2 Controlling Pollution in Small-scale Recycling Industries: Experiences in India and Japan

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A bath for extracting copper from printed circuit board in informal recycling workshop in India. Provided by IRG Systems South Asia

Pollution Control Facilities in Lead Recycling Plant in Japan.
Photo by Michikazu KOJIMA

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Introduction

Recycling industry often causes pollution. It is the same as any other industrial activities. Paper recycling may cause water pollution, which may affect agricultural and fishery production. Refinery of metal scrap may cause air and water pollution. If hazardous heavy metals are discharged to the environment, it causes health damages. In fact, many small scale recycling industries without any pollution control mechanism exist in developing countries.

If recycling factory has large production capacity, it can afford to invest in pollution control equipment and hire experts to control pollution. It is easy for government to enforce pollution control regulation on big companies, which have financial and technological capacity to deal with the problem.[40] It has been observed both in developed and developing countries that if the government strengthens the enforcement in small scale industries, it is possible that small scale industry migrate to another area, and carry out same business behind the wall.

It has also been observed that informal recyclers dominate the market of collected recyclable waste, because their cost of recycling is cheaper than that of formal recyclers. The competitiveness of informal recycler comes from non payment of taxes and no investment in pollution control. As a result, formal recycler with pollution control equipment and systems faces lack of recyclable waste, which becomes obstacle for the growth of formal recycler. This situation makes recycling industry as one of the most polluting industries in developing countries.

Japan also faced pollution from recycling industries around 1960s and early 1970s. But the situation changed in 1970s. In this chapter, situation analysis of pollution control related to recycling industry in Japan and India has been described. This chapter has been formatted in three sections. In the Section 1, the history of pollution control of lead acid batteries recycling in Japan has been described. Lead acid batteries recycling is a typical industry causing environmental pollution in developing countries. In Section 2, situation analysis related to pollution from small scale recycling industry in India has been described. In Section 3, the Japanese and Indian experiences have been compared. The possible policy and institutional measures to prevent pollution from recycling industry have been discussed.

2.1 Controlling Pollution from Small and Medium Recycling Industries in Japan: Case of Recycling of Lead Acid Battery

2.1.1 History of Pollution Control of Lead Recycling Industry

Japan faced the problem of pollution from small and medium recycling industries until 1970s. A typical example of small and medium recycling industry causing pollution in Japan is lead recycling industry. In this section, we review the experiences of pollution control in lead recycling industry in Japan.

Recycling of lead in Japan dates back to the beginning of the nineteenth century. However, it was around 1960 that measures for pollution control were adopted in lead recycling plants. Osaka Namari-Suzu Seirensho Co., Ltd. (a recycling company) in Nishi-Yodogawa-ku of Osaka was one of the first companies to install a cyclone dust collector[41] in 1960s. This

[40] Agency in charge of environment in developing countries often faces difficulties to enforce the regulation to big companies, in political reason, because big companies have usually political power.

[41] Small and Medium Enterprise Agency (1973).

technology was, however, able to recover only about 30% of the lead from smoke. Remaining 70% was discharged into the environment. In response to the "Regulation on Emission of Smoke and Soot" and "the Blue Sky Plan of the Osaka Metropolitan Government", the company installed a dry bag filter to recover lead contained in the smoke in 1964. The dry bag filter was designed and developed by a manufacturer, on the request of the company. It was considered to be the earliest effort to control pollution in lead recycling factories in Japan.

Local governments in Japan carried out research and made recommendations on the technology of pollution control in 1960s. Tokyo Metropolitan Government prepared "Instruction Standard for Air Pollution Control Facility in Non-ferrous Metal Industries" in 1966, which prescribed air pollution control measures for smelter of lead recycling in Tokyo Metropolitan area. Hishida, a staff of Urban Pollution Department of Tokyo Metropolitan Government reported the effectiveness of pollution control measures for lead recycling (Hishida 1969).

The Hyogo Prefectural Institute of Environmental Science inspected the exhaust smoke and dust of two lead recycling plants in Hyogo Prefecture around 1969.[42] The inspection report pointed out that the lead contents significantly exceeded the standards of the Air Pollution Control Law. The report said that the particles were too small to be effectively caught by the wet-type pollution prevention systems, which the plants had introduced. In this context, in January 1970, lead recycling plants in Amagasaki-shi of Hyogo Prefecture were recommended to improve the facilities and operations or to move to other areas. The plants terminated the operation at Amagasaki and moved to Kameoka-shi of Kyoto Prefecture and Kusatsu-shi of Shiga Prefecture. Other lead recycling factories were also moved from urban are in Hyogo and Osaka to rural area in Kyoto and Shiga Prefecture. For example, another lead-recycling plant moved to Funai-gun of Kyoto Prefecture from Osaka. Since June 1970, five lead-recycling plants located in Kyoto Prefecture and Shiga Prefecture, including the above three plants, faced opposition from the local residents.

The protests by local residents were very strong. They submitted petitions to local governments, blocked access road to the factory, and disrupted electricity supply to the factory by damaging electric pole. As a consequence of these pressures, factories were forced to install pollution control equipment, to abandon operation or to change business.[43]

In May 1970, medical investigations revealed that considerable amount of lead had accumulated in the bodies of residents around the Yanagi-cho Crossing of Shinjuku-ku, Tokyo. Although the cause of lead pollution was attributed to leaded gasoline, this incident enhanced awareness of people on pollution of lead and other heavy metals. It stimulated the public opposition to factories causing pollution.

In response to these events, Ministry of International Trade and Industry, Government of Japan carried out national survey on factories which effluent may contain lead (MITI 1971). This survey covered 285 factories belonging to lead recycling industry, electroplating industry and others. Among them, the effluent of forty seven factories exceeds the standard, 1 ppm for lead.

The lead recycling industries embarked on finding a technical and institutional solution to the pollution. In this regard, the 17 lead smelting companies near Tokyo formed the Kanto Lead Smelters Pollution Prevention Council in June 1970. Further, in July 1971, they established the Kanto Lead Smelters Pollution Countermeasures Committee with the approval of

[42] Matsuda et al. (1970).
[43] *The Kyoto Shimbun*, June 6th, 7th, 14th and 27th, 1970 and other sources.

the Ministry of International Trade and Industry. These associations had function to disseminate the information of environmental regulation and pollution prevention technologies to its members e.g. Ichikawa Smelter and Tanada Trading Co., Ltd., both being members of the committee, installed bag-filter type dust collectors in March 1971. In order to promote pollution control, these two companies were given loan at low-interest rate by the Environmental Pollution Control Service Corporation and the Japan Finance Corporation for Small Business to cover investments in pollution control systems. Only seven companies out of the above 17 companies, including these two companies mentioned above, had installed large dust collectors as of April 1971.[44]

Since it became difficult to process lead in the plant due to public opposition, some informal operators used drums in stead of smelting furnace to heat batteries by propane to melt electrolyte lead to recover lead without any pollution control. They conducted such operations in midnight or early morning, and moved from one place to another to avoid being arrested.[45] It is reported that the police and the healthcare centers dealt with these operators, upon notification by the residents.

