that it shows metals for which the ratio of reserves in natural mines is larger. The recycling of these metals is thought to be guided more by energy limitations or national resource procurement limitations than by resources limitations on a global level. Figure 2.2c shows examples of metals that can be calculated in other ways. While these are mostly by-product elements (with the exception of W), the main products of Cu, Zn and Pb account for a large proportion of the amount already excavated, so it shows the same kind of trend. Additionally, there are materials such as Hg and Cd at the bottom that deserve attention because of pollution problems; their high ratio of on-surface stock suggests the importance of controlling such toxic materials.

2.2.2 *Practical Potential*

The amount of on-surface stock is only estimated quantitative potential of urban mining. The activity of recycling is required in order to utilize these on-surface stock to available resource as raw material of industry. UNEP reported the recycling rate of metals [10]. Three different recycling parameters are shown in the UNEP report. They are overwritten in Fig. 2.3. Why various parameters? The reason is that there are several different viewpoints on recycling. The greatest difference is the viewpoint from end of life (EoL) management and raw material management. UNEP report classifies the efficiency of recycling at the EOL into three levels. Considering the life cycle of recycled material in Fig. 2.4.

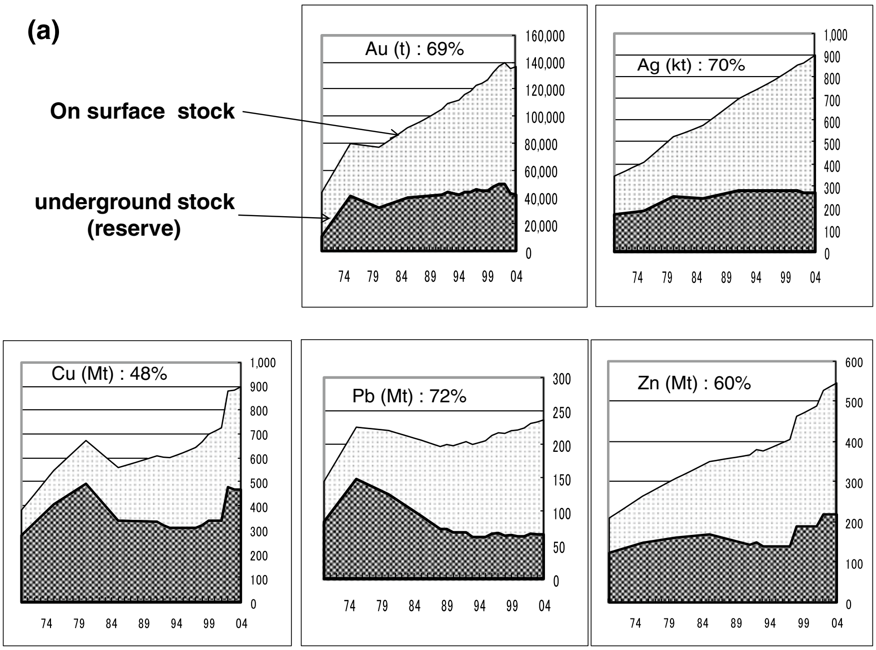

Fig. 2.2 On-surface stock and Underground stock of **a** Au, Ag, Cu, Zn, Pb. **b** Fe, Al, Ni, Platinum group metal, and Co. **c** W, Sb, Bi, Cd and Hg

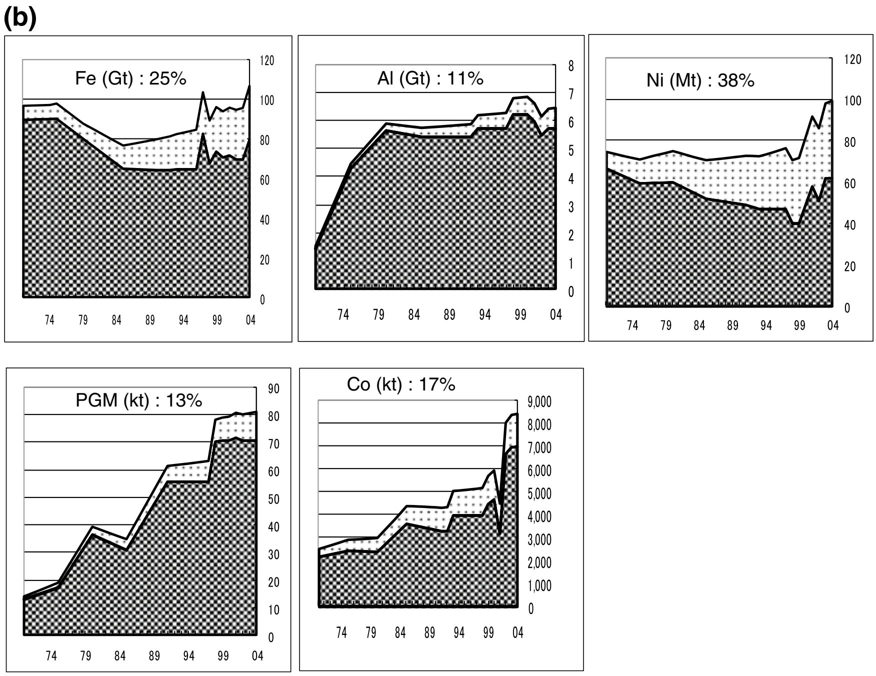

Fig. 2.2 (continued)

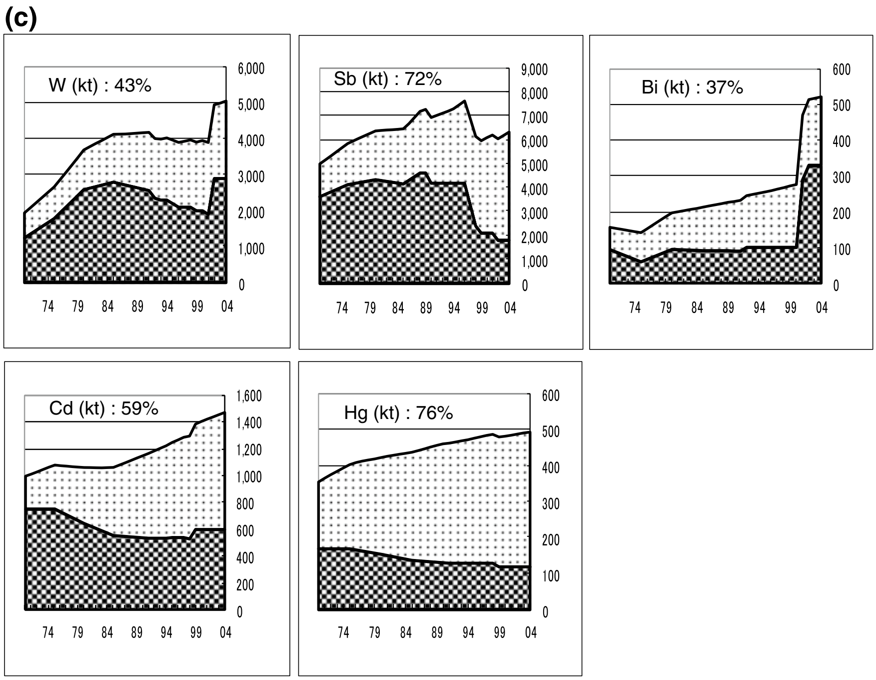

Fig. 2.2 (continued)

