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Electronic Waste Generation and Technology for an Appropriate Management in Mexico

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Resumen. Este artículo incluye una revisión de la problemática relacionada con los residuos electrónicos en México, así como los resultados del primer diagnóstico nacional basado en reportes y bases de datos de fuentes oficiales para los residuos de equipo de cómputo, televisores, teléfonos celulares, teléfonos no celulares y aparatos de audio y video. Asimismo, se describen las principales operaciones realizadas en los procesos de reciclaje utilizados en algunos países desarrollados. Finalmente, se realiza una reflexión sobre las necesidades a ser consideradas para el desarrollo de una política específica en materia de residuos electrónicos en México.
Palabras clave: Residuos electrónicos, productos al final de su vida útil, análisis de ciclo de vida, inventarios de residuos, metales pesados en productos.

Abstract. This paper includes a review of the main concerns related to electronic wastes in Mexico, as well as the results of the first national diagnosis based on official reports and databases for wastes of end of life computers, televisions, cellular telephones, non-cellular telephones, and audio/video equipment. On the other hand, the main operations included in the recycling processed used in some developed countries are described. Finally, some thoughts on the needs and considerations for the development of an specific policy for electronic wastes in Mexico are shown.
Key words: Electronic wastes, end of life products, life cycle assessment, wastes inventories, heavy metals in products.

Introduction

The definition of "electronic waste" includes several types of electrical and electronic equipment that have lost any value for their owners [1]. The use of electronic elements in products has been increased in recent decades throughout the world, especially in appliances such as computers, cell phones and electronic devices for entertainment, which at the end of their lifetime are to be disposed together with municipal solid wastes, since most of them are generated by the population and there is no specific legislation [1].

Computers represent only a small part of the universe of electronic wastes generated along with other appliances such as cellular telephones, televisions, compact disc players, etc. In 1994 it was estimated that approximately 20 million computers (7 million tons) became obsolete around the world, rising to above 100 million in 2004. It is estimated that about 500 million computers came at the end of its useful life between 1994 and 2003, generating approximately 287 2000 tons of plastic, 718,000 tons of lead, cadmium 1363 tons and 287 tons of mercury [2]. In Mexico, around 2006, 2,375,000 computers were dismissed [3]. Such trends are motivated primarily by an increase in the market and the reduction of the lifetime from 6 years in 1997 to 2 years in 2005 [4].

Some of the most important heavy metals found in electronic products, outstanding by their toxicity, are: mercury, lead, cadmium, beryllium, chromium and barium. These can be leached when electronic wastes are disposed jointly with municipal solid wastes in environmental conditions. Another group of substances of interest are flame retardants which are incorporated in electronic products to reduce the degree of their flammability. Among them, the most outstanding due to the international consensus regarding their toxicity, are as indicated in figure 1 [5, 6]:

1) Penta-bromo-diphenyl-ether (pentaBDE)
2) Octa-bromo-diphenyl-ether (OBDE)
3) Decabromo-diphenyl-ether (DBDE)
4) Tetrabromobisphenol A (TBBPA).

These substances can bioaccumulate in biota and represent a potential risk to human health. High levels of pentaBDE, dioxins, furans and polycyclic aromatic hydrocarbons have been reported in air, water, soil and sediments, as well as in blood and breast milk of people living close to areas where uncontrolled recycling companies are located, reaching con-

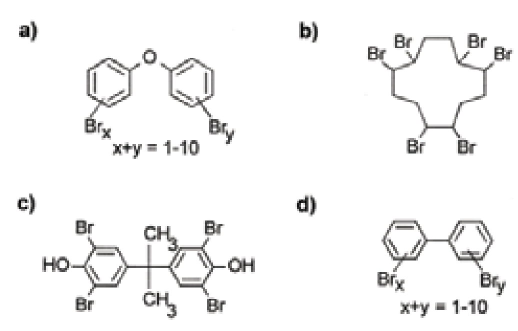

Fig. 1. Chemical structure of most commonly used polybrominated flame retardants.

centrations up to 100 times higher than the average concentrations for non-contaminated sites [7, 8]. Regarding to the workplace, elevated levels of polybrominated biphenyl ethers in blood of workers have been found at electronic waste recycling companies [6].

