Substance Flow Analysis of Heavy Metals' Recycling - How to deal with Decreasing Markets

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Introduction

Environmental problems related to heavy metals have a long history. Heavy metals have toxic properties, leading to adverse effects on human and ecosystem health even in small doses. Another problem-causing property is their non-degradability: once they enter the environment they will remain there for a long time. Metals tend to accumulate in soils and sediments, with immobilisation due only to geological, and therefore extremely slow, processes. Accumulation in the food chain may lead to an increased stock in biota, thereby magnifying the human dose. A number of problems in the past have given rise to policies restricting the use of these metals on the one hand, and close their economic cycles on the other hand. Recycling is an important part of these policies. On the one hand, recycling prevents waste; on the other hand, it reduces the need for using virgin materials. For a number of metals, recycling has been upped to include the major part of the waste stream. In most cases, there is no difference in quality between secondary and primary produced metals.

However, in some cases recycling can have side effects, which reduce its obvious usefulness. This is due to the fact that in these cases the supply is disconnected from the demand. In this paper, three cases in point are discussed: cadmium, mercury and lead. For all three of these heavy metals, although for different reasons, the disconnection of supply and demand may have adverse consequences for recycling. The question addressed in the last section of this paper is how to avoid the potential environmentally nasty consequences of this phenomenon.

Substance flow analysis

The conclusions reached in the three cases presented below have been reached by conducting Substance Flow Analyses (SFA) for these metals. Substance Flow Analysis is a method out of the Industrial Ecology toolbox, specifying flows of a certain substance in, out and through a regionally demarcated system. SFA is based on the mass balance principle: what flows in, must also come out again, although possibly with a delay. It has been used and proven useful in many case studies before (Ayres, 1997; Bergbäck & Lohm, 1997, Hansen & Lassen, 2000; Stigliani & Solomons, 1993). Inflows of heavy metals occur by mining of ores of these metals, or of raw materials containing them as a contaminant. Once mined, metals are refined and applied in products entering the stocks-in-use. Outflows are landfilled waste and emissions, occurring at all life-cycle stages. Secondary production appears as an internal flow, originating from stocks-in-use or in-storage. On the sub-global level, imports and exports of raw materials, products and waste complete the picture of inflows and outflows. SFA is particularly useful in case datasets are incomplete or conflicting. The principle of mass balance can make this apparent and set one on the track of trying to refine specific data. In some cases it can even be used to estimate missing flows.

The case of cadmium

Cadmium is used in a number of applications, most important of which are nickel-cadmium batteries. Other uses include plating and alloys. Application of Cd as a stabiliser or pigment has been reduced due to environmental policies. In an analysis of cadmium flows in the European Union, the origins of certain environmental problems related to cadmium were assessed and the effectiveness of a number of policy measures was estimated (Van der Voet et al., 1994). A variety of direct causes can be identified for these problem flows, and responsibility can be traced back to a limited number of economic sectors. These sectors are the same for each problem flow, but with different contributing sources in each case. Ultimately, the Cd flows can be traced back to two main economic inflows: the import of phosphate rock and the import or extraction of zinc ore. Zinc ore is the main source of the intentional applications of Cd, which end up mostly on landfill sites or accumulate in the economy. In phosphate rock Cd occurs as a contaminant, polluting the most important P-product: fertiliser, and causing Cd to circulate in the economic-environmental agricultural system.

The EC policy, according to the proposed lines of (1) end-of-the-pipe measures, (2) a phase-out of certain applications, and (3) recycling of batteries and plating, conforms to those notions. SFA modelling shows however that various forms of problem shifting can be expected to appear as a result of these measures:

- diffuse emissions will be replaced by local emissions
- emissions within the EU will be replaced by emissions outside the EU
- current emissions will be replaced by emissions at a later date.

This policy does not appear to offer a sustainable solution to the cadmium problem, mainly because it does not consider the inelastic nature of cadmium supply, that is, primarily as a by-product of zinc. In order to be effective, a cadmium policy must take into account the way Cd enters and filters through the economic system. Normally, an increased availability of secondary materials through recycling would result in a reduced demand for primary materials, which in turn would lead to a reduced supply. For cadmium, this last step is not taken, since the supply of cadmium does not depend on the demand for cadmium, but on the demand for zinc. Increased recycling of cadmium thus leads to an increased supply, for which there may be no demand.