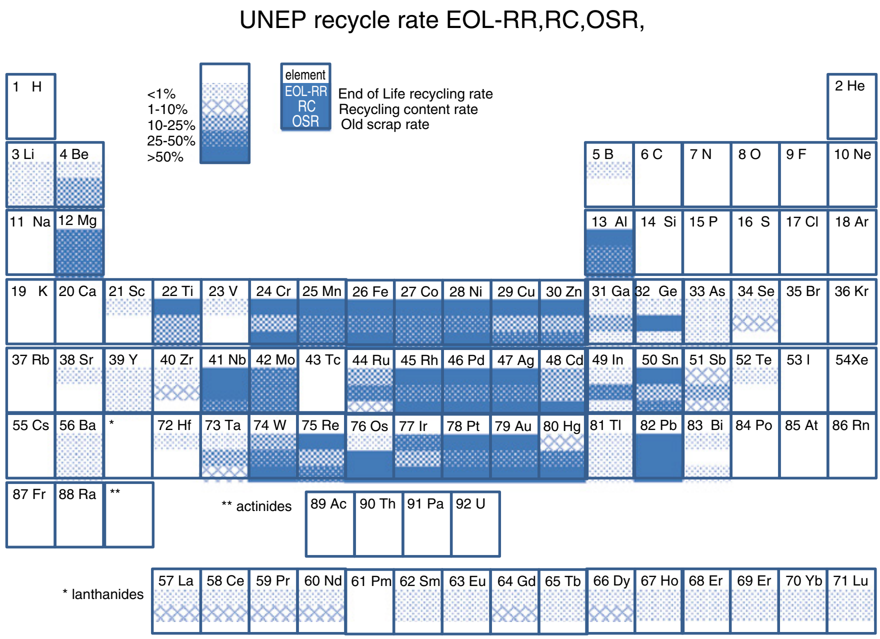

Fig. 2.3 Recycling rate of metals reported by UNEP [10]

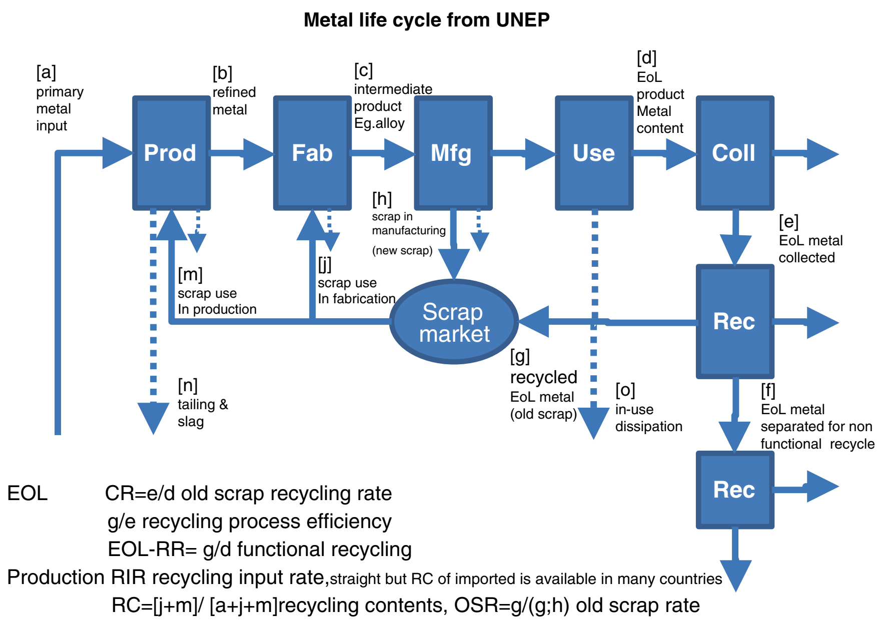

Fig. 2.4 Simplified Life-cycle of recycled material

(a) CR: old scrap collection rate—How much of the EOL metal is collected and enters the recycling chain (=e/d).
(b) Recycling process efficiency rate—What is the efficiency in any recycling process, namely metal recovery rate in the recycling process (=g/e).
(c) EOL-RR: EOL recycling rate—recycling rate of functional recycling which excludes the circulation as tramp elements (=g/d).

From the viewpoint of raw material managing, there are two important parameters.

(d) RIR: recycling input rate—The percentage of recycled material in the total metal input in the system.
(e) RC: recycling content—How much recycled material is contented in a fabricated metal (=(j + m)/(a + j + m)).

By the way, while UNPE report uses the equal sign in the formula of RC, approximation is correct by considering the difference of tailing material in any processes.

UNEP report also mentions about another viewpoint from scrap flow management as

(f) OSR: old scrap ratio—the rate of scrap from EOL in the total scrap which include manufacturing scrap (=g/(g + h)).

On the other hands, International Standardization Organization (ISO) has another definitions of recycling. "Recycled content" (ISO 14021) is expressed as the ratio of the amount of secondary resource to the total amount of resource consumption. For the output index, "recoverability rate" (ISO 22628) is the ratio of the amount of recoverable material to the amount of discarded material. The former corresponds to RIR in UNEP classification. The latter is similar to RC, but UNEP' RC is the result of recycling while ISO 22628 is only the possibility of recycling which is intended in the products design stage.

As seen above, it is difficult to discuss the current status of recycling with numeric parameters. From physical viewpoint, RC shows the absolute recycling status of material, if we can distinguish virgin metal atom from secondary used metal atom. However, it is difficult to estimate RC by material flow date. As recycling flow is not single life stage but multi stage, infinite flow trace is required to estimate. RIR can be simplified (m + j)/c when the loss of metal scrap in the process is assumed negligible small. The date of fabricated material and that of charged scrap are comparably easy to obtain in each country. Thus, from this onward, current status of recycling is discussed by use of simplified RIR, namely (m + j)/c.