It is considered that from 1970 to 1972, most of lead recycling industries in Japan installed pollution control systems. But some of them adopted insufficient pollution control measures or improper operational practices e.g. Institute of Pollution Control of Kyoto Prefecture found that a lead recycling factory stopped the pollution control equipment in the night time in 1974. In 1977, another lead recycling factory was discovered in Kyoto Prefecture, which emitted lead at twenty time of the standard. So the factory was forced by the regulators to invest in additional dust collector.

Table 1 Number of Secondary Lead Smelting and Refining Enterprises (including Lead Alloy Manufacturers) in Japan

	Persons							
	1 - 3	4 - 9	10 - 19	20 - 29	30 - 49	50 - 99	100 - 199 or more	200 or more
1967	46	57	17	6	14	2	1	1
1970	40	83	16	6	10	6	3	1
1975	61	74	15	8	7	4	6	0
1980	60	71	15	15	5	4	3	0
1985	53	58	14	16	7	2	3	0
1990	37	54	14	13	4	3	1	1
1995	45	30	12	8	5	2	3	1
1999	42	25	12	8	8	5	2	1

Source: Compiled from corresponding year's version of *Sigen tokei nenpo* [Annual statistics on resources], Research and Statistics Department, Minister's Secretariat, the Ministry of International Trade and Industry.

44 *The Nikkan Kogyo Shimbun*, November 22, 1971 and April 12, 1971.

45 "Such private-run recycling of lead has become a problem in developing countries," *The Kyoto Shimbun*, evening issue of June 9, 1970.

It is reported that a lead recycling factory was relocated to industrial park in the late 1970s, in the response to complains from local residents. The local residents report complaints on water and noise pollution to the city government. After investigations by the city government, the factory improved the quality of effluent, but it was difficult for the factory to reduce the noise in sufficient level. The factory was forced to be relocated to industrial park.

The trends in secondary smelting and refining of lead, including manufacture of lead alloys from 1980 to 1998 indicated that the number of small-scale lead-recycling industries have decreased (See Table 1). The reduction of the number of the enterprises is considered to be a result of stricter enforcement of pollution control. In addition, this trend also reflects declining production of weights and solders which have traditionally represented one of major demands for recycled lead.

2.2.2 Discussion

In general, adoption of regulations and rigorous enforcement thereof were carried out in a manner prompted by individual pollution disputes. In early 1970s, the delayed and inadequate response to the victim's claims by local government triggered protests by local population. However, in the mid of 1970s, the response by local governments became quick and adequate. Local government gave hearings to victims and factories simultaneously and carried out scientific research on pollution in order to settle these disputes.

Some of major pollution cases in Japan were resolved at court, such as Itai-Itai Disease, and Minamata Disease in Niigata. But in the case of lead recycling, these cases were resolved in alternative dispute resolution including local government instruction. Therefore, it should be noted that the Environmental Pollution Dispute Settlement System was formulated in 1970. Each local government and national government made a desk to receive complains related to pollution. How to handle such complains was standardized at that time. The dispute settlement system made possible costs of scientific investigation to be borne by the government.

In Japan, lawsuits seldom last longer than 10 years. In lawsuit, the victims, or plaintiffs, are required to provide scientific evidences to show the potential responsibility of polluters. In other word, victims bear the burden of proof in a certain degree, in the circumstances that polluter do not provide related information. So the dispute settlement system reduces the burden of victims, and shortens the periods of lawsuits thereby, succeeding in reducing the costs of pollution disputes for reaching settlements. Before this system was established, the regulation was not fully enforced, and in many cases the victims were obliged to just swallow damages without receiving compensations, or forced to blockade or to burn the plants responsible for the pollution.

Pressures form local residents and local governments also forced the factories to take action on pollution control. But medium- and small-scale industries cannot necessarily afford investment in pollution control. They also lacked knowledge about pollution control technologies. If strict regulations are enforced, the units will be closed and unemployment may increase. Not a few enterprises of Japan were forced to be closed in the face of oppositions to pollution and enforcement of stricter regulations. But industrial associations such as the Kanto Lead Smelters Pollution Countermeasures Committee served as routes to channel technology and low-interest finances to individual industries. Such associations can also prevent any particular enterprise from becoming advantageous in market by neglecting necessary investment in pollution control.

The national policy on low interest loan helped the investment in pollution control by small and medium industries. The loan was co-financed by the private bank and semi-governmental organization which got the budget allocation from the government. The private bank had role to check financial aspect of applicant and the semi-governmental organizations checked the technological aspect of the pollution control.

Increasing public awareness of pollution prevention also played an important role in prevention of pollution by small-scale factories and/or the informal sector. Public movements against pollution, notifications on contamination from people to the police and healthcare centers put pressure on businesses emitting pollutants. The awareness of local residents was raised by reports of mass-media. It may be inferred that a combination of policy measures, e.g. low interest loan, judicial mechanism catalyzing scientific studies by the government and short duration dispute resolution mechanism and institutional mechanism e.g. recyclers/ industry association paved the way to implement pollution control in lead recycling industry in Japan.

2.2 Pollution from Small and Medium Recycling Industries in India

The scrap recycling industry in India is growing at an exponential pace. The major source of raw material for this industry is recyclable scrap generated from municipal solid waste and domestic industry. India generates about 47 million ton per annum of municipal solid waste and 7.2 million ton per annum of hazardous waste. About 11 million ton per annum of the recyclable scrap is generated from the two sources. The majority of recycling industry operates in medium to small scale unorganized sector without any pollution control. This results in uncontrolled emissions leading to environmental pollution. Therefore, it is pertinent to assess the structure of small to medium scale recycling industry, their recycling technologies used, and their pollution potential.

2.2.1 Structure of Small and Medium Recycling Industry

At sector level, the recycling industry is organized into paper, plastic, ferrous and non-ferrous sectors. In the non-ferrous sector, the majority of recycling industry is involved in zinc, copper and lead production. E-waste is a new waste stream, which provides raw material to the ferrous and non-ferrous recycling sector.

India produces about 6.5 million tons of paper annually out of which 54% is produced from wood and remaining 46% is produced from waste paper. India’s domestic demand for paper is expected to grow at a CAGR (Compound Annual Growth Rate) of 6-7% and is expected to touch 8 million ton per annum by 2010. To meet part of its raw material needs, the industry has to rely on imported wood pulp and waste paper. There are, at present, about 400 small to medium waste paper recycling units engaged in the manufacture of paper.