If we have a look at global developments, this analysis is supported. The production of Cd has increased over the last century, to stabilise at a level of 20,000 tonnes/year since 1980 (Figure 1). At the same time, cadmium prices have gone down enormously over the last century, from roughly $ 30,000 / ton in 1900 to $ 300 / ton in 2000 (Figure 2). Presently, around 10% of the cadmium supply comes from secondary sources. This is expected to increase in future, when growing amounts of NiCad batteries will be recycled (USGS, 2001). Reduced demand through environmental legislation combined with increased supply puts the price under further pressure, with unclear consequences for the profitability of the recycling industry.

Figure 1 Worldwide cadmium production, 1900 - 2000 (tonnes/y) (source: USGS, 2002)

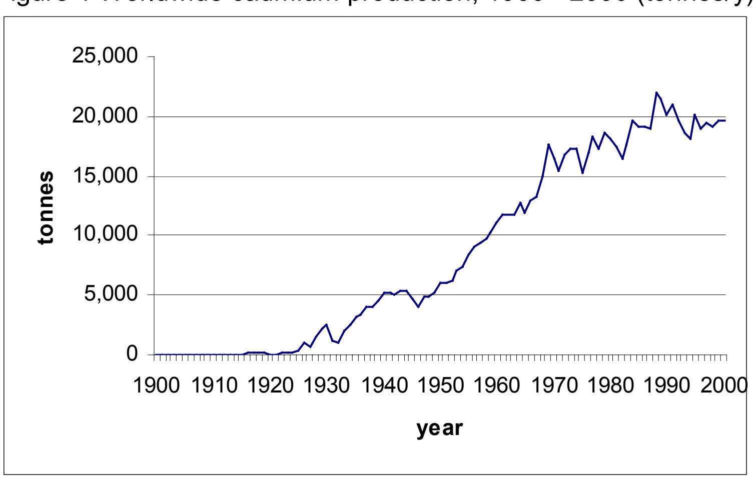
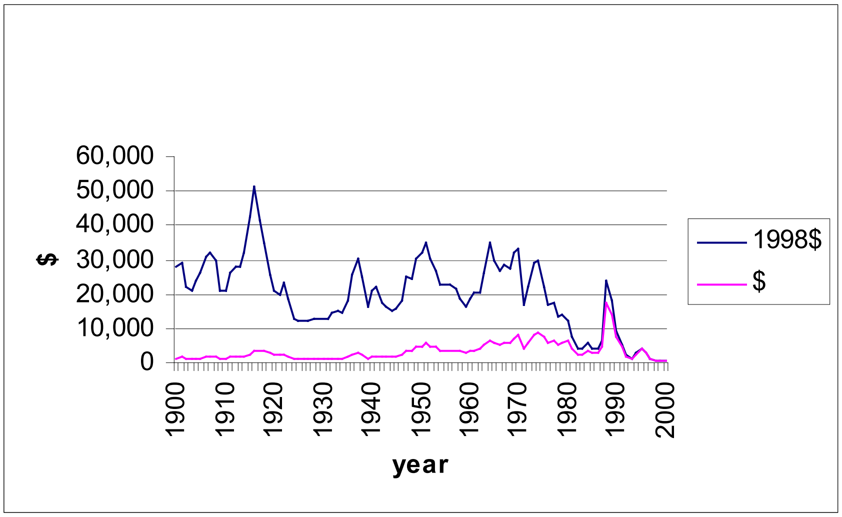


Figure 2 Cadmium world market price in $/t, 1900 - 2000 (source: USGS, 2002)



The case of mercury

Mercury is a material that has a wide variety of industrial and consumer applications. Some decades ago it was acknowledged that mercury could have adverse effects on health and the environment. In various parts of the world, a number of mercury applications has been reduced or phased out altogether for that reason, especially the open applications such as in pesticides or paints. This has had a worldwide impact on the demand for mercury, which has gone down steadily over the years, especially in the developed countries. Of industrial applications, the use of mercury in the chloralkali industry - especially the European industry - is at present the largest one. The use in batteries used to be large but is very much reduced. Remaining consumer applications include dental amalgams, switches, TL tubes, laboratory and medical instruments, thermometers etc.. Alternatives exist for most of these applications, putting more pressure on the demand for mercury, which can be expected to go down even further in the future.