Unfortunately, UNEP report does not cover RIR. The simple RIR of major metals are calculated from industrial statics data. Figure 2.5 shows the transition of recycling rate as RIR from 1980. In 1980, the recycling rate was almost 50 % for iron, in the 40 %-range for copper and lead, and in the 20 %-range for other metals. At present, the rates are: 45 % for lead (2004), 39 % for iron for silver, 16 % (2004) for zinc, and 7 % (2004) for tin. However the recycling rate of major metal was expected to increase in these 10 years because of the progress of recycling, their practical recycling rate is not so progressive but decreasing in these 30 years. While the theoretical potential of urban mining has been enlarged, real activity of recycling is not so developed.

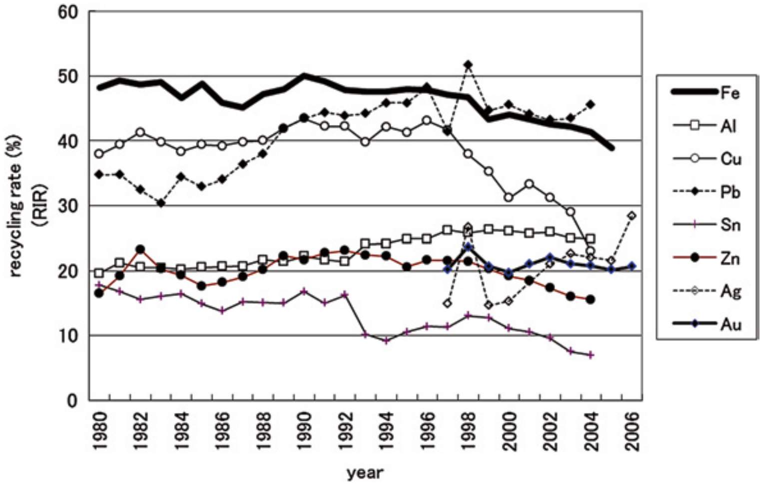

Fig. 2.5 Recycling rate of major metals from 1980

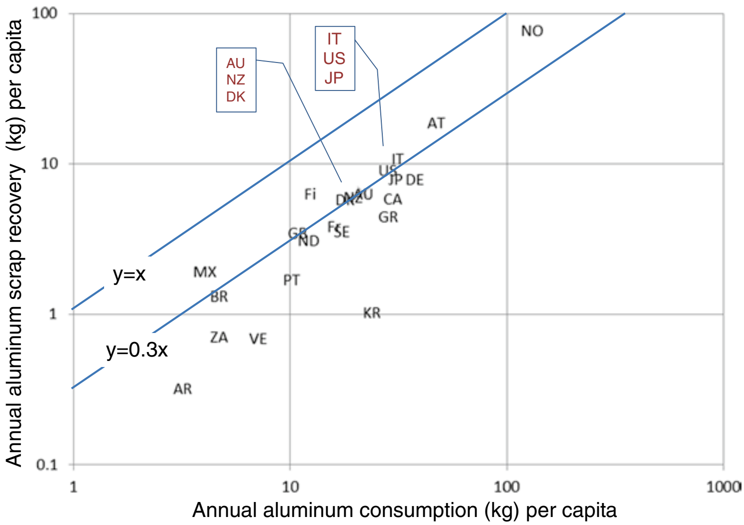

Fig. 2.6 Aluminum consumption per capita versus its scrap recovery per capita in several countries

The differences of recycling rate among each metals are plotted as the relation of metal consumption per capita as the denominator and scrap recovery per capita as the numerator in Figs. 2.6, 2.7, 2.8 and 2.9 for aluminum, copper, lead and tin respectively. The status of each country is plotted by the two alphabetic capital characters of international country code. In these figures, two lines are drawn. One is the line of y = x. This line means that the amount of recovered scrap is the same as the

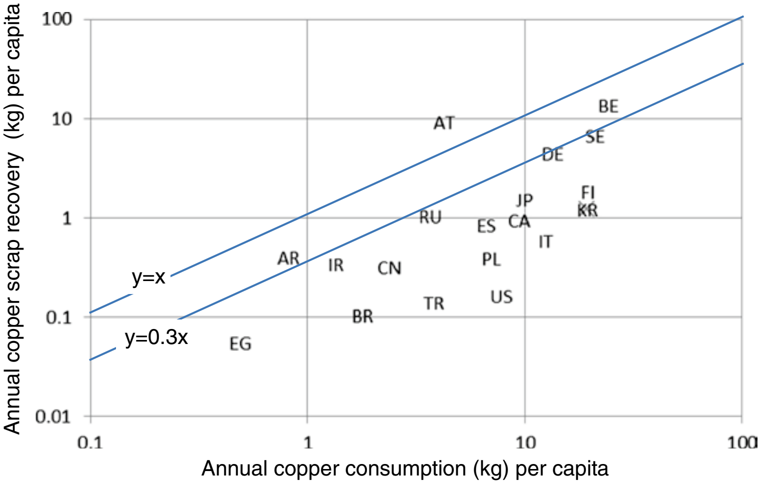

Fig. 2.7 Copper consumption per capita versus its scrap recovery per capita in several countries

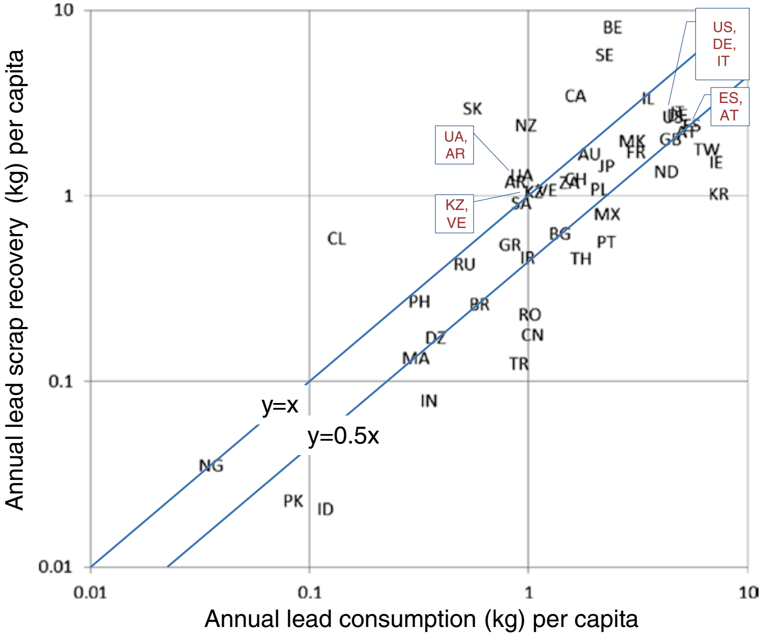

Fig. 2.8 Lead consumption per capita versus its scrap recovery per capita in several countries

amount of consumed metal. The other line describe a (recovered metal)/(consumed metal) ratio. For example, the line Fig. 2.6), many countries, such as Italy (IT), United States (US), Japan (JP), New Zealand (NZ), Australia (AU), Denmark (DK),