The uncontrolled worldwide generation of electronic wastes has encouraged developed countries to send large volumes of electronic wastes to developing countries for treatment and disposal [9], which together with the fact that these activities are found to be profitable businesses, as the recovery of valuable metals such as gold, silver and copper is possible, has prompted the trans boundary (legal or illegal) movement of electronic wastes. Historically, the recovery of precious metals from electronic waste has been one of the biggest incentives for the recycling industry. It is reported that circuit boards have a very high content of precious metals, having from 40 to 800 times the content of gold and from 30 to 40 times the amount of copper than those found in natural ores. However, manufacturers of electronic products have gradually reduced the size and content of metals in order to reduce costs [10-11].

The Basel Convention on the trans boundary movement of hazardous wastes includes in the list A of its Annex VIII, toxic substances such as cadmium, mercury and lead [12]. From 2006, several partnership programs were initiated to manage mobile phones and computer equipment, with the purpose of controlling the illegal trade and regulate the export of electronic second hand products to developing countries, which have to deal with the problem of their disposal when they reach the end of their useful life.

Moreover, in recent years, the European Directive 2002/96/EC on Waste Electrical and Electronic Equipment (WEE) was published, which stipulates that these materials should be handled in an environmentally appropriate way, reducing the amount sent for disposal in landfills and increasing the reuse and recycling of products. The classification established for these residues is shown in Chart 1 [1].

The generation of these wastes in the European Union is distributed as shown in figure 2.

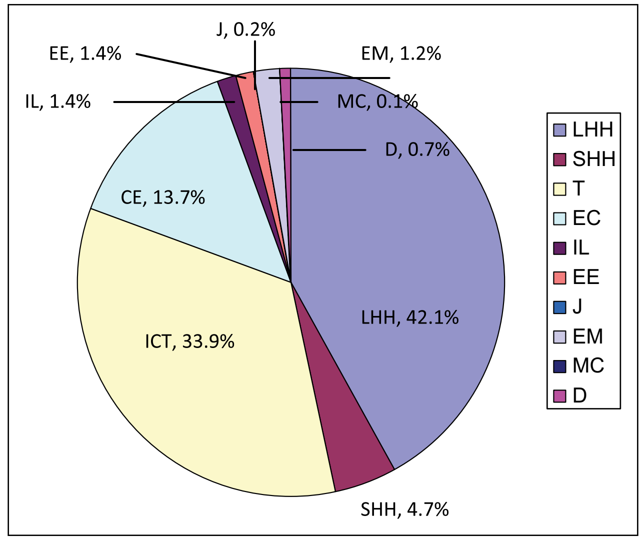

Fig. 2. Generation of e-wastes in the European Union. Source: Widmer *et al.*, 2005.

Additionally, the European Union published the Directive for the Restriction of Hazardous Substances (RoHS), which establishes limiting values on the content of hazardous substances in electronic products, and promotes the use of less harmful alternative substances [13].

Regarding the situation in developing countries, China and India have faced the accelerated increase in the amount of electronic waste generation by domestic market and illegal imports. In these countries, the lack of regulation or monitoring, promoted the growth of a semi-formal or informal economy, which includes trading activities, repair and recovery of materials. As a consequence, the potential risks to human health and the environment has increased [1].

Regarding the existence of management models for electronic waste, it was documented that the system used in Switzerland is based on charging a fee for recycling to consumers when they purchase products, which, upon reaching the end of their useful life, are returned through retail outlets,

Chart 1. Electronic wastes classification as established by the European Union Directive (WEEE).

