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GOOD THINGS AND WRONG THIKINGS ON RECYCLING

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Recycling is one of the key terms in maintaining sustainable development in the next century. Although there is no doubt that recycling saves energy and resources, it does require primary energy and other types of resources. From an engineering point of view complete separation of materials can not be achieved. This suggests that there are limits to recycling which are dependent on the boundary conditions of energy cost and the regulations of harmful substances. All substances can be recycled if energy are unnecessary in recycling. We must determine whether recycling is environmentally friendly and what the optimal rate of recycling is. This paper looks at the role of recycling and discusses the direction of the recycling society.

Key words: recycling, market economy, environment, waste treatment

1. INTRODUCTION

The 21st century is being called the "century of the environment". A key concept in maintaining a balance between the enhancement of production activity and retaining environmental safety is recycling. The argument is really whether or not recycling done well is the solution to the environment problem for the following generation. If energy is not necessary in the recycling, there are no materials which need not to be recycled. The greatest interest among the environmental issues is the regulation of CO_2 gas emission. It must be recognized that it is not possible to completely renew expended energy. Some of the recycling systems currently used are thought to increase the load on the environment rather than to be beneficial.

The Relation between processing cost and the degree of material separation is shown in Fig.1. Energy consumption is larger in the separation of materials with improvement in the degree of separation. The cost of the recycling process becomes extremely high when the recycling ratio closes to 100%, suggesting that a high recycling percentage alone is simply not always a wise policy. Shibata attempted to evaluate this matter overall(1).

Recycling and waste treatment are actually different. Depending on the system, there are many instances where recycling and waste treatment are done at the same time, so that they are often confused. Waste treatments sometimes has in a trade-off relation to the energy consumption and is used to contract a CO_2 gas emission problem. The meaning of recycling from an economic viewpoint and from the aspect of environmental maintenance in the future are assessed.

2. MOTIVATION OF RECYCLING

The materials flow show in Fig.2 depicts a period long ago when industrial production was not as large as it is now. Recycling occurred naturally in flow of the materials. For example, waste materials were mainly bones, shells and excreta which were circulated in the river, sea and ground by microbes early in the age of agricultural production. Intensive recycling was not necessary at the same time, and even energy which is thought to depend on the burning of trees was renewed

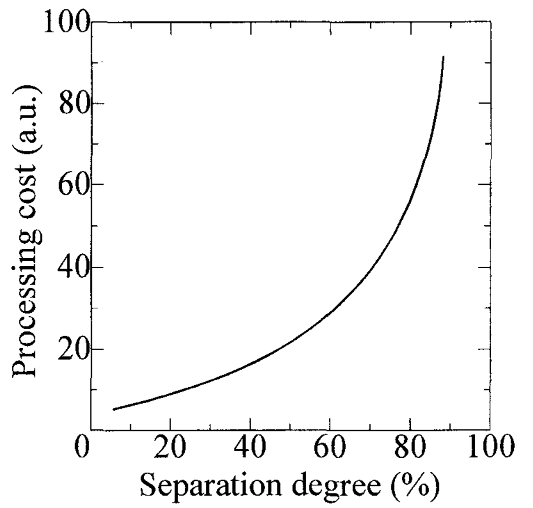


Fig. 1 Relationship between the processing cost and the separation degree.

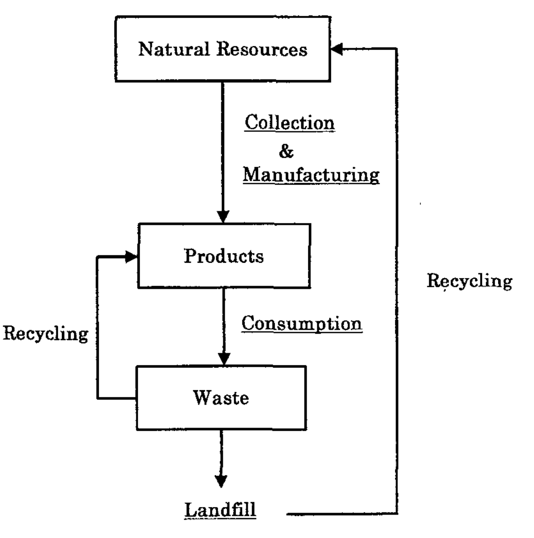


Fig. 2 Materials flow in old age when the industrial production was small.

naturally by light synthesis.