In India, plastic consumption will exceed 12.3 million ton per annum registering a growth rate of 14% by 2010. Currently, polyolefin account for 60% of total plastic consumption in the country. Major sectors, which consume plastics, are packaging, consumer products and construction industry. About 47% of the plastic waste generated in India is recycled. There are more than 40,000 units engaged in plastic product manufacture out of which 12% are in organized sector and remaining 88% are in small scale unorganized sector. In addition to these units, there are more than 30,000 polymer processors in India.

India has a current steel production capacity of 35 million metric tons, which is less than the existing demand. The demand for steel in India is expected to rise to 90 million tons by 2020. Indian steel industry can be divided into two distinct producer groups of major steel producers/ integrated steel producers and other producers consisting of smaller stand alone steel plants. These include producers and processors/re-rollers, which are units producing small quantity of steel (flat/long products). Their output is produced from materials procured from the market or through their own backward integration system. There are 1,500 small to medium scale entrepreneurs in unorganized secondary steel sector, which produce about 40% of the total steel production in India.

The annual demand of Zinc in India has been estimated to be about 500,000 ton per annum during 2006-07. The existing installed primary production capacity of zinc is about 260,000 ton per annum. Around 15-20% of demand for zinc in India is met through secondary production. The annual production capacity of secondary zinc metal and its sulphate are estimated to be 100,000 and 240,000 ton respectively. The primary zinc production facilities fall under large industry sector, while the secondary/ recycling sector exists in medium to small scale sector. There are more than 200 zinc chemical units (zinc oxide, zinc sulphate, zinc chloride, etc.) in small scale sector in India.

Indian copper industry has an installed capacity of about 477,500 ton per annum with a domestic demand of approximately 350,000 tons. Irrespective of the current domestic demand growth rate of about 6% and a surplus capacity, India's intensity of copper use will continue to increase until 2050. By 2100, copper use in India could rise from the current 0.3 Tg Cu/year to a range between 9 and 17 Tg Cu/year. Currently, copper production from secondary copper meets approximately 40% of the demand. The industry currently has just 3 major players and other players consisting of around 1000 small scale industries (SSIs), which are primarily involved in converting scrap into ingots. Currently, there are 108 registered copper recyclers with Ministry of Environment and Forests (MoEF)/ Central Pollution Control Board (CPCB).

In India, the current demand for lead has been projected to be 184,300 ton for 2007-08. The current demand is met with a supply of 92,000 ton from primary lead producers and above 60,000 tons from secondary lead producers. There is a demand and supply gap of 18% while secondary lead producers supply 32% of the total demand. Currently, lead acid batteries account for about 75percent of the lead consumption. There are around 160 lead recycling units registered with CPCB/MoEF as lead re-processors having environmentally sound technology/processes in the country. In addition to these registered units, a number of small scale and backyard units are operating in India. The main source of lead in these plants is scrap batteries, which are recycled in an environmentally unsound manner.

Waste/ used lube oil is the major source of waste/ used oil in India. Indian lube market consumes around 1,500,000 tons of lube oil annually, out of which about 65% is utilized by the automotive sector as engine crankcase oil, hypoid gear oil, etc. Used oil potential from automotive sources is estimated to be about 25-35% of total supplies. This has potential to generate over 100,000 tons of re-refined oil. The bulk of used motor oil generated in India generally goes into undesirable applications and only a very small amount is currently re-refined. There are 156 registered units for waste/used oil recycling in India. There are a number of small scale waste/ used oil refining units operating in unorganized sector in India.

E-waste is one of the fastest growing waste streams in India. Currently, 330,000 metric ton of e-waste is generated annually, while an additional fifty thousand metric tons is illegally imported into the country. This is about 0.8% of total solid waste generated in India. Considering an E-waste inventory of 146,180 tons in 2004-05, the inventory has nearly doubled during the current year. This is expected to exceed 800,000 tons by 2012. The increasing obsolescence rates of electronic products added to the huge import of junk electronics from abroad create complex scenario for solid waste management in India. It has been estimated that only nineteen thousand metric tons of E-waste is recycled in India. There are about five small scale formal E-waste recycling facilities in India. There is no large scale organized e-waste recycling facility in India and the entire recycling exists in un-organized sector.

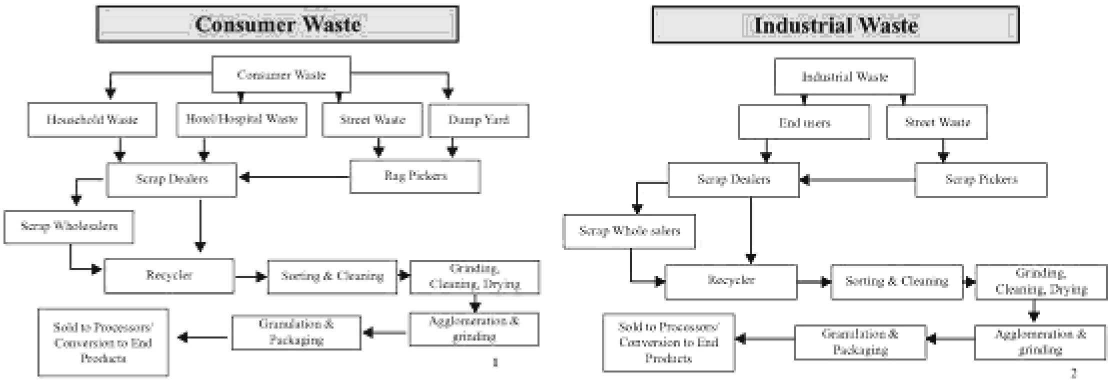
2.2.2 Processes and Technologies for Recycling

Processes and technologies used in recycling sector ranges from advanced to very crude in nature. Waste paper pulp is produced from two types of plants. The low quality of paper is produced by mechanically pulping the waste paper without chemical use. This pulp is used to produce brown paper and paper board. The good quality paper is produced by mechanical pulping followed by removal of inks/ pigments and bleaching. Most de-inking is done by 'washing' or floatation, or a combination of both the techniques. Washing is used to remove small particles of ink while flotation is used to remove ink particles which are too small to be removed by screens and cleaners but too big to be removed by washing. Both the processes involve the use of chemicals. The washing technique uses chemicals known as wetting agents and surfactants to detach ink particles from wastepaper. The particles are then removed through repeated washing. The floatation process is based on ink agglomeration chemistry. After the ink is detached from the wastepaper, the ink particles are made to stick together by using suitable collectors like fatty acid soap. The resulting slurry is then taken to a flotation cell where lime is added to make them hydrophobic (so that they do not dissolve in water). The ink particles then get attached to air bubbles passed through the slurry and are finally discharged as foam sludge. This process can handle both old newspapers as well as coated paper, which is used to print magazines. Starch and calcium carbonate are added to strengthen the pulp followed by blending with water to achieve proper pulp to water ratio. Alum, rosin, talc and acid are added to condition the paper before it is sent to paper machine, where steam is used for drying.