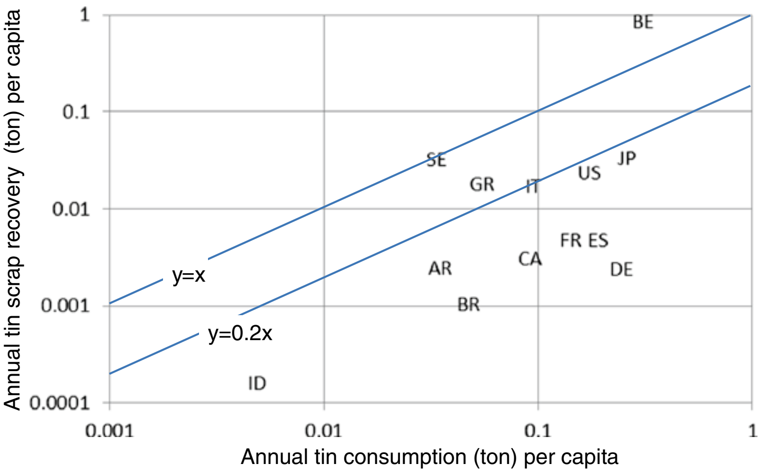

Fig. 2.9 Tin consumption per capita versus its scrap recovery per capita in several countries

Greece (GR), Netherlands (ND), Brazil (BR) have nearly 30 % of (recovered)/(consumed) ratio, while the consumption amount per capita are different. This means that we can compare the recycling ratio of each country without consideration of the total consumption of metal. From that view point, Norway (NO), Austria (AT), Finland (FI) and Mexico (MX) have better practices of aluminum recycling. The reason why the (recovered)/(consumed) ratio of Korea (KR) is lower is that great amount of consumed aluminum in Korea is exported as products not for domestic use.

The opposite case of Korea in Fig. 2.6 of aluminum is Austria in Fig. 2.7 of copper. Austria (AT) is plotted at higher position beyond the line y = x. Austria recovers copper scrap more than consumed copper. This comes from that Austria imports products and machines which include copper and recovers copper from these products. This means that we need to consider the material flow in imported and exported products when we discuss the potential of urban mine in each country. Excepting Austria, Belgian (BE), Sweden (SE), Germany (DE) and Argentine (AR) have (recovered)/(consumed) ratio more than 30 %.

Several countries, such as Belgian (BE), Sweden (SE), Canada (CA), New Zealand (NZ), Ukraine (UA), Argentia (AR), Slovakia (SK) and Chili (CL), have higher (recovered)/(consumed) ratio more than 1. The product which has most greatest share in lead is lead secondary battery. Used secondary battery is transported over the country boundary. These countries are considered to recover lead from the imported used battery. As lead is toxic if it is scattered in the environment, the recovery ration of lead is high in general. Many countries including United states (US), Germany (DE), Italy (IT), France (FR), Japan (JP) are plotted between the line of y = x and y = 0.5x.

In the case of tin, (recovery)/(consumption) ratio is not so high in almost country. Many countries including Japan (JP), Germany (DE), United States (US) are plotted under the line of 20 %. This comes from that the major utilization product of tin is solder in the electric circuit board. Then, the large amount of product is exported not to be recovered domestic. Adding it, the difficulty of separative disassembling of solder from electric circuit board pulls down the ratio of recovery. The effective recycle is expected to collect e-waste intensively and to extract tin from this. Belgian (BE) seems to be the country where tin is recovered from e-waste gathered over Europe. These discussion suggests that when we discuss the potential of urban mining by bottom up method, namely accumulation of each countries' potential, we need to use material flow analysis.

In above discussion, the data of the total consumption of metals was obtained from the *Sekai Kobutsu Shigen Databook* (World Mineral Resources Data Book) published by the Mining and Metallurgical Institute of Japan (MMIJ) [9]. The databook was complied based on *Metal Statistics* published by the Metalgeselshaft and *World Metal Statistics* published by the World Bureau of Metal Statistics (WBMS). The data of the secondary metal production were also obtained from the *Sekai Kobutu Shigen Databook* (MMIJ) which included data from *World Metal Statistics* (WBMS).

The recycling rate of gold and silver were calculated using the total supply reported in *Gold Survey 2007* of the Gold Fields Mineral Services [11], the *World Silver Survey 2007* of the Gold Fields Mineral Services [12]. For iron, the calculation used data compiled by the International Iron and Steel Institute (IISI), with the "crude steel production" figure in *World Steel in Figures 2007* [13] and "scrap consumption".

2.3 Domestic Potential of Urban Mining in the Case of Japan

2.3.1 Flow Estimation Method

As it is discussed in Sect. 2.3, material flow analysis is important when the domestic potential of urban mine is discussed. The main flow is absolutely the flow after the consumption, namely end-of-life flow. Most simple approach to estimate the end-of-life flow is assuming that sold products are all consumed and are extraditable to recycling. If the amount of each metal which consists in products is obtained, the total amount of each metal which is extraditable to recycle can be estimated by multiplying the amount of annual production of the products.

MITI and MOE of Japanese government made a collaboration group with several local government and companies associated recycling. This group, named Study Group on Rare Metals Recycling from End-of-life Small size Electric appliances, estimated the amount of metal by this method. The Study group analyzed the contents of rare metals in major small electric appliances and calculated the amount of each metals which is extraditable to recycling [14]. Figure 2.10 is described by use of the data which were estimated by this committee.

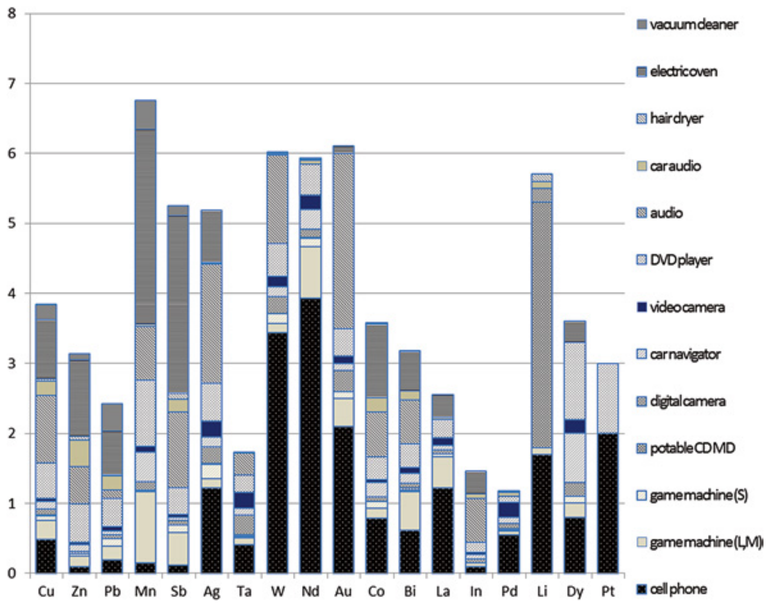

Fig. 2.10 Estimated annual amount of metal which are included in small electric appliances in Japan