On the supply side, the trend is a reduction of the worldwide primary production from mines. Mercury is also extracted as a by-product from other materials, such as zinc, lead and natural gas, wherein it occurs as a contaminant. The by-production of mercury has increased, mostly due to stricter demands regarding the quality of the host material. Recycling provides a third and also increasing source: the release of mercury from societal stocks-in-use, or strategic storages in society. The European chloralkali industry is presently shifting to different production processes. Since the new processes do not require the use of mercury, the present stocks-in-use will no longer be needed and may become available on the market. The size of these stocks is estimated at 12 - 15 ktonnes for EU countries. The present annual worldwide demand is estimated at 3 - 5 ktonnes. The release of these stocks therefore may be expected to have a significant impact on the world market, even if it is spread out over a number of years. Similar concerns were voiced when mercury stocks became available in the US and were put on the market roughly a decade ago. The release of industrial and governmental stocks has caused the US to temporarily change from a net importing to a net exporting country. Past trends show a drop in the already low mercury market price around that time. These stocks however were much smaller than the stocks presently residing at the European chloralkali industry. The increasing availability from by-product and secondary sources, together with the decreasing demand, puts further pressure on the primary production from mercury mines. Here, too, we have a case of disconnection of demand and supply, with uncertain consequences for the recycling business.

Figure 3 Mercury supply in the US, 1975 - 1996, tonnes/y (source: Matthews et al., 2000)

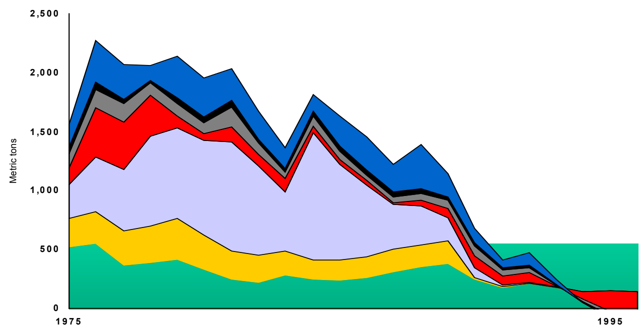
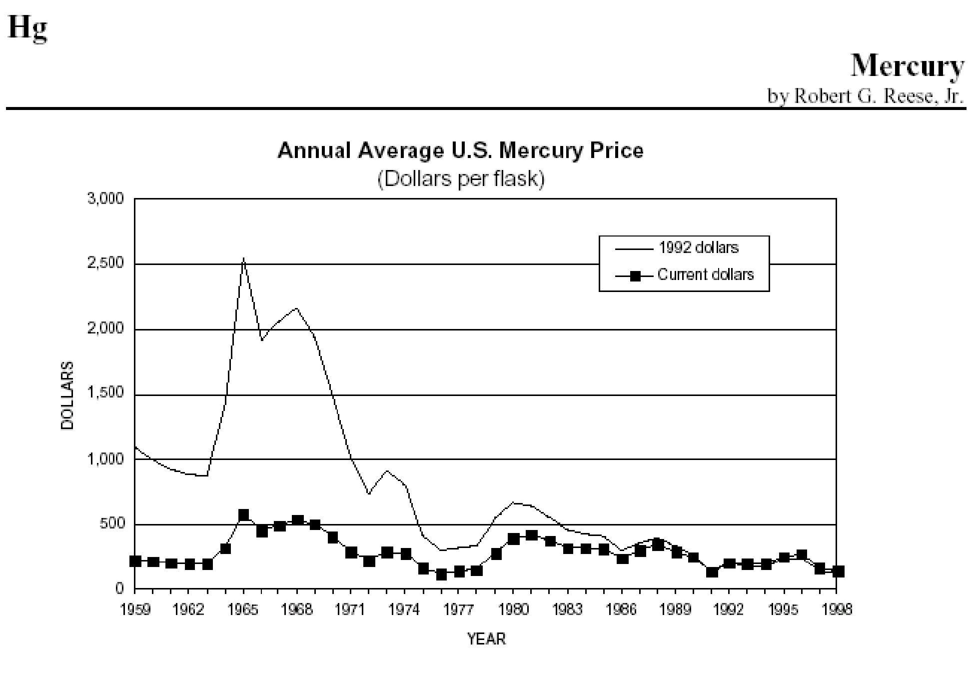


Figure 4 Average US Mercury prices ($/flask), 1959 - 1998 (source: Reese, 2000)