No.	Classification	Symbol
1	Large Household Electrical Appliances	LHH
2	Small Household Electrical Appliances	SHH
3	Telecommunication equipment	T
4	Consume equipment	EC
5	Illumination equipment	IL
6	Electric and electronic tools	EE
7	Toys, entertainment and sports appliances	J
8	Medical devices	EM
9	Monitoring and control devices	MC
10	Automatic dispensers	D

Source: Widmer *et al*, 2005.

distributors and collection centers for recycling. In contrast, the system used in India is based on a small organized system where small collectors pay a fee to consumers for their obsolete equipment and afterwards sell those to larger collectors, which separate different types of wastes and selectively sell them to recyclers who recover metals, plastics and other components [9].

Technology for Recycling of Electronic Waste

Traditional methods for the disposal of electronic waste are incineration and disposal in landfills. However, several strategies have been developed for successful segregation of the components of electronic waste at the end of their useful life. The available infrastructure determines the process and amounts that can be recycled, and among them, the following elements should be considered: transport, collection, recovery and re-sale. The main factors that may affect the existence of infrastructure are: a variable quantity in the waste stream, regulations by governments, and economic factors related to products at the end of their useful life [14]. The key factors for the recycling of these wastes are shown in Figure 3.

It was estimated that, in 2003, over 54 million computers were sold in the United States and nearly 63 millions were dismissed. This indicates that the obsolescence rate has exceeded production volumes. In addition, lifetime for computers in 1992 was close to 4.5 years, which fell to 3 years by 1999 and to 2 years by 2005. The biggest motivation to promote recycling in the United States is the prohibition of incineration and disposal of cathode ray tubes (CRT) in the states of California, Maine, Minnesota and Massachusetts [14]. The stage of collection and transportation is the most expensive part of the process of reuse and recycling of electronic products; this represents over 80% of the total cost.

The door-to-door collection can be performed on a regular basis through a municipal collection system or application. The coexistence of a system for electronic waste collection can significantly reduce operating costs and is very comfortable and convenient for residents. However, it may lead to the abandonment of unwanted equipment or theft of equipment for recycling, affecting the volumes required to operate the recycling system. Collection events might also be organized to maximize the participation of the residents. Under this option, the degree of people's involvement and climatic conditions are critical. These events are successful when it is possible to separate the valuable objects at the site for resale, repair and reuse. Another option is the use of municipal solid waste collection centers as e-wastes permanent reception sites; this is the best cost-effective option. However, such programs are not best suited to small communities. Finally, producers of original equipment can establish a collection system where consumers might return obsolete equipment for their sound management, (such as in the European model). This option generally considers that the costs of recycling are included as part of the original cost of the electronic product when it is acquired [14].

Facilities for the recovery of materials

The facilities for the recovery of materials separating those reusable and recyclable. Equipment and parts that can be reused are separated from the waste stream and the rest is sent as scrap or recyclable material [14, 15]. The flow chart of this process is shown in Figure 4.

The biggest market is related to all repaired products that may be sold or donated to secondary users, and the second largest market is for components that can be resold and reused.

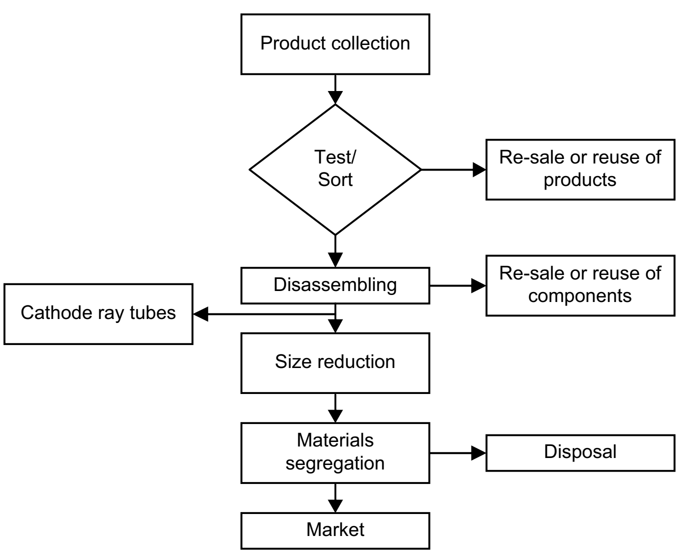

Fig. 3. Simplified diagram for recycling electronic products. Source: Kang & Schoenung, 2005.