The digit of longitudinal axis is different from 1,000 ton to 10 kg depending on the kind of metal. The most content is copper, nearly 4,000 ton per year zinc, lead, manganese, antimony, silver and tantalum follows it. Comparing among the kind of small size electric appliances, cell phone, audio machine and electric oven have considerable amount of rare metals. Figure 2.11 is rewritten from Fig. 2.9, by converting into price from weight. Gold and silver which were less weight than copper go ahead. Total value of recycling potential from small size electric appliances is nearly 330 million dollar. Among this, gold is 240 million dollar and silver is 28 million dollar, and the major appliances are cell phone and audio machine.

In the case of small size electric appliances in Japan, annual consumption of the products is nearly same. But, the amount of end-of-life products is not the amount of currently produced one. The flow for recycling is emerged from “in-use-stock”. In-use-stock is the material of product which is used and possessed currently. And it is emerged after when the product finishes its roll. It is called end-of-life of the product. The time delay of the material flow as “in-use-stock” should be considered in the case of the application to long life products.

Figures 2.11 and 2.12 show transitions in the volume of industrially consumed Au and Platinum group metals (PGM), respectively, from 1995 to 2005. Data are obtained from Ref. [9] and Platinum 2007 by Johnson & Mathey co. [15]. The column on the left shows the major applications of each metal in domestic industrial use. Domestic remaining rate is the percentage of product which is used domestically, and it is explained briefly in the next chapter.

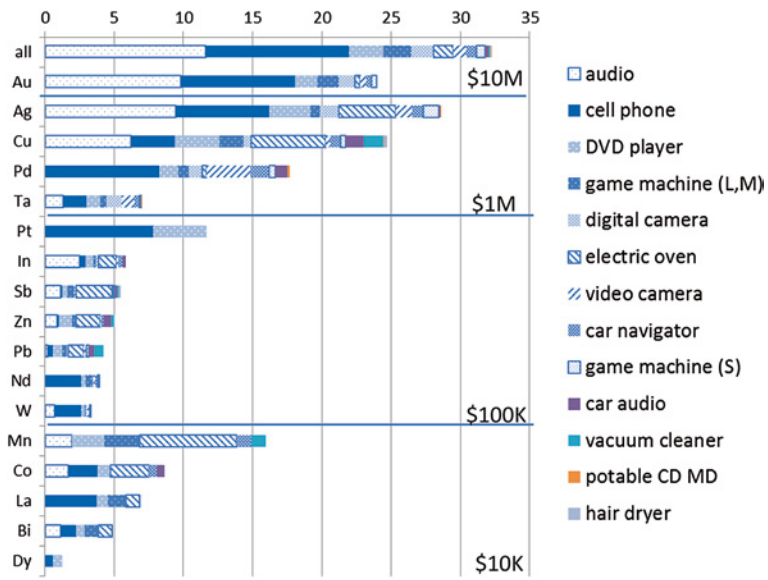

Fig. 2.11 Estimated value of annual amount of metal which are included in small electric appliances in Japan

Au (industrial use)				In-use stock 149t			End-of-life flow 42t/year				
	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996	1995
Electric device	36.252	31.068	30.636	**28.944**	25.524	38.196	21.348	18.432	18.324	16.236	13.176
Plating	9.045	10.62	10.575	10.125	10.17	**11.25**	4.725	4.725	5.355	4.365	5.94
Fountain pen			0.015	0.015	**0.01**	0.01					
Watch	0.8	0.8	0.8	0.8	0.8	0.8					
Ceramic	1.4	1.4	**1.5**	1.2	1.0	1.0					

Fig. 2.12 Transitions in the volume of industrially consumed Au from 1995 to 2005 and an estimation of In-use stock and end-of-life flow of industrial gold

In these table, the white numbers on the black background show typical ranges of legally useful life for the product. If we assume for the time being that the legally useful life is equal to actual product life, then the white numbers represent the amount of in-use stock. The bold-type numbers on the white background denote the used part for the applicable year, which is the “used stock” and is emerged into “End-of-life” flow. The used stock is changed into the accumulation of “dissipated stock” if “End-of-life” flow is not well recycled. The numbers in italics on the right side correspond to numerical values of dissipated stock in cases where the used stock is not managed properly. From these tables we can see that in-use stock was 149 tons for gold, and 169 tons for platinum, while used stock consisted of 42 tons of gold and 35.8 tons of platinum.

2.3.2 Domestic Stock Estimation Method

In the Sect. 2.3.1, we discuss the importance of material flow analysis to estimate the potential of urban mining in a country. And further, we discuss that only material flow is not enough but the consideration of stock especially in-use stock and used stock are important. Further more, we have found that other type of stock, namely dissipated stock, which is the accumulation of the outflow from end-of-life flow to recycle flow. If we discuss the maximum possibility of urban mining, the dissipated stock should also be estimated in order to re-mine from the dissipated stock which is also the resource which exist not in the nature but in the human activity area.

It is very difficult to estimate the dissipated stock by accumulating material flow analysis. But, considering that the total of in-use stock, used stock and dissipated stock is the domestic accumulated amount of the material, this problem is solved by estimating the domestic accumulation.

When calculating domestic accumulated amounts, a problem is encountered that does not appear in the case of the global level; the input and output over national boundaries, that is, imports and exports. Imports include imported ores and intermediate resources, materials, parts, and finished products. In addition, some finished products are imported with other finished products contained inside, such as batteries that are included in electronic equipment. The import of materials includes not only virgin materials but also scrap. These patterns also occur with exports.