Both consumer and industrial plastic waste generated in India is recycled by using the same process as shown in Figure 1. After sorting and cleaning, the plastic waste is grinded, cleaned and dried. After drying, it is agglomerated and further grinded. After grinding it is granulated and packaged.

Small scale steel producers using scrap-sponge iron-pig iron combination produce steel ingots (for long products) using Electric Arc Furnace (EAF) or Induction Arc Furnace (IAF) route as shown in Figure 2. However there are number of electroplating/galvanizing units operating in organized sector.

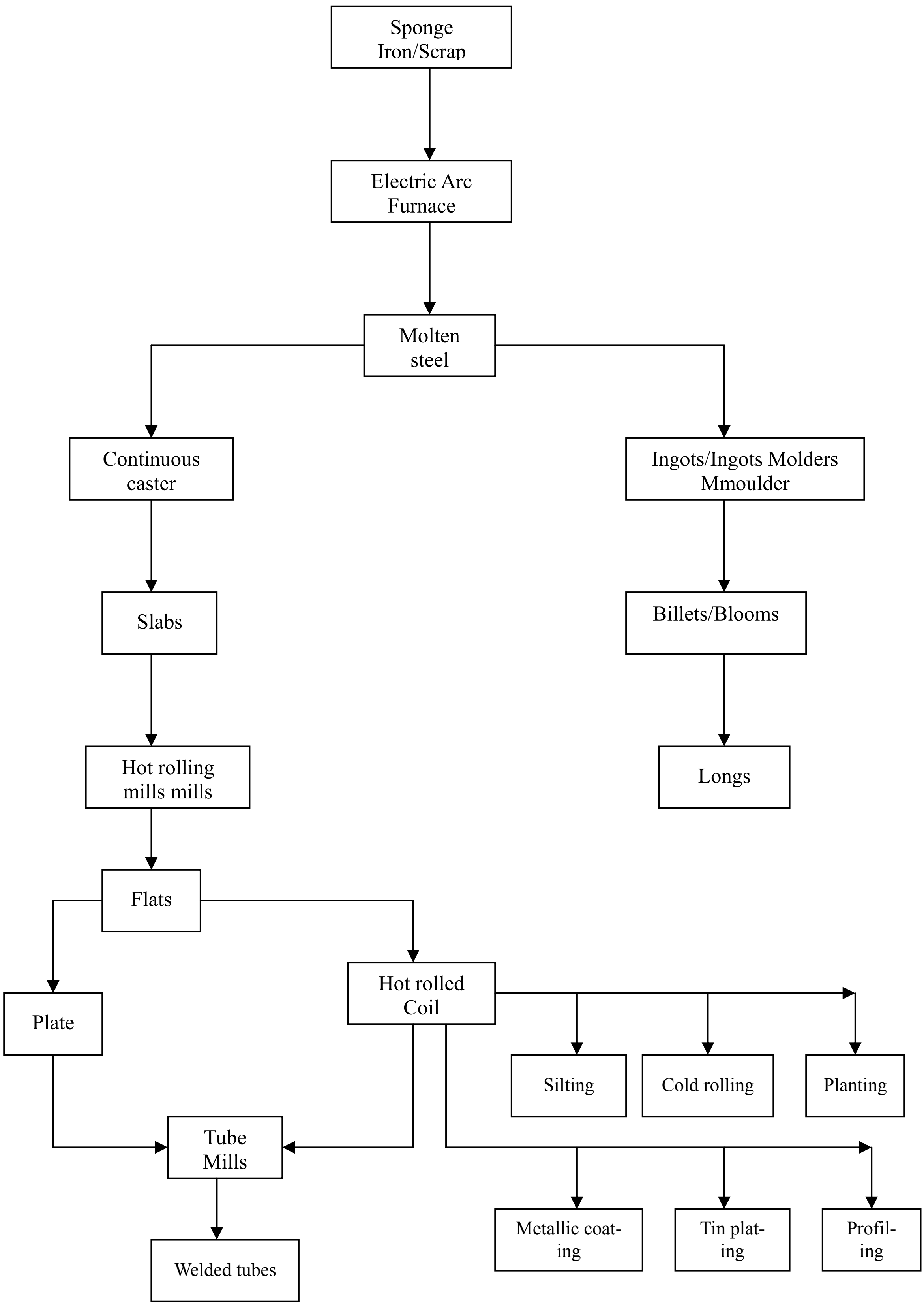
Fig. 1 Recycling Process of Plastic Waste



Source: Compiled from various sources.

The majority of the secondary zinc units use both mechanical and electrolytic method while some units recover zinc from zinc ash by mechanical methods and sell fines (mainly 50-60percent zinc oxide) to zinc chemical manufacturers. The raw material used for secondary zinc production by zinc recyclers in India is zinc ash/ skimming/ dross and steam blowing, which arises as a waste from domestic and imported galvanizing industry. Two types of dross namely top dross that floats on the top of the bath and the bottom dross that sinks to the bottom of the galvanizing bath based on the specific gravity of the material are obtained as raw material from the galvanizing industry. Zinc content in dross's lies in the range 90–96%. The technology followed to extract zinc is hydrometallurgical based involving leaching, metal purification, separation, precipitation and electrolysis. In some of the units, ZnO is manufactured from the secondary zinc following pyro-metallurgical processes, which involves carbon reduction and vaporization of zinc followed by controlled oxidation to produce ZnO. The process of zinc extraction from zinc ash consists of material preparation, leaching, purification, electrolysis/melting and bleeds off. Zinc ash is generally available in the form of lumps and chips. It is therefore, first crushed and then pulverized to separate out metallic zinc from fine ash. On melting and casting, metallic zinc is obtained. Fine ash is subjected to calcination in oil fired rotary kiln at 9000C. Calcined ash lumps are pulverized again to get particle size of 100 mesh. The calcined fine ash is then treated with sulphuric acid and/or spent electrolyte generated during electrolysis for leaching operation. During this operation, compressed air and pyrolusite (MnO2) are added to oxidize ferrous ions to ferric ions. Leaching of zinc is continued till pH 4.5 to 5 where oxidized impurity of iron is hydrolyzed to ferric hydroxide precipitate. The clear solution of zinc sulphate is then sent for purification. In the first stage, copper is cemented out with addition of zinc dust/powder. The resultant pulp is filtered to remove copper as copper cement and filtrate to taken to second stage purification. In the second stage, solution is treated with Di-methyl Glycol (DMG) to remove impurity of nickel. In the third stage purification, activated charcoal is added to remove organic impurities. The purified solution mixed with spent electrolyte is electrolyzed using lead anodes and aluminum cathodes. Zinc metal deposits on cathode and oxygen is given off at anode and sulphuric acid is regenerated in the process. Deposited zinc is stripped off manually after every 24 hours and is melted in oil fired crucible furnace. Molten zinc metal is cast as zinc ingots. Spent acid is reused in the process. Bleed off, to lower down the impurities in the system some zinc sulphate is bled off time to time. This is used to manufacture zinc sulphate crystals.