Many mineral resources are now consumed using fossil fuel as the energy, so that the story is no longer simple. Fossil fuel cannot instantly renew itself. The present materials flow in which industrial products are manufactured from natural resources is shown in Fig.3. Many recycling loops including those for re-use are created from the time of production to the disposal of the waste. Generally, re-use has priority because of its minimal energy consumption compared with recycling which requires energy and primary resources. It becomes a problem whether to produce goods by a system utilizing primary resources or one producing goods from secondary resources, both of which maintain a comfortable life with an essentially identical level. This confusion has occurred because it is not yet possible to do a quantitative evaluation of the environment load.

Motivations for recycling are :

① economic profit.
② reduction of the environment load
③ prevention of the drying up of natural resources
④ In vogue

Private companies continue to recycle because it enhances the company image. If recycling truly decreases the overall environment load, whatever reason it is done for is thus acceptable. A simple economic examination is of interest.

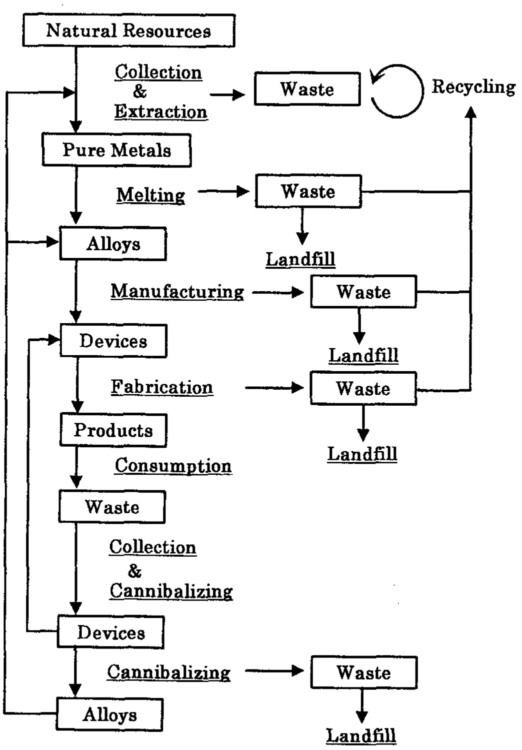


Fig. 3 Materials Flow in modern age when the industrial production was large.

3. THE ECONOMY OF RECYCLING

Here, we assume that our society is governed by a free market economy. This means that the condition of equation (1) must be satisfied for recycling to be economical.

$$B_1 = V_2 - V_1 - C - T - E > 0 \quad (1)$$

B_1 : profit
V_1 : purchase price of scrap
V_2 : product price
C : collection cost (including transportation).
T : processing cost
E : disposal cost

This relation can be satisfied when V_2 is high and C, T, E are low. This balance was achieved in earlier times by the recycling of precious metals. Since the precious metals have a common high density and are noble, the collection cost and refining cost are low. Therefore, the precious metal scrap can be traded among the continents. Whenever equation (1) is satisfied the recycling is done spontaneously.

Waste treatments follows equation (2).

$$B_2 = Q - C - T - E > 0 \quad (2)$$

B_2 : profit for the processing trader
Q : processing expenses
C : collection cost (including transportation).
T : processing cost
E : disposal cost

The fact that waste treatments can't produce profit by themselves is important. They have a negative sense only in the production activity using primary raw materials. The ignoring of waste treatments seems to be running a business without paying a tax. Most companies, however, did not spend a large amount of this in the past. Since pollution became a big problem in Japan 30 years ago, the regulations on exhaust gases and waste discharged from factories have become severe and the cost of waste treatments is now included in the product cost. In other words, this cost is decided at the time by disposal regulations mandated.

If materials which are valuable and can be sold in the market remain after the waste treatments, V_2 occurs. Then, equation (3) should be applied and the promotion of waste treatment moves ahead economically.

$$B_3 = Q + V_2 - C - T - E > 0 \quad (3)$$

Thus, recycling and waste treatments progress as above. This is economically very simple.

Q and C, T, E depend on regulations decided by local conditions but V_2 is normally controlled by an international price. Especially, the costs of E and T depend on the country; they are very high in OECD countries but extremely low in non-OECD countries. Therefore, the waste, especially hazardous waste, discharged from OECD countries is moved to non-OECD countries due to very cheap cost of treatment. The Basel convention agreed to prevent the transboundary movement of hazardous wastes. Beside, goods produced without considering the environmental load can be cheaper than considering such a load. The environmental standard of the ISO14000 series was proposed to defend products made considering the environmental load. This is one of the non-custom duty barriers protecting the environment of a specific area.