Figure 2.13 shows the relation with the system boundary. The area encompassed by the double frame is the system boundary of Japan. The amount flowing into this area includes domestically mined materials derived from resource statistics, and imports of ores, metals, intermediate materials and scrap obtained from foreign trade statistics, etc. The amounts of outflow include metals, scrap and intermediate products obtained from trade statistics. The export ratio was calculated using I/O Tables as mentioned afterwards, and was combined with material

PGM (industrial use) | In-use stock 169t | **End-of-life flow 35.8t/year**

	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996	1995
automobile	20.79	18.522	17.658	15.984	14.31	13.446	14.31	**12.096**	8.37	7.074	6.966
electric equipment	6.222	5.429	5.307	3.782	6.466	**20.496**	20.008	21.167	27.572	19.642	31.354
chemical plant	1.3	1.25	1.2	0.9	0.8	0.6	0.6	**0.6**	0.6	0.6	0.6
petroleum plant	0.3	0.16	0.16	0.16	0.16	0.16	0.16	0.16	**0.16**	0.16	0.16
glass industry	1.9	1.7	1.6	1.9	2.6	2	2	2.5	2.6	**2.5**	3.3

Fig. 2.13 Transitions in the volume of industrially consumed Pt from 1995 to 2005 and an estimation of in-use stock and end-of-life flow of industrial platinum group metal

flow analysis to derive the amount of exports as intermediate and final products. The internal area of the boundary was not subjected at all to this estimation. Therefore, in-use stock, used stock and dissipated stock were calculated together as broadly defined cumulative volume. It should be noted that dissipated stock includes materials that were ultimately processed as waste that had almost no chance of being recovered, materials such as Zn plating that reverted back to the natural environment while they were being used, and so on. It should also be noted that the outflow of used stock in a form that is not listed in industrial statistics was not included in the present calculations.

As the amount that is currently being extracted from natural mines in Japan is only a minuscule amount, the on-surface stock within Japan is calculated from the difference between imports and exports. Here, the amounts of ores, materials, scrap imported and exported are calculated directly from data such as the international trade statistics; UN COMTRADE [16]. When trade statistics gives insufficient information such as in, industry publications such as Industrial Rare Metals by Alumu Shuppan [17] are helpful. Based on these information sources, these numerical values were turned into a database in the Sekai Koubutu Shigen Databook [9] and were used as reference materials for the present calculations.

The problem exists in the estimation of metals in products, parts and materials as imports and exports. For example, in cases such as Fe which can be exported in the form of automobiles, it is possible to derive a rough value by multiplying the average amount of Fe which is used in one automobile by the total number of automobiles exported. However, the content depends on the type of equipment in the case of Au which is used in electronic equipment. Furthermore, electronic equipment is exported not only as consumer goods; there are numerous cases where it is exported in combination with other products, such as car navigation systems in automobiles. These flow are difficult to be estimated by bottom-up method with tracing the product material flow. But, a top down method such as Input/Output analysis can give rough information of flow among industrial sectors. Fortunately, the content of metal in products in the same industrial sector is similar because of the same aim of utilization of the metal. Halada et al. [18] joined I/O analysis and material flow analysis to estimate the metals in products, in order to estimate the domestic accumulated potential of urban mine. In the case of Au, the amount that we can understand is the yearly amount that is used as inputs in the industrial sector such as the electronics industry that is derived from census of manufacturers, material flow analysis, and so on. Halada et al. [18] obtained data on the amount of parts and final products exported from Trade Statistics of Japan. Thus, it has become possible to estimate the amount of metal contained in exported products by combining these two types of data sources.

Then, the two types of data using input–output analyses are combined. The Input–Output (I/O) Tables of Japan, which show inputs from one industrial sector to another on a price basis, cover all industries. These I/O Tables are currently issued once every 5 years by the Ministry of Internal Affairs and Communications [19].

Table 2.1 shows the calculated exportation rate of semi-product including the derived demand of exportation by using I/O matrix calculation. The first column

Table 2.1 Calculated export ratio in each industry

Code	Item	Metal	Export (direct)/ production (%)	Export (derived)/ production (%)
221101	Plastic articles	Sb, Sn	4.6	24.2
207909	Other chemicals	Zn	15.8	34.2
2623021	Coated steel	Zn, Sn	21.3	37.8
2721011	Wires and power cables	Cu	14.1	39.3
2722011	Wrought copper	Cu, Zn	25.1	46.3
2722021	Wrought aluminum articles	Al	10.8	28.6
2722099	Other non-ferrous products	Ag	17.1	50.1
2811011	Structural metal products	Fe	0.5	1.6
2812011	Building metal products	Fe, Al	0.2	3.1
289903	Powder metallurgy products	W, Co, Ta	8.9	29.6
2899021	Metal cans	Zn, Sn	0.7	16.4
289	Other metal products	Ta	5.9	22.0
301	Industrial machinery	Fe	25.5	36.2
321	Electric equipments	Fe, PGM, Ag	25.0	38.6
3341021	Integrated circuit	Au	40.7	63.8
3359021	Liquid crystal elements	In	14.4	41.7
3359099	Other electric devices	Au, In, Ta, Sn	19.0	55.3
340	Power electric device	Ag	23.4	45.9
351	Automobile	Fe, PGM	25.1	46.3
36	Vehicle	Fe	26.4	46.4
37	Precious instruments		24.6	29.9
3711011	Camera	Ag	37.7	43.0
39	others		6.7	19.1

of the table shows the industry classification code (I/O code). This emphasizes the ability to respond to individual metals by category of demand industry in the material flow analysis. For some industries, the last 6- or 7-digit code is not only shown, but the upper 2-digit code is also used for summarizing including wider categories. The metals listed in the 3rd column are the targets of the various types of industrial demand. It should be noted that the low demand in the material flow has little effect, so it is ignored. The 4th column lists the direct export volume, which is used here for reference. The column on the far right is the export ratio for each industrial sector. For example, the rate exported directly from the plastics sector is a mere 4.6 %, but if we consider indirect exports then that figure rises to 24.2 %. In other words, if another 1,000 tons of antimony is used as auxiliary fire-retardant agents in the plastics sector, then 242 tons of that is exported, and 758 tons is considered to remain in Japan. The exported materials with the highest export ratio are IC boards (63.8 %) and electronic devices (55.3 %), and more

Table 2.2 Result of estimation of the accumulation of each metal in Japan

Metal	Accumulation possibility of rban mine in Japan (ton)	Ratio of Japanese urban mine's potential to world reserve (%)	(Accumulation)/(Japanese annual consumption) (year)
Al	**60,000,000**	0.2	14.3
Sb	**340,000**	[3] 19.1	48.7
Cr	**16,000,000**	2.1	17.3
Co	**130,000**	1.9	8.9
Cu	**38,000,000**	[2] 8.1	14.2
Au	**6,800**	[1] 16.4	22.1
In	**1,700**	[2] 15.5	1.9
Fe	**1,200,000,000**	1.6	10.3
Pb	**5,600,000**	[4] 9.9	17.6
Li	**150,000**	3.8	149.0
Mo	**230,000**	2.7	8.8
Ni	**1,700,000**	2.7	71.9
PGM	**2,500**	[3] 3.6	28.8
REE	**3,000**	0.4	14.2
Ag	**60,000**	[1] 22.4	15.6
Ta	**4,400**	[3] 10.4	4.1
Sn	**660,000**	[5] 10.9	17.4
W	**57,000**	2.0	2.3
V	**140,000**	1.1	51.5
Zn	**13,000,000**	[6] 6.4	20.0

The fourth column gives the calculated value of accumulation of each metal in Japan. World annual consumptions and amount of reserves are shown as references

than half of metals input into their respective sectors are calculated as being sent overseas.