Fig. 2 Electric Arc Furnace Route of Producing Steel

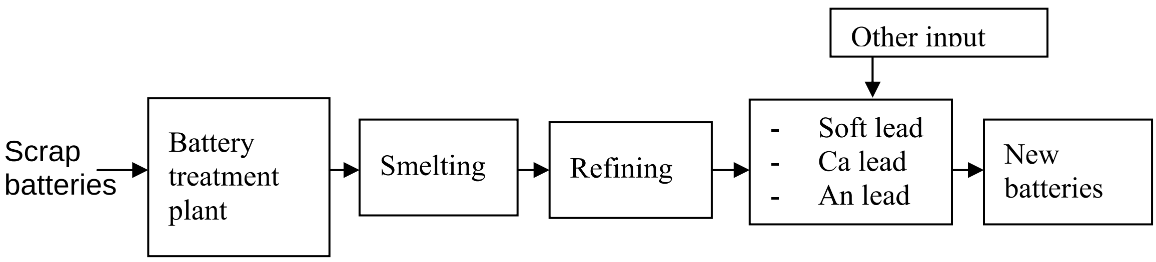


Source: Compiled from various sources.

Copper recycling sector uses copper based industrial waste suitable for copper recovery through pyro-metallurgical and hydro-metallurgical processes. The choice of the process can be made on the basis of physical form, copper content, chemical nature, chemical composition and possible recovery process. These wastes include converter slag, anode slag, ETP (effluent treatment plants) sludge, anode slime etc. Wastes like dross, reverts etc. are best recycled by pyro-metallurgical process including melting, fire refining and electro-refining. The converter slag is also recycled using smelting furnace and precious metals like Ag and Au are recovered from the anode slime by using electrolysis. Other waste except for high grade mill scale can be recycled by hydrometallurgical processing, e.g., slag is subjected to copper recovery by flotation and the residual slag can be smelted in an electric arc furnace.

Secondary lead refining process is a batch process based on traditional pyro-metallurgical methods. Batch refining is carried out in hemispherical vessel usually stirred to mix the reactants. The metal is held molten while reaction products float out and recovered from the surface. These systems typically have no pollution control system. However, lead of purity of 99.99percent is recovered in these units. The flow diagram of a typical lead refining plant is given in Figure 3.

Fig. 3 Process Flow for Secondary Lead Smelter



Source: Compiled from various sources.

Most of the waste/used oil re-refining units in the small scale sector in India use the acid-clay process. This process has the disadvantage of resulting in the generation of large quantities of hazardous and toxic acid sludge and clay contaminated with oil and heavy metals. This oil is currently reclaimed by either using acid bleaching by informal sector or using vacuum distillation by more organized sector. Currently, there are three different techniques, which are used in India by registered recyclers for used/waste oil recycling. These techniques are given below.

- acid/clay technique
- vacuum distillation/clay technique
- vacuum distillation/hydro-treatment technique

Evaluation of these three techniques for their suitability to recover waste/ used oil is given in Table 2.

Table 2 Comparative Evaluation of Recovery Techniques

Item	Acid/Clay	Vacuum Distillation/Clay	Vacuum Distillation/Hydro
Lube yield[a]	Low	Medium	Medium
Bright stocks[b]	Recovered	Lost	Lost
Utilities[c]	Low	Low	High
Overall energy[d]	High	Low	Medium
Hazardous chemicals[e]	Sulphuric acid	Caustic	Caustic

Source: Compiled from various sources.

[a] Lube yield: the oil yield in acid clay process is low because of the losses to acid sludge. The two distillation processes do not recover the bright stock and this is reflected in their moderate lube oil recovery.

[b] Bright stocks: they are recovered only in the acid clay process. This process would be favored in unusual situation where used oil contain extremely high proportions of bright stock.

[c] Utilities: this refers to total external energy requirements (power plus fuel).

[d] Overall energy: this is the total external energy (utilities) plus potential energy lost in non-recovered oil.

[e] Hazardous chemicals: in the acid clay process, the operators are exposed to the risk of handling acid and the resulting acid sludge.

There are more than twenty three processes, which are used for E-waste recycling in India. The majority of these processes occur in unorganized sector in India. The list of these processes is given below in Table 3. The outputs from these processes are electronic components, plastics, glass, ferrous and non ferrous metals including precious metals.

Table 3 E-waste Recycling

S. No.	Processing Components	Process Details
Personal computers		
1	Cathode ray tube (CRT), computer casing, printed circuit boards (PCBs), printed wire boards (PWBs), integrated circuits (ICs), yoke copper and copper, computer casing, rare earth core and gold from pin and comb	Dissembling of monitor and extraction of components
2		Regunning of CRTs
3		IC's extraction from PWB
4		Acid bath for PWB
5		Surface heating of PWB and extraction of components
6		Wire PVC and copper
7		Plastic shredding
8		Gold extractions from pins and comb
9		Yoke core and copper extraction from wire
10		Metallic core of transformer and copper
11		Rare earth core of transformer and copper
12		Rare earth core of static transformer
Television		
13	TV cabinet, CRT, yoke core and PCB	Dismantling of TV cabinet and CRT
14		Regunning of CRTs
15		Yoke core and copper extraction from wire
16		Plastic shredding

Cellular phone		
17	Aerials, battery connectors, PCBs, gold-coated edge contacts on PCBs, ICs, keyboards, LCD screens, lenses, microphones, phone housings, screws, SIM card assemblies and speakers	Separate metals recovery (including precious and semiprecious metals)
18		Batteries repairing and reselling
19		Outer body plastic granulation and reuse
20		Reuse of valuable components (flash memory devices, PCBs, ICs, keyboards, LCD screens, lenses, microphones, phone housings, and speakers) with minor repairing
Refrigerators		
21	Casing, cotton insulator, evaporator, heating rod, condenser, compressor, fan and motor	Dismantling of refrigerator and segregation of compressor and cooling box
22		Extraction of steel and copper from heating rod
23		Extraction and shredding of ABS plastic from fan

Source: Compiled from various sources.

The recycling technologies/ usage in other sector are described in Table 4 given below.

Table 4 Recycling and Reuse Options Increasingly Adopted for Certain Industrial Solid Wastes

S. No.	Industrial Solid Waste	Physical State	Source	Non-environmental Friendly Option	Recycling/Reuse Options
1	Fly ash	Powder/ slurry	Coal-based thermal power station	(i) Pumped to low lying areas in form of slurry in wet system of disposal (ii) In dry method fly ash is conveyed to dumps	- Road construction - Land reclamation - Dam/earthen Waste - Portland pozzolina cement - Lime fly ash bricks blocks and aggregates - Cellular concrete and construction industries
2.	Steel & blast furnace slag	Solid lumps (granulated/ ungranulated)	Iron & steel industries	Open dumping	- Blast furnace slag cement - As binding material - Road aggregate

Source: Compiled from various sources.