The necessity of recycling is shown by the drying up of resources and can be expressed by considering V_2 in equation (1). V_2 becomes extremely high when the amount of resources is reduced. We can do nothing to do if resources are running out. Even thought of with a clear head, this is situation difficult to fully comprehend. Just two oil shocks in the 1970' frightened us but it is very difficult for us to feel such awareness of the present situation.

Many private companies, however, are now making an effort to recycle. The biggest reason is that it is fashion. It is possible to sell more products if their business image is raised by this activity, even though the cost may be little higher with the recycling. Therefore, in this case, it is good business even if it does not essentially follow the market principle of recycling, and it does reduce environmental impact. In an extreme sense, it is possible to assume as the CM expense, too. Recycling in such form is stopped in time in the pass-able one but if it does not offset to drying up-ability and reduction of the environment impact, it is a detriment to essential recycling.

Recycling is only justified in a free market economy when equations (1) and (3) are applied. The right or wrong of recycling is decided by V_2, B_2 and C, T, E. Moreover, to decide B_2 and C, T, E depends on the condition in which one views the environment problem.

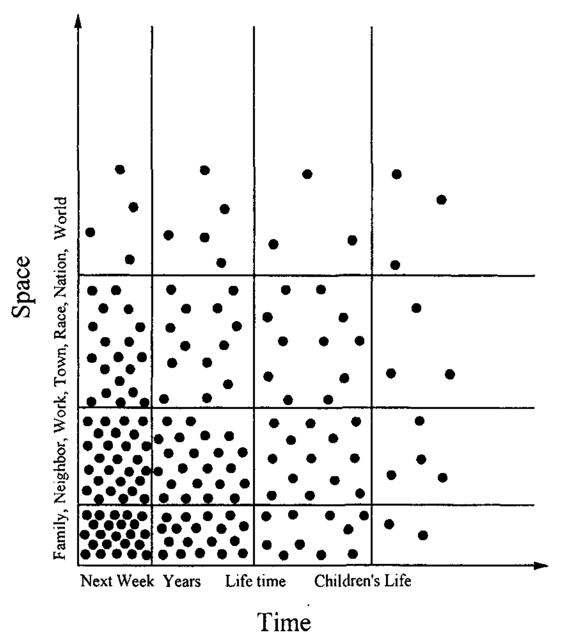


Fig. 4 Schematically illustrated our sensitivity and recognition.

4. BOUNDARY CONDITIONS OF THE ENVIRONMENT

Originally the problem of recycling and environmental preservation were different issues. However, there is actually a close relationship between the two. Therefore, to decide the right or wrong of recycling depends on the balance of the relationship between pursuit of profit and environment preservation. Concretely it involves how to estimate the cost of V_2 and C, T, E for the future. For this purpose, the boundary conditions must be clear. To take the drying up-ability of resources into consideration, a system must be developed in the times of which hit of being clear.

Generally, the range in which the human being can be recognized is narrow. A schematic illustration of our sensitivity and recognition in time and space is shown in Fig.4. It was originally drawn for " Limits to growth" by Meadow et al.(2). Although the recognition depends on each personality , most people have a general interest in the family and neighborhoods in their space and in the near future in time. The difficulty of the environmental problem is simply to recognize something which can't be recognized. Incidentally, it is difficult how to apply an agreement like rationality in the market economy. This is not possible to determine except where it meets the boundary conditions when considering the environment problem in this paper. It is necessary to recognize when and where the recycling system and technique will be developed.

A qualitative evaluation of V_2, T and Q, E, C versus time has been done in this paper. The changes of V_2, T and Q, E, C against time are represented in Fig.5 and Fig.6 respectively. The dotted line of Fig.6 is obtained when the concept of Life Cycle Assessment(LCA) will be truly applied to products. Estimation of the absolute age can not be exact but V_2 will rise due to the drying up of the resources and T will gradually decrease due to the improvement of the techniques in