Significant event affecting mercury prices since 1958

1971 Mercury declared a hazardous air pollutant by the U.S. Environmental Protection Agency

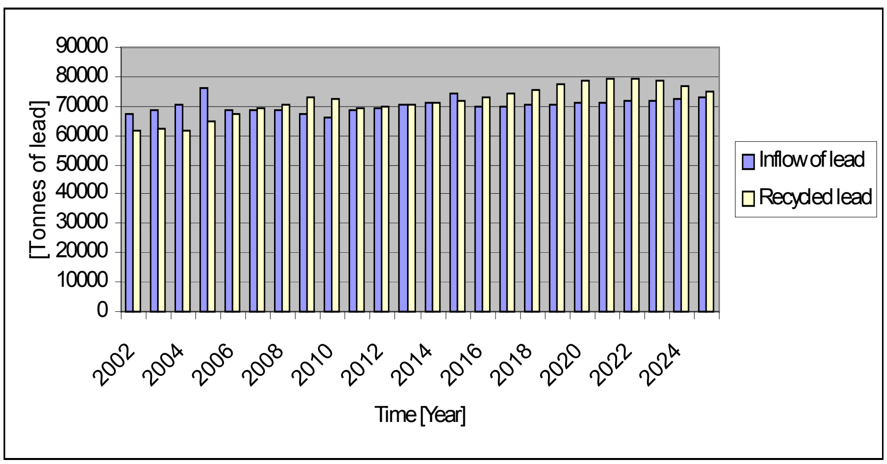
The case of lead

Within the framework of a PhD project aiming at the development of a dynamic SFA model, a case study is conducted on lead flows and stocks in the Netherlands (Elshkaki et al., 2002; Elshkaki et al., in prep.). Large applications of lead are its use in industrial and car batteries, and in lead sheets in buildings. A rapidly increasing application is its use in cathode ray tubes. Some applications have been subject to regulation and are very much reduced or even completely phased out, especially the use of lead as a stabiliser or a pigment and the addition of lead to gasoline. With the dynamic SFA model, forecasts have been made of future inflows and outflows of lead (Elshkaki et al., 2002). A very important role in the dynamics is played by the stock-in-use of lead. This stocks acts as a buffer and a large reservoir of lead. Its main component is lead in sheets used in buildings. Although the inflow of SLI batteries is larger, the life span of lead sheets is much longer, causing the lead to remain in the stock for a very long time.

Although some lead applications are banned, no significant reduction is expected in the demand for lead. Most applications continue or even increase, due to growth of welfare and population. On the whole, the future demand for lead is expected to remain more or less at the present level. This is not true for the outflow. In the past, huge stocks-in-use have accumulated. These stocks will slowly release their lead containing products over a long period of time. The results of the dynamic model show that the stock is expected to start decreasing in size within the next decade. The outflow will increase, while the inflow remains more or less at the same level. Instead of a sink, the stock thus will become a source of lead in the near future.

Presently, most of the lead entering the waste stage is recycled. This flow of recycled lead therefore also will increase. Figure 5 shows that in the near future the amount of lead available for recycling will become larger than the demand for lead. This means that at least in the Netherlands the demand will be more than covered by the supply of secondary lead only. If likewise developments can be found in other countries, it may imply that lead will become a similar case to the much smaller scale metals cadmium and mercury, and that supply and demand will be effectively disconnected.

Figure 5. Estimated future demand for lead and supply of secondary lead in the Netherlands, 2002 - 2025 (source: Elshkaki et al., 2002).



The world production of lead in tonnes has been more or less stable since ca. 1970. The fraction of this demand met by secondary lead has increased: in 1945, it was one third, while at present it is around three-quarters of the total production. This suggests that it may indeed be possible that such developments as now occur in the Netherlands will occur on a global scale as well. At present, this is not yet the case. The lead price has been dropping over time, but not as dramatically as for cadmium and mercury. If such events would occur, the scale would be much larger since lead is used in much higher quantities.

Figure 6 Worldwide lead production, 1945 - 2000 (tonnes/y) (source: USGS, 2002).