2.2.3 Pollution Potential

In addition to 7.2 million tons per annum of hazardous waste and 47 million tons per annum of municipal solid waste, India generates about 55 million m3 per day of waste water and 304,656 tons per day of particulate matter. Central Pollution Control Board (CPCB), Ministry of Environment and Forests, Government of India has identified 17 categories of highly polluting industries contributing to industrial pollution. These 17 categories of industries comprising 1551 industrial units discharge their effluents into rivers, lakes, land and surrounding atmosphere. A list of 17 categories of industries and key pollution challenges associated with them are described in Table 5.

Table 5 Highly Polluting Industries in India

Industry Sector	Key Pollution Control Challenges
Aluminum smelting	Pot room secondary emission
Basic drug and pharmaceutical manufacturing	Incinerator performance, VOC
Caustic soda	High BOD / COD load
Cement (200 tpd and above)	High BOD / COD load
Copper smelting	SO_2 emission, sludge disposal
Dyes and dye intermediate	High COD waste, incinerator performance, fugitive emission, VOC
Fermentation (distillery)	High BOD / COD load, composting, color, lagoon discharge
Fertilizer	High COD waste
Integrated iron and steel	High BOD / COD load, coke oven plants toxic gas emissions, waste utilization, BOD plant performance
Leather processing (inc. tanneries)	High BOD/ COD load, heavy metals, salt, TDS, chorine recovery
Oil refinery	SO_2 emission, oily sludge, VOC,
Pesticide formulation and manufacturing	High COD waste, incinerator performance, fugitive emission, VOC
Pulp and paper (30 tpd and above)	High BOD / COD load, AOx, lime sludge disposal, chemical recovery plant, odor issues
Petrochemical	High BOD / COD load, hazardous waste, VOC, valve leakage
Sugar	High BOD / COD load, emission from boiler
Thermal power plants	High BOD / COD load, heavy metals, coal quality, clean coal technology, high ash, Fly as management, emission of SO_2 /PM
Zinc smelting	High BOD / COD load, SO_2 emission, sludge disposal

Sources: Central Pollution Control Board: 2006.

Due to vast geographical distribution of recycling industry and part implementation of monitoring mechanism, their pollution potential has been assessed based on their contribution for production and their total number of recycling industries in each sector as described in Table 6. It is assumed that units involved in primary production of materials are environmentally compliant and have either environmentally sound technologies or have pollution control devices in place. The licensed recycling units also use environmentally sound technologies as per Hazardous Waste (Management and Handling) Rules, Battery (Management and Handling) Rules and Recycled Plastic Manufacturing and Usage Rules.

The major pollutants emitted from waste paper pulping are effluents and solid waste. Effluents are generated during pulping especially during de-inking, blending, conditioning and drying. De-inking is a complex chemical process. It involves separating ink from the fibers or 'ink detachment' followed by its removal. Processing wastepaper generates sludge. In case the wastepaper is de-inked, the sludge contains heavy metals. Industrialized countries usually incinerate de-inking sludge. But in India, most of it is disposed of in landfill or sold out.

Table 6 Pollution Potential from Medium to Small Scale Recycling Industries

S. No.	Sector	Production from Primary Sector (%)	Production from Secondary/ recycling sector (%)	Medium- to Small-scale Recycling Units (No.)	Licensed Medium- to Small-scale Recycling Units
1	Paper	54	56	400	Data not available
2	Plastic	95	5	35,200	Data not available
3	Iron/steel	60	40	1,500	Data not available
4	Zinc	80-85	15-20	200	154
5	Copper	60	40	1,000	108
6	Lead	61	39	Data not available	160
7	Waste/used oil	Data not available	Data not available	Data not available	156
8	E-waste	1.2	98-99	Data not available	Data not available

Source: Compiled from various sources

Plastic recycling process generates fugitive dust, waste water on account of cleaning and solid waste. Since no chemical process/ burning is involved in plastic grinding and granulation, effluents have high suspended solids.

Though the units in steel sector are in small scale sector but quantity of pollutants generated by them is significant. The number of units in different clusters produces huge quantity of obnoxious fumes and discharge effluents without any pollution control devices, causing severe pollution in surrounding areas.

Air and water pollution and solid waste management are the major issues in secondary zinc recovery units. Pollutant emissions take place from rotary kiln. In registered units the rotary kiln is equipped with cyclones, settling chamber and scrubber. Effluent discharge occurs during leaching, electrolysis and bleeds off. In registered units the units have effluent treatment plant or their effluents are discharged into common effluent treatment plants. However, in non registered units they are discharged into water bodies or on land. Waste is mostly in the form of residues, which are often disposed off in unsystematic landfills, though some industries follow the safe handling and disposal procedure laid down officially by monitoring agencies.

Most of the secondary copper units do not follow the proper processing technologies and discharge effluents in the surrounding environment, causing air, water and soil contamination. Pollutant emissions, which take place from the secondary copper recovery processes, are particulate matter, fugitive emissions, volatile organic compounds, hydrogen chloride gas, dioxins and chlorinated furans. In registered units the units are equipped with pollution control equipments like air cyclones, settling chamber and scrubber. Acidic effluents are discharged during electrolysis and bleed off. In registered units the units have effluent treatment plant or their effluents are discharged into common effluent treatment plants. However, in non registered units they are discharged into water bodies or on land. Solid wastes from secondary copper units in the form of residues, metal oxides, un-burnt insulation, products of incomplete combustion are often disposed off in unsystematic landfills, though some industries follow the safe handling and disposal procedure laid down officially by monitoring agencies.

Most of the secondary lead smelting units do not follow the proper processing technologies and are handling the spent lead-acid battery scraps without resorting to the pollution control norms. Some of the pollution related issues include air and water pollution and solid waste management. A standard lead-acid battery generally has 70–80percent lead metal and metal oxide, 5–6% polypropylene, 12% electrolyte (free H2SO4) and 2–3% others (Ebonite, PVC, Paper). During the processing of spent lead-acid battery in backyard units, operations like breaking, crushing, screening, dry mixing etc. generate airborne lead dust which directly or indirectly enter into the human system and the surroundings of the working area. The rotary kiln furnace process used by some of the secondary lead manufacturers in the unorganized sector needs to be modified particularly to handle the dust and smoke (gases) from the system, besides lowering lead level to less than 2% for proper disposal. In addition to lead dust and fumes, there are air emissions with respect to the SPM level, SO2 and CO. The pollution control is done by installing cyclone and bag filters in the secondary lead production units. Effluent discharge occurs during battery treatment. Registered units have their own effluent treatment plants or discharged into common effluent treatment plants. However, non registered units are discharged into water bodies or on land. Since lead is a very toxic material, disposal of the solid wastes from secondary lead production in the secured landfill is essential and mandatory. Several of the backyard smelters recover 60–70% of the metal using home made technologies because of the low melting point of the metal and simply throw the slag containing very high lead into the environment.