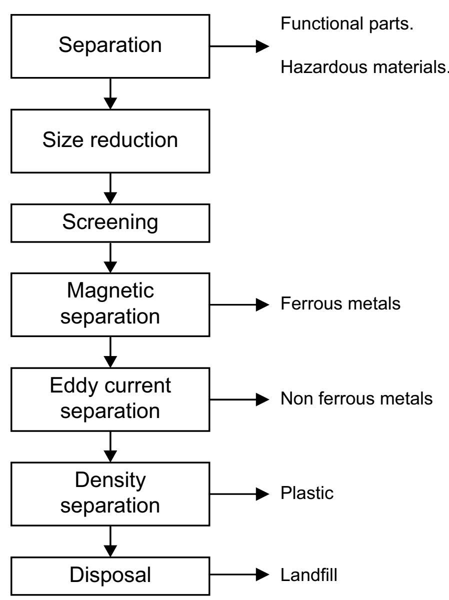

Fig. 4. Simplified diagram of a facility for the recovery of materials. Source: Kang & Schoenung, 2005; C-Tech, 2007.

The third market is for recycled materials. From the data generated in collection programs in the United States, it was found that over 50% of discarded computers are in good condition and generally find a market in countries such as China, India and Pakistan to use as secondary products [14].

It is estimated that electronic wastes collected in the United States has the following composition: 49% metals, 33% plastics and 12% for CRT, and the particular case of computers is: 25% glass, 48% metals, plastics and 23% (Chart 2).

Cathode ray tubes (CRT)

Cathode ray tubes are composed of two main parts: 1) A piece of glass (glass funnel, glass panel, glass welding and neck) and 2) non-glass components (plastic, iron, copper, phosphorus coating). Since CRT contain lead, they require special handling to prevent air, water or soil pollution. Currently, there are two technologies for recycling CRTs: 1) recycling from "*glass to glass*", and 2) recycling from "*glass to lead*". Before starting the recycling process, the carcasses must be removed and pipes should be depressurized [14]. The flowchart for the recycling process of CRT is shown in Figure 5.

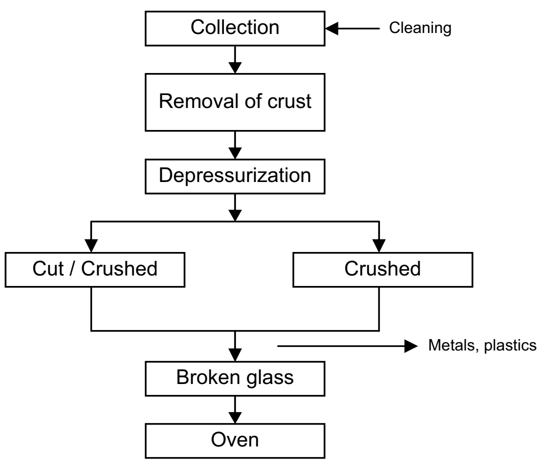

Fig. 5. Flowchart for recycling CRTs. Source: Kang & Schoenung, 2005.

In the "*glass to glass*" process, glass is separated from the panel to be sent to manufacturers of CRT for developing of a new product. The recycling of glass from CRT is a relatively small component for glass recycling companies, because it is difficult to obtain from it an homogeneous composition. For the "*lead to glass*" process, lead and copper are recovered from a CRT cast process. The composition of the typical CRT contains between 0.5 to 5 kg of lead and from 1 to 2.3 kg of copper. [14]

Recycling of plastic

Generally, plastic thermo-sets are crushed when recycled since they can not be melted to develop new products; these are usually used in circuit cards, electrical switches, and motors and resistors components. On the other hand, thermoplastics can be melted and molded into new products, and thus have a higher recyclability [14]. Different options for the management of plastic waste from electronics is shown in Figure 6.