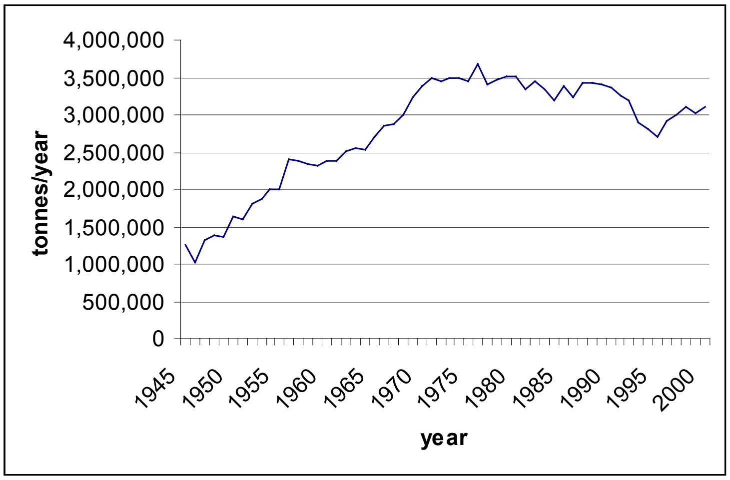
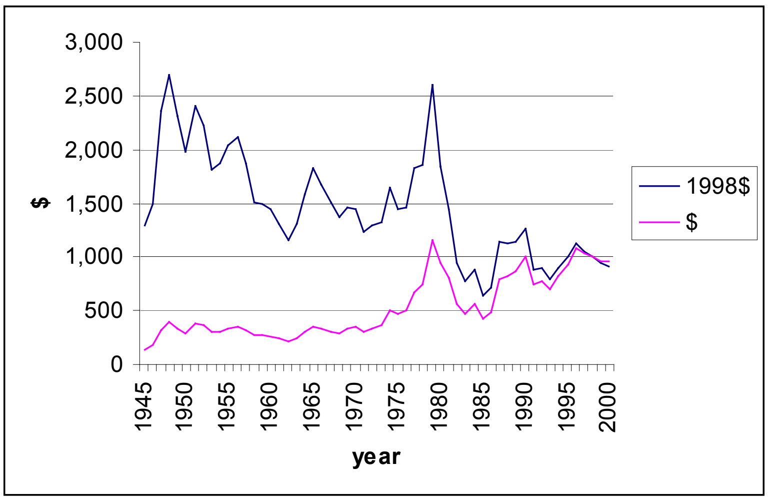


Figure 7 World market price of lead, 1945 - 2000 ($/t) (source: USGS, 2002)



Discussion and conclusions: recycling and decreasing markets

Above, three cases have been presented of heavy metals, where due to policies the demand has been reduced while at the same time the supply has not, partly or wholly through recycling. Effectively, supply and demand of these metals have been or might be disconnected. For mercury and cadmium, the demand will further decrease while the availability of secondary and by-product materials will increase. For lead, the demand has stabilised but the supply of secondary lead will grow further, possibly to a level higher than the demand. What will be the consequences of these developments?

A disconnection of supply and demand often implies a drop in the price. For cadmium and mercury, prices have been dropping considerably already, especially over the last decades since they have become an environmental concern. For lead, prices are also decreasing over time but in a more moderate pace. However, in future this might change if indeed supply and demand become detached.

There are various possible reactions of the world market to an oversupply:

- Reducing primary production: the larger availability of secondary metals reduces the need for primary production, while a reduced price makes primary production less attractive anyway. So far, the oversupply has resulted in a reduction of mining but not to a complete stop. For cadmium, this would not be possible since its supply depends on the demand for zinc. For mercury it is possible but has not happened for various reasons. For lead, it would be difficult since in many cases other metals are extracted together with lead from composite ores.
- New applications: the larger supply may cause shifts in use patterns. Often when prices drop, new applications are found for the material in question. In these cases it is doubtful whether this will happen, since applications of the three metals are under heavy regulatory pressure already.
- Relocation: the larger supply, especially if accompanied by lower prices, will not affect the use in industrialised countries but may lead to an increase of the use in developing countries where regulations are probably less strict. This may concern industrial use - for example, the use of mercury by the chloralkali industry in China - but consumer uses as well. This may also lead to increased waste and emissions in these countries.
- Increase in waste and emissions: when the materials become less valuable, recycling options may become less attractive and recycling schemes may be abandoned. In turn this may lead to an increase of metals in final waste streams.

From a resource availability point of view, the problem seems to be a surplus, not shortage. From an environmental point of view, only the reduction of primary production seems favourable. The latter three out of the four options mentioned above are undesirable because they may lead to less, not more controlled streams. Which one or more of the above possibilities will be likely to actually take place is not easy to say. It depends on many factors, especially on the presence and content of policies related to these metals.

However that may be, it puts some question marks to the policies aiming at phasing out the applications of these metals. Emptying of old societal stocks may be disruptive to markets. This may be regarded as a temporary problem. Reduction of use also means that the metals becoming available anyway through recycling and as by-products have nowhere to go. If they can no longer be applied, what then will happen? Most of the options are unfavourable.

Recycling dilutes, but also extends the time span of this problem. It can make the difference between a quick large release of waste and emissions and a lengthy but much smaller release per unit of time. It is not automatically clear which is to be preferred from an environmental point of view: after all, metals don't degrade and therefore remain in the environment for a very long time. Moreover, recycling may backfire onto itself: the larger availability of materials could cause prices to drop and thus render the recycling business to be unprofitable. If this happens, recycling will only be possible by subsidising it. And still the question remains: what to do with the metals that no longer can be applied? In all, it seems that an important part of any future metals management has to be the end-of-life treatment of waste metal streams from old societal stocks and from resources from which it is extracted as a by-product.

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