Thus the amount of metal in the exported products can be estimated. The next step is make summation of imported materials and subtraction of exported materials for every year.

2.3.3 Domestic Stock Estimation

Table 2.2 shows the results obtained by applying this method to various metals. The bold letters in the 2nd column of the table show the estimated values of metals that have been accumulated in Japan. The 4th column makes a comparison between the calculated accumulation in Japan and the annual domestic consumption. The accumulation corresponds more than 10 years' stockpile for several important metals. Figure 2.14 shows the comparison of Japanese urban mining potential to the global demand of each metal. It is appeared that only Japanese

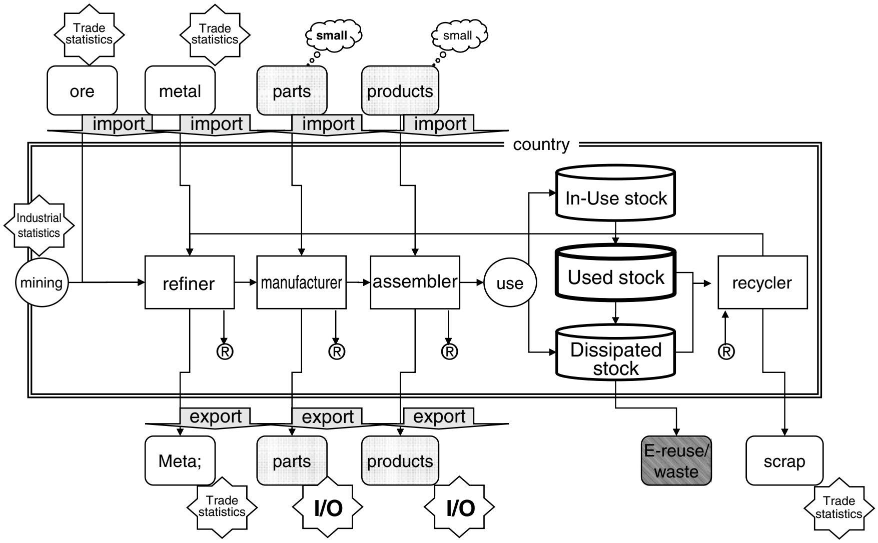

Fig. 2.14 System boundary of the domestic accumulation of metal in a country

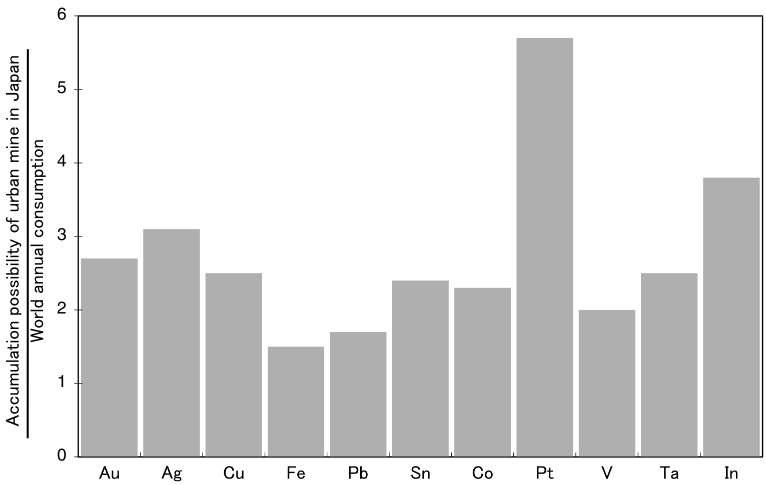

Fig. 2.15 The ratio of accumulation in Japan to the amount of annual consumption in the world

potential corresponds to the several years global demands. This means that domestic urban mining potential should be considered as a resource source of industrial materials as important as natural metal resources. The 3rd column of Table 2.2 shows a comparison with world reserves, and they are shown in Fig. 2.15. Many metals accumulations are estimated to be equivalent to 10–20 % of reserves. For reference, by arranging this broadly defined cumulative amount in order of amount

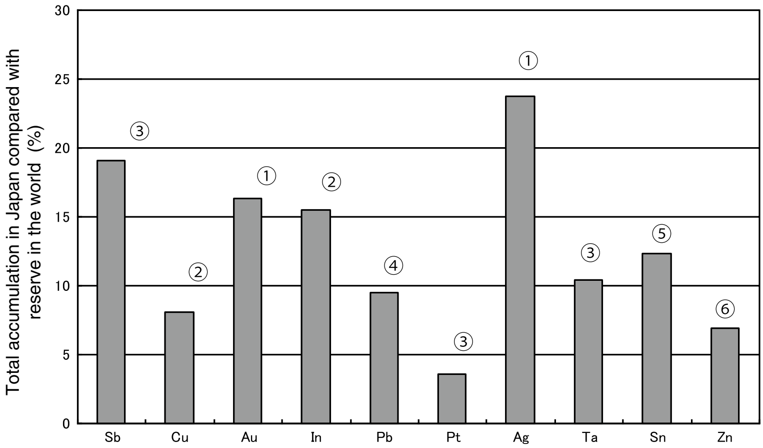

Fig. 2.16 Corresponding percentages of accumulation in Japan compared with the amount of reserves in the world

of reserves held by the world's resource countries, we can get an idea of the extent to which this is ranked by the numbers at the left side of 3rd column (Fig. 2.16). For Au and Ag, the accumulated amounts lying dormant exceed the reserves of South Africa and Poland, respectively. Indium is equivalent to the amount of reserves in China. Cu is equivalent to the next order of the reserves of Chile. Of course, this does not mean that the amount of owned reserves of Au and Ag, which have different extractable levels, are the highest in the world, but if recycling technology and systems can break through this wall, then they should have enormous potential.

2.3.4 Comparing with Activities in Japan

Finally, let's look at the relation between broadly defined cumulative volume data as potential for urban mining, and the amount that is being recycled at the present time. Table 2.3 shows the recycling rates (*a*)/(*b*) for various metals that were interpreted from JOGMEC's material flow analyses and the cumulative volume ratio (*a*)/(*c*). While there are various definitions for the recycling rate, here it is the amount of recycled inputs such as scrap (target metals conversion) divided by the demand including exports (listed simply as "demand" in the table). It should be noted that for siderophile rare metals such as Cr, Ni, Mn, and Mo that are often used and recycled as alloys, values for structural alloy, stainless and high-tensile steels were interpreted from the 2006 edition of the Non-Ferrous Metals Statistical Yearbook. By finding typical corresponding compositions, the recycled amount was estimated and this value was corrected to a hypothetical 100 % recycled rate.