Mechanical recycling process. The acrylonitrile-butadiene-styrene (ABS) and high-impact polystyrene (HIPS) are used to manufacture monitors and televisions for the protection of the CRT. Additionally, Polyphenylene oxide (PPO), Polyphenylene ether (PPE), polyethylene and polyvinyl are used in various components of televisions and computers. Plastics most widely used in the electronic industry are HIPS with 56% of the total, ABS with 20% and 11% with EPP [14]. Given the complexity of the plastics mixture used, it has a reduced market until separated. To identify the different types

Chart 2. Material recovered from televisions and computers in the United States (wt%).

	Computer*	Cell phone**	Television***
Component	Content (% total weight)	Content (% total weight)	Content (% total weight)
Plastic	22.99	57.00	22.90
Lead	6.30	0.30	1.30
Aluminum	14.17	1.00	2.17
Iron	20.47	5.00	5.30
Copper	6.93	13.00	5.22
Nickel	0.85	0.10	0.22
Gold	0.0016	0.03	0.0010
Palladium	0.0003	0.02	0.0004
Silver	0.02	0.13	0.01
Glass	24.88	2.00	62.00
Other	3.39	21.41	0.87

Source: * Román, 2007, ** Hagelüken, 2003, *** Lehner, 2003 y Agencia Ambiental Europea, 2003.

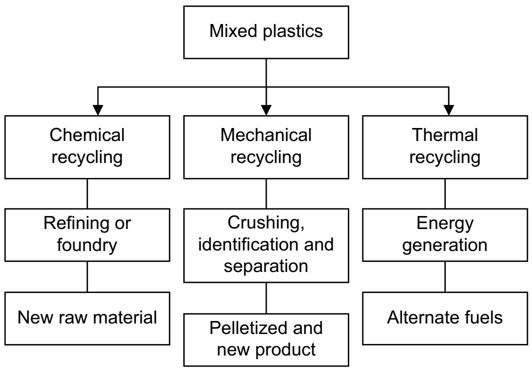

Fig. 6. Options for recycling of plastics from electronic waste. Source: Kang & Schoenung, 2005.

of plastics in electronic wastes, one of the first actions is to remove coatings and paints by abrasion or grinding, or even by the use of solvents. Subsequently, downsizing of particles is used to facilitate its further handling and to generate uniform particles and release dissimilar materials. Then separation is achieved by difference of charge to facilitate their separation with the use of a rotating drum [14].

Chemical recycling process. The process of de-polymerization and conversion involves the application of heat to reach a temperature of 350 to 400 ° C. At this stage, the metals are removed. Subsequently, the polymer chains are broken into small units [14]. The process is described in figure 7.

Thermal recycling process. The purpose of thermal plastic recycling is for energy recovery only because most of them have high calorific value. In European countries, 70% of plastic generated by electronic waste is recycled by this means [14].

Metal Recycling

In 1998 nearly 29 000 tons of metal were recovered from electronic wastes in the United States: 4 500 tons of aluminum, 19 900 tons of steel, 4 600 tons of copper and 1 ton of precious metals [14].

Separation method. The magnetic separation is used to take apart ferrous components from non-ferrous ones, and is usually preceded by a crushing stage. Following this, Eddy current might be used to separate non-ferrous metals such as aluminum or copper from non-metallic materials by generating a magnetic field through a revolving magnet which repels the metals before mentioned, thus separating them [14].

Lead recovery. For the recovery of lead a reverberate oven is used to reduce metallic lead while other materials are oxidized within the slag. The purity of lead generated in these ovens ranges near 99.9%. The slag generated may contain between 60-70% lead [14]. The flow sheet for secondary lead recovery is shown in figure 8.