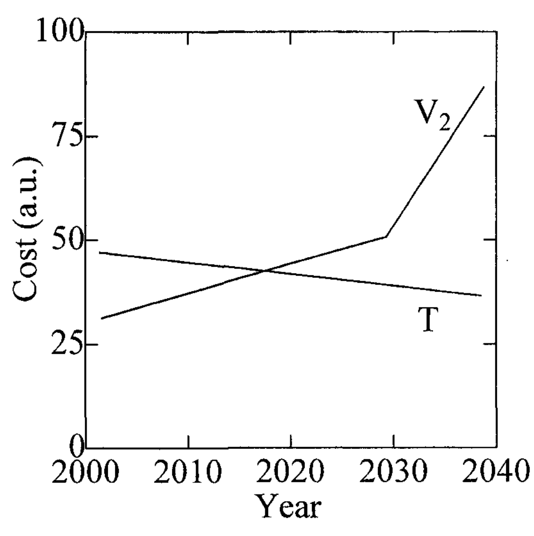


Fig. 5 Changes of V_2 and T costs against year.

Fig.5. Q, C and E will greatly rise if we can do nothing to make a new paradigm of production activity. C will drastically decrease and a rapid increase of E will be prevented if the concept of LCA is successfully applied to our society because of a decrease in the amount of waste. Recycling which has a very small environmental impact is thus promoted. Consideration of energy cost, of course, is essential in the far future.

Information on what kinds of wastes are discharged in production activity is very important to evaluate the cost of B_2 and T, C, E and to decide how to treat them. When the rule of disclosure for them is not clear, it is not possible to keep the environment safe. If there were not a severe watch and a penalty rule when someone broke a regulation on handling of wastes, we would not be able to have a safe and beautiful environment in the future. A nice future depends on cooperation between citizens, private companies and local administration.

5. RECYCLING OF NON-FERROUS METALS

General problems of recycling were only mentioned above chapters. Recycling of non-ferrous metals are discussed for a deep understandings of present situation of recycling.

Fig. 7 shows a logarithmic plot of recent annual production of metals against Clarke's number after Masuko(3). They claimed that there are two major reasons why recycling of metals should be seriously considered. The first, is the preservation of volatile resources and the second is the minimization of hazardous elements which accompany the sought after element(s). As an example, consider the case of copper extraction from the chalco-pyrite group as defined by Goldschmidt(4).

Non-ferrous metal production in general is a complex process comprising of a series of sequential operations aimed at the separation of metal units from mined ore. The first step, in general, is the separation of desired principal mineral, chalcopyrite in the case of copper, from the native ore. Here, as mentioned above, 99.5% of the material processed is waste minerals. Second, is the selective refining of those compounds. In the case of copper, iron sulfide is partially oxidized to produce a slag phase and a waste gas stream bearing sulfur dioxide. The melt, referred to as a matte, is then further oxidized to copper metal. The waste gas from further oxidation contains additional sulfur dioxide together with the oxide form of less noble metals as fume. Finally, the impure copper is purified in an electro-winning process and separated from more noble metals contained in the mineral including precious metals such as silver and gold. Emissions include minor elements such as arsenic, mercury, selenium and tellurium. The resource balance from a copper smelter in a year assuming a total production of 9 million tons could be summarized as follows: discarded minerals, 20 billion tons; sulfur, 9 million tons; iron oxide, 9 million tons; as well as additional minor amounts of other metals, and electricity and fuel. In contrast, recycling metals has the advantage of not impacting on the planet by avoiding mining operations and also avoiding the concentration of potentially undesired elements on the surface of earth. However, recycling has the disadvantage of high labor cost associated with collection and separation.

Global sulfur emissions by source are summarized in Table 1. In compiling this data, there is very large uncertainty associated with the emissions of sulfur from natural sources such as for example marine creatures, which have been estimated to produce 30 million tons of sulfur on an annual basis, and volcanoes, which produce approximately 7 million tons on an annual basis. Fossil fuel and the non-ferrous smelting industry