Since the informal waste/ used oil recycling occurs in small scale sector, they are a major source of environmental pollution. A large number of roadside garages drain used oils from automobile engines without any record of the next destination of such oils. Used motor oil is also burned, generally in inadequate equipped installations. Such operations produce large quantities of heavy metal emission particles, toxic gases (SO2, NOx, HCl) and residue products, which are ranked among the most toxic in comparison with other environmental particles. Used motor oil can be a dangerous pollutant product due to the presence of high content of heavy metals (e.g., lead, zinc, copper, cadmium, chromium, nickel) and high concentration of PAHs, such as benzopyrenes, which are carcinogenic in nature. The PAH content of used motor oil can be considerably more than that of new motor oil. Spillage of used motor oil into soil can induce a drastic change in the microbial communities and affect the biological cycles in the soil. Used motor oil in aquatic environments causes significant damage in shell fish. It is mutagenic to bacteria, as it has PAH content. About 1 to 1.5 liters of used oil creates an oil film that can cover two and a half acres of surface water. The film will block the entry of oxygen, and also the sunlight needed to support aquatic life, into the water. The comparative analysis of pollution potential of the acid/ clay, vacuum distillation/ clay and vacuum distillation/ hydro processes is given in Table 7.

Table 7 Pollution Potential of the Three Waste/Used Oil Recovery Process

Item	Acid/Clay	Vacuum Distillation/Clay	Vacuum Distillation/Hydro
Solid waste:			
Acid sludge	High	None	None
Oily clay	High	Medium	None
Caustic sludge or spent caustic	None	Medium	Medium
Liquid waste:			
Process water	Low	Medium	High

Source: Compiled from various sources.

The liquid effluents and solid waste from the units using these technologies are treated in ETPs/ CETPs or secured hazardous waste landfill sites.

Major amount of E-waste generated in India are recycled in unorganized sector. The processes used by unorganized sector are manual dismantling, chemical treatment to extract non ferrous and precious metals and open burning. These processes produce air emissions, which may include dioxins due to open burning of plastics, highly acidic liquid effluents containing heavy metals due to chemical treatment to extract non ferrous metals and hazardous solid waste left after burning and chemical treatment of E-waste.

CPCB has estimated that there is a potential of reducing the consumption of resources by 10 – 15% in small and medium scale industries. This inefficiency in resource consumption leads to high pollution loads from these industries. Since majority of recycling industries fall in small to medium scale sector, it can be inferred that they are a major source of pollution in India. Only a limited percentage of medium to small scale recycling industry is licensed and uses environmentally sound technologies. There are 115 common effluent treatment plants (CETPs) and 22 common treatment, storage and disposal facilities (TSDFs), which are operating in India to cater to medium and small scale industries, but the pollution generated far exceeds the existing capacity of treatment system.

2.3 Policy Measures to Control Pollution in Developing Counties

2.3.1 Enforcement of Pollution Control Regulation and Awareness

Japanese experience in pollution control of recycling industry showed the importance of enforcement of the regulations. In India, recyclers should follow several regulations including air and water pollution control, but enforcement of the regulation was still weak.

During 1990s,Ministry of Environment & Forests (MoEF), Government of India adopted policy for abatement of pollution, which provides multi-pronged strategies in the form of regulations, legislations, agreements, fiscal incentives and other measures to prevent and abate pollution. As per new National Environmental Policy 2006, pollution abatement is an important issue affecting the health and having a linkage to poverty. The major focus is on optimizing the resource efficiency and minimizing the pollution load. At institutional level, there is focus on decentralization of functions and review of existing regulatory regime, legislations and acts. The review of policy statements show that initially the major focus was on the control of pollution, which is gradually changing into recycling, recovery and reduction. This will assume significance in the operation of recycling industries in future.

Legal framework with respect to recycling industry has been briefly described in terms of “basic” requirement and “others”. “Basic” requirement need to be complied with irrespective of recycling industry being “hazardous” or “Non-Hazardous” in nature. “Other” describes the specific requirement like dealing with hazardous process/ waste and hazardous chemicals. The application of each regulation at planning, construction and implementation along with the implementing agency has been described in Table 8.

Table 8 Legal Framework for Industrial Waste

	Planning	Construction	Operation	Central Gov.	State Gov.
Basic:					
Factories Act	√	√	√		√
EIA Notification	√	√	√	√	√
Air Act	√	√	√		√
Water Act	√	√	√		√
Others:					
Municipal Solid Waste (MSW) Rules	√		√		√
MSIHC Rules	√		√		√
Hazardous Waste (Management & Handling) Rules	√		√	√	√
Batteries (Management and Handling) Rules,	√		√	√	√
Recycled Plastic (Manufacture & Usage) Rules 1999/ Amendments 2003	√		√	√	√

Source: Compiled from various sources.

Factories Act, EIA Notification, Air Act, Water Act are applicable at all the three stages i.e. planning, construction and operation. Their application involves “Environmental Clearance, Consent to Establish, and Consent to Operate, Site Notification and On-site Emergency Plan Clearance”. In addition to above legal framework, recyclers are required to register with State Pollution Control Boards (SPCBs) and MoEF, if they are handling hazardous waste as per Hazardous Waste (Management & Handling) Rules 2003, lead acid batteries as per Battery (Management & Handling) Rues 2001 and plastics for recycling as per Recycled Plastic (Manufacture and Usage) Rules 1999/ Amendments 2003. The registered recyclers are required to undertake clearances under the applicable regulations identified in Table 6 and maintain account of quantities recycled along with inputs and outputs for annual reporting. They are required to use environmentally sound technologies for recycling/ re-refining. They are also required to follow proper marking system to identify and transport hazardous waste. There are no specific rules for E-waste.

Central Pollution Control Board (CPCB) has developed National Standards for Effluents and Emission under the Air Act and Water Act. Effluent standards for 37 categories of industries and Emission Standards for 31 categories of industries have been evolved and notified. The relevant list of recycling industries having emission and effluent standards is given in Table 9.

Table 9 List of Industries/Activities Having Emission and Effluent Discharge Standards

1	Aluminum
2	Battery manufacturing industry
3	Beehive hard coke oven
4	Boiler (small)
5	Bullion refining
6	Coke ovens
7	Copper, lead & zinc smelting units
8	Cupola furnace
9	Diesel generator sets
10	Foundries
11	General standards for discharge of environmental pollutants
12	Oil refinery
13	Petrochemicals
14	Small-scale industry
15	Standards/guidelines for control of noise pollution from stationary diesel generator (DG) Set

Source: Compiled from various sources.

The coverage of the regulations is very broad. But it may be difficult for governments to monitor all of recyclers. As shown in Section 1, the activity of local residents surrounding the recycling plant was a major driving force for the local government to strengthen the enforcement and for recycling plant to investment in pollution control in Japan. The role of mass-media was also very important in raising awareness of people. So it is the alternative measure to increase the awareness of recycler and surrounding residents on health risks of recycling.