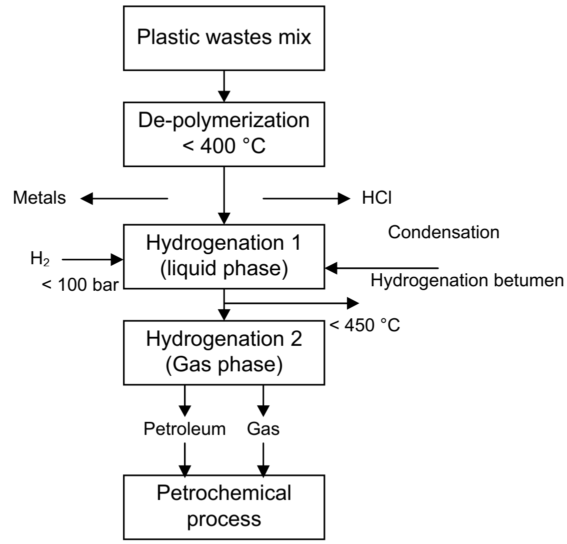

Fig. 7. Process diagram for depolimerization and converting of plastics. Source: Kang & Schoenung, 2005.

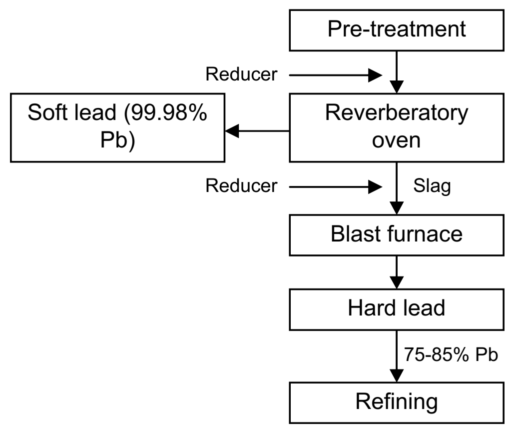

Fig. 8. Diagram of the recovery process for secondary lead. Source: Kang & Schoenung, 2005.

Copper recovery. Electronic wastes contain from 5 to 40% copper; this is fed into a furnace where it is reduced to generate copper metal. Plastics and iron are concentrated in the slag and elements such as tin, lead and zinc can be reduced in the form of vapor. Generated copper has a purity of 70-85%. Subsequently, the partial product is taken to a copper converter with excess oxygen to generate an oxidized form of copper with a purity of 95% and then, with a new foundry, an anodic copper with a 98.5% purity is obtained. Finally, it generates high purity copper through an electrolytic process [14]. It is important to note that some studies report that the energy required to produce copper from electronic wastes is six times lower than that required using copper ore [16].

Recovery of precious metals. It is possible to recover gold, silver, palladium and platinum from electronic wastes. For its processing, the residue of the of electrolytic copper process is used; this material is dried and melted in a precious metals furnace with the addition of additives to recover selenium as a first stage. The remaining materials, mainly silver, are forged in a silver anode and subsequently, with the use of electrolytic processes of high intensity, gold anodes and silver cathodes are obtained. Finally, through the leaching of gold anodes, high-purity gold, palladium and platinum are precipitated [14]. The description of the process is shown in figure 9.

Methodology

Development of a national inventory

National inventories of wastes generation are developed worldwide according to one of the following methods [3, 17]:

- Estimations based on official reports of generators (considerations: size of the universe, sample size, type of report, Pollutant Release and Transfer Registry (PRTR) vs Manifests, reporting time, etc.).
- Estimations based on reports of treatment companies.
- Estimations based on economic indicators and reports in relation to other countries (number of employees, same processes = same residues).
- Projections for the entire country based on reports zones or geographic areas.
- Calculations based on consumption (use) of products before disposal.
- Calculations based on the material balances in the country (production + import – export = waste accumulation or potential).

Since official reports showed discrepancies and many of them were not properly validated, a combination of the above methods was used to make a first approximation of a national inventory. The methodology consisted in the integration and analysis of information obtained from various sources:

1) Reports of imports and exports of electronic equipment from official data bases of the Ministry of Economy and reports of national manufacture from the Institute of Statistics, Geography and Informatics (INEGI).
2) Data on individual weight of each device, stratified, in some cases, different sizes from information resulting from field investigations.