Table 2.3 Recycling amount and ratio of metals at 2006 in Japan

	(a) Recycle	(b) Demand	(c) Accumulation	(a)/(b) (%)	(a)/(c) (%)
Fe	34,686,000	116,226,000	1,200,000,000	29.8	2.9
Al	1,121,000	4,201,000	60,000,000	26.7	1.9
Cu	1,235,000	2,667,000	38,000,000	46.3	3.0
Cr	163,000	923,000	16,000,000	17.7	1.0
Zn	108,000	650,000	13,000,000	16.6	0.8
Mn	150,000	633,000		23.7	
Pb	112,000	318,000	5,600,000	35.2	2.0
Ni	29,800	236,300	1,700,000	12.6	1.8
Ti	983	63,858		1.5	
Mg	?	47,019			
Sn	1,092	37,976	660,000	2.9	0.1
Mo	1,798	26,200	230,000	6.9	0.8
W	2,616	25,180	57,000	10.4	4.6
RE	?	21,179	300,000		
Sr	?	18,416			
Co	9,117	14,639	130,000	62.3	7.0
Ba	107.5	13,716		7.8	
B	0	11,779		0	
Zr	?	8,429			
Sb	690	6,983	340,000	9.9	0.2
Ag	317	3,847	60,000	8.2	0.5
Cd	119	3,102			
V	439	2,719	140,000	16.1	0.3
Bi	12.5	1,391			
Ta	?	1,076	4,400		
Li	7.97	1,007	150,000	0.8	0.00
In	408	905	1,700	45.0	24.0
Se	26	788		3.3	
Au	23.7	307	6,800	7.7	0.3
Ga	92.9	168.4		55.2	
Cs	3.65	115		3.2	
Be	25	89		28.1	
Te	?	63.2			
Pd	31.7	51.6	1,100	61.4	2.9
Pt	6.83	35.1	1,400	19.5	0.5
Rh	1.49	26.0		5.7	
Ge	0	42.3			
Hf	0	2.3			
Hg	0.198	0.258		76.7	
Tl	0	0.8			
Rb	0	0.01			

Additionally, in regards to Au, the numerical value for industrial rare metals was used because of the ambiguous definition of recycled gold.

As we can see in Table 2.3, with some exceptions the recycled amount of rare metals is less than the accumulated volume, and even for metals such as Au, Ag and Pt which have a high recycling rate from junk items, the utilization rate is less than 1 %. This means that a large amount of stock such as in-use stock does not enter the stage of processing for recycling. At the same time, for metals such as Fe, Al, Cu, and Pb that have a high recycling of more than 10 % and for which recycling occupies a major position in the production system, the proportion of recycled volume is about 2–3 %, but this does not mean that the accumulated volume can just be extracted as recycling. However, taking into account the ratios of rare metals to those of Fe, Cu, etc., there is a high possibility that the recycled volume of rare metals increases.

2.4 Summary

The potential of urban mining is getting greater. From the global view, the potential of urban mining, namely the estimated amount of on-surface stock which has been mine form the geo-sphere into the techno-sphere, is comparative to natural resource which is still in geo-sphere as underground stock. Japan, which is considered a typical exporter of materials, has great potential of urban mining which come s from domestic demand of products. However, real activity of development of urban mine, namely recycling, is not so effective, especially for minor metals which sometime called rare metals from the viewpoint of the importance in industries. We need to develop the technology and system for urban mining, just now.

References

1. Halada K, Shimada M, Ijima K (2008) Forecasting of the consumption of metals up to 2050. Mater Trans 49(3):402–410
2. Nanjo M (1987) Urban mine. Bull Res Insti Miner Dressing Metall Tohoku Univ 43(2):239–241 (in Japanese)
3. Nishiyama T (1993) Shigen Keizaigaku no Suusume (Encouragement of resource economics). Chuko Shinsho, Tokyo
4. Shiratori T, Nakamura T (2006) Concept of artificial mineral deposit. Shigen to Spozai 122:325–329
5. Japan Ferrous Raw Materials Association (2013) Accumulated quantity estimation of Japan. http://www.tetsugen.gol.com/kiso/5chikujapan.htm. Accessed 1 Nov 2013
6. JOGMEC Mineral Research Information Center (2013) http://www.jogmec.go.jp/mric_web/jouhou/material_flow_frame.html. Accessed 1 Nov 2013
7. Metal Economics Research Institute of Japan (1996) Dou Namari Aen Kokunai Material Flow Chousa (survey on the domestic material flow of Cu, Pb, Zn) (in Japanese)
8. US Geological Survey (2013) Minerals information, commodity statics and information. http://minerals.usgs.gov/minerals/pubs/commodity/. Accessed 1 Nov 2013

9. MMIJ (2006) 2nd edition of world mineral resources databook, Ohmu-sha (Tokyo) (in Japanese)
10. UNEP (2011) Recycling rate of metals. ISBN:978-92-807-3161-3 DTI/1381/PA
11. Gold Fields Mineral Services (2008) Gold survey 2007
12. Gold Fields Mineral Services (2008) Silver survey 2007
13. International Iron and Steel Institute (2008) World Steel in Figures 2007. http://www.steelonthenet.com/kb/files/World_Steel_in_Figures_2007.pdf. Accessed 1 Nov 2013
14. Ministry of International Trade and Industry Japan, Ministry of Environment Japan (2009) Report of study group on rare metals recycling from end-of-life small size electric appliances (in Japanese)
15. Johnson & Mathey co (2008) Platinum 2007
16. UN COMTRADE, United Nations commodity trade statistics database. http://comtrade.un.org/db/default.aspx. Accessed 1 Nov 2013
17. Industrial Rare Metal, vol 124, Alumu-Shuppan-Sha, Tokyo (in Japanese)
18. Halada K, Ijima K, Shimada M, Katagiri N (2009) A possibility of urban mining in Japan. J Jpn Inst Met 73(3):151–160 (in Japanese)
19. Ministry of Internal Affairs and Communications (2007) The input-output (I/O) tables of Japan

Springer

http://www.springer.com/978-4-431-55074-7

Urban Mining Systems
Nakamura, T.; Halada, K.
2015, VII, 50 p. 36 illus., 26 illus. in color., Softcover
ISBN: 978-4-431-55074-7