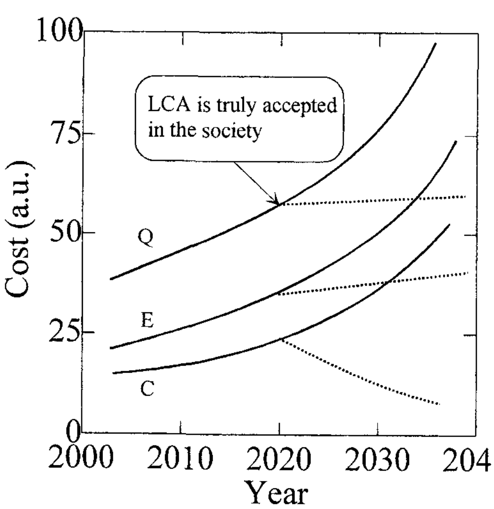
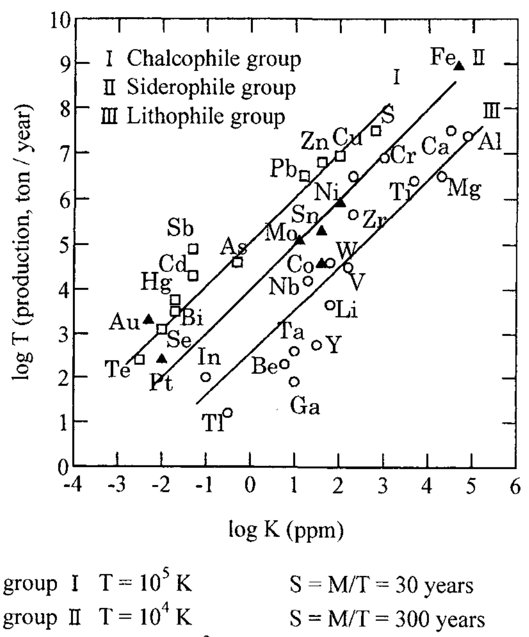


Fig. 6 Changes of Q, E and C costs against years.



group I $T = 10^5$ K $S = M/T = 30$ years
group II $T = 10^4$ K $S = M/T = 300$ years
group III $T = 2.5 \times 10^2$ K $S = M/T = 1.5 \times 10^4$ years

Fig. 7 Relationship between annual production amounts and Clarke's numbers.

Table 1 Sulfur emission in the world.

Events	Term	Material 1(M Ton)	Material 2	Material 3	Total (M Ton)
Fossil Fuel	1994	**Oil**	**Coal**	**Natural Gas**	
	Production	3477	3510	1358	
	Sulfur Conc.	1.5%	0.8%*	?1%?	
	Sulfur Tons	**52**	**28**	**13**	**93**
No-ferrous Smelting	1994	**Copper**	**Zinc**	**Lead**	
	Ore**	9.3	7.7	2.6	
	Metals Conc.	29%	53%	57%	
	Sulfur Conc.	29%	31%	20%	
	Sulfur Tons	**9.3**	**4.5**	**0.9**	**15**
Natural Sources					
	Volcanoes	Non-Explosive	Explosive		
		2	4.5		**6.5**
	Creature	Marine			**?30**
Grand Total					**114.5(144.5)**

*(Estimated by using Blast Furnace Data and others) **(Metal Base,1990)

produce 90 million and 15 million tons, respectively. Overall, it would appear that the metals industry is responsible for approximately 10% of the total annual sulfur emissions.

As previously mentioned, the use of virgin ore has an strong negative impact on the environment from a geographical point of view and in terms of global emissions. The economics of recycling materials have also been discussed and are presently not very favorable. What about the environmental impact of recycling? At the present time pseudo- or cascade-recycling of materials takes place. In reality, as a material undergoes multiple recycling it is contaminated and experiences a cascade decrease in quality from first to second grade, then second to third grade, and so on until it is unusable. In a sense, the recycled material undergoes a re-mineralification, that will require at some point a primary-type processing step in order to produce a pure useable material once again. This primary-type processing step will have associated with it consumption of energy resources and emissions.

Aluminum metal is an excellent candidate for recycling because of the high energy consumption in its production. If the scrap of aluminum could be recycled to the original purity by simple remelting, more than 90% of energy could be saved compared to production via smelting from bauxite. Metallurgists, however, know that the development of a commercial process for purification of molten aluminum, from scrap hinges on being able to remove Fe, which is difficult. Thermodynamically, removal of Chalcophile and Siderophile elements such as Cu and Fe from aluminum is extremely difficult. Most of secondary aluminum, therefore, is used as a very low grade aluminum such as aluminum source for cast products or the deoxidation reagent for a steel making process.

Finally it should be pointed out that from a LCA (life cycle assessment) point of view, alloying of chalcophile elements to siderlophile metals and siderophile elements to lithophile metals must be limited even though the alloys show a better performance.

6. CONCLUSIONS

A simple explanation of the economic perspective was offered for the meaning of recycling. The systems and techniques of recycling depend on the boundary conditions, so that we must think of them when developing recycling systems and techniques. We must also examine whether or not it is possible to recycle gently with the environment under both the present and future market economy.

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