The judicial mechanism in addressing pollution related disputes is in developmental stage in India. Though judiciary has played major role in addressing problems related to hazardous wastes, solid waste and air pollution, the actual outcome of the dispute resolution can take many years.

2.3.2 Formal Recycling vs. Informal Recycling

As described in Section 2, informal recycling sectors have a significant share in recycling industry in India. Since they do not invest in pollution control nor pay taxes, they can compete with formal sectors. Formal recycler faces the difficulty in collection of recyclable waste, because informal recyclers collect the recyclable waste in higher price. Similar situation can be observed in other developing countries.

Around 1970 in Japan, there were informal recycling industries which caused pollution problems. But since the regulations and their enforcement were tightened rapidly, recycling industries invested in pollution control in a short period. The situation of "formal versus informal recycler" had not been the problem in the recycling system in Japan at that time.

But “illegal dumping versus formal treatment of industrial waste” in 1980s and 1990s in Japan is similar to the situation of informal versus formal recycler in developing country. Companies, which illegally dumped industrial waste can offer lower treatment fee than companies which comply the regulation. Illegal dumping of industrial waste has been a problem since 1980s. Government took measures to put more responsibility on waste generator and impose more punishment on illegal dumping. The responsibility of generator included formal contract with formal waste treatment company, manifest system which make the flow of waste traceable. Japanese experiences show that the regulation of transaction is one of the important policy tools. Monitoring “hot spot”, where illegal dumping is frequently occurred, by government officials was also effective to prevent illegal dumping. The government also has supported the development of recycling industries. India introduced the regulation of transaction for waste lead acid batteries in 2001, namely, Batteries (Management and Handling) Rules. As per these rules, dealers shall ensure that the used batteries are collected back as much as 90% of number of units sold.[46] Dealer also has responsibility to ensure safe transportation of collected batteries to the designated collection centers or to the registered recyclers. Auctioneer which usually generates a big volume of waste lead acid batteries shall ensure that used batteries are auctioned to the registered recyclers only. But the impact of this regulation is still limited, since enforcement is still weak. Further this tool is available only in the case of batteries. The registration of recyclers has limited scope and is applicable to lead, non-ferrous metals and waste oil/ used oil only. The import of hazardous waste is permitted for recycling under Hazardous Waste Management Rules in line with Basel convention. However, the limited extent of transaction regulation to support pollution control inhibits the growth of formal recycling industry.

In order to solve the problem that formal recycler faces is the lack of availability of recyclable waste due to the collection by informal recycler, both enforcement of regulation of pollution control and the regulation of transactions should be strengthened. Financial support for collection mechanism of waste by formal recycler is an additional measure, which can strengthen waste treatment in formal sector.

2.3.3 Institutional Mechanism

The concept of SMEs (small and medium enterprises) forming industry association to address pollution control is gaining momentum in India. The major examples are lead/ non ferrous recycler’s association and industry associations, which are instrumental in implementing Combined Effluent Treatment Plants (CETPs) and Hazardous Landfill facilities all over the country. However, SME recycler’s associations need to be further organized and play the role of financial intermediary to review loans/ grants for pollution control.

2.3.4 Information about Pollution Control Technology and Financial Support

If the intention to comply with the regulation is ensured by enforcement of regulations then the awareness of recyclers, information of pollution control technology including end-of-pipe

[46] In the first and second year, required percentages are 50% and 75%, respectively. Ninety percent is the requirement after two years of implementation.

technology and cleaner production technology should be provided by public authority or experts. Otherwise, they can not choose environmentally sound technology.

Since such technology is expensive, recyclers may not afford installing pollution control equipment. If possible, low interest loan should be provided to small scale recyclers through industry associations, which can act as financial intermediary and a vehicle to disseminate information on the risks of pollution, the technologies and the financial options.

Associations of recycling industries were the body to disseminate the information of technology and financial option in Japan. In India, "Waste Minimization Circle" has similar function of information dissemination, but they put more emphasis on cleaner production technology which can reduce inputs and cost of production. The program of Waste Minimization Circle is operated by National Productivity Council. Small enterprises make a circle to analyze the problem they have in hand and seek a solution together with experts. The target industries are not limited to recycling industries, but recycling industry can also participate in the program e.g. Aluminum utensil manufacturer in Jagadhri industrial cluster which use Aluminum scrap formulated a waste minimization circle.[47] They improve the process of screening Aluminum scrap and the pretreatment of furnace oil. They also modify the furnace. Through these changes, they reduce the fuel consumption, improve the quality of products, and reduce the rejection rate in the rolling process to zero. The measures are not the end-of-pipe technology, but cleaner production technology. Though this arrangement addresses pollution prevention, similar arrangement can work for pollution control in recycling industry.

2.3.5 Recycling Industrial Park

Recycling industrial parks have been established in Japan, China and Taiwan. In Japan, tens of recycling industrial park have been developed since late 1990s under the Eco-town project, which is supported by Ministry of Environment and Ministry of Economy, Trade and Industry. But the reason of their establishment is to promote recycling industry, not to control pollution.

Taiwan established two recycling industrial park in Kao-Hsiung in 1980s, in order to monitor recycling plant more closely (Terao 2005). Chinese government also promotes establishing recycling parks, where imported recyclable waste are dismantled and recycled. It becomes easy for local government to enforce regulation of pollution control, because recyclers are concentrated at one place. On the other hand recyclers can extend their facility in newly developed industrial parks. Waste water treatment and other facilities are collectively operated. Some incentives such as tax exemption are applied to the factories. Some recycling villages in Vietnam also constructed industrial zone. Some parts of the operation have been moved from backyard of household to industrial zone. In India, the majority of recycling industries though organized in a cluster geographically are not located in one industrial zone or industrial park. They are scattered and dispersed in the industrial cluster, which makes the task of developing common control facilities very difficult. Although the use of common pollution control facilities is not sufficient, the relocation to the industrial zone will be an opportunity to prevent pollution.

[47] G. Girrech (2002).

Conclusion

Recycling is considered to be good for the environment. But some material recycling processes cause environmental pollution, if proper pollution control measures are not applied. Relocation of the factory without any pollution control does not provide solution to the problem.

Enforcement of pollution control regulation is a pre-condition for recycler to invest in pollution control facility. If regulation is not enforced well, informal recyclers without pollution control can collect recyclable waste more than formal recycler. In addition, Awareness of local residents might force the factories to invest in pollution control equipment. However, it should be supported by judicial system with the backing of scientific and technological studies.

If recycling plant is willing to invest in pollution control, information of pollution control technologies should be provided. If possible, financial support such as low interest loan can promote such investment. An institutional mechanism like recyclers association at a local level can play roles of information dissemination and financial intermediary. Further, recycling industrial park is an option to make common pollution control facilities and strengthen the monitoring.

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