With the above information, the amount of electronic products within the country was determined. A "lifetime average" was assigned to 5 electronic devices selected for this study, which is also considered as encompassing the fraction of electronic devices most commonly used. The average lifespan was allocated based on experience and supported in some usage data in other countries, even if there is only partial information from European countries whose usage patterns and consumption can not be applied directly due to the difference in economic conditions between them and Mexico. It was also meant as a first approximation a "scrap rate" of 50% annually for 5 electronic waste devices even if it could vary depending on the type of each one, whereas the other portion remains in use or is transferred to a second user and therefore this fraction will be unavailable as waste and will create an "environmental liability" growing with time [3].

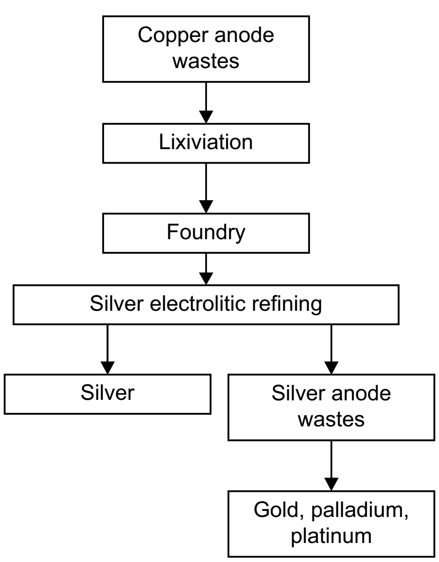

Fig. 9. Diagram of recovery of precious materials. Source: Kang & Schoenung, 2005.

Results and Discussion

Development of a national inventory

There is a growing concern regarding the management of electronic waste in Mexico, since the increase in the manufacture and use of electronic products has clearly surpassed the development of management schemes and infrastructure needed for a increasing amount of end of life wastes. During 2006, a national inventory on the electronic wastes generation in Mexico was estimated, based on official reports and secondary sources. The current generation and future potential generation of these wastes range from 180,000 to 250,000 tons for 2006, as well as the historic generation as shown in figure 10 [3].

Regarding the distribution of the national electronics industry, some of the most significant regions are: 1) El Salto, in the State of Jalisco, due to the strong presence of computer equipment and software manufacturers in the area called “The Mexican Silicon Valley”, 2) Other important areas for the generation and consumption of electronics are the metropolitan areas of Mexico City, Monterrey and Tijuana, where industrial activity and generation of end of life products is important [18-19].

The national inventory also identified the lack of formal infrastructure for handling e-wastes as well as proper management plans based on the principle of shared responsibil-

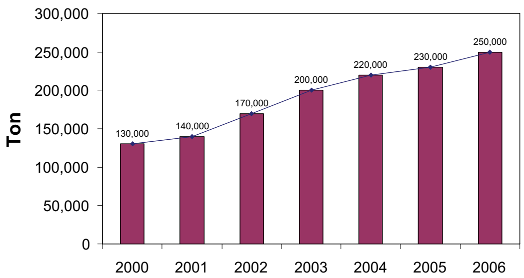

Fig. 10. Electronic wastes generation in Mexico (2000-2006). Source: INE, 2006.

ity among generators, distributors and customers. Estimations made to scale the size of recycling activities of obsolete electronic equipment in the Country have found that between 5 and 10% of the waste generated are potentially recycled regarding some of its components, mainly for computer equipment, cellular telephones and printing equipment. It is noteworthy that most of these companies are limited to disassembly of equipment, recovery of useful parts, grinding and separation materials. National recycling activities focuses in reprocessing of plastic, glass and copper, while the valuable material is sent abroad for the recovery of precious metals [20].

With regard to the existing legislation, it is considered that NOM-052-SEMARNAT-2005 establishes guidelines for proper waste management for the electronic sector since most of the waste generated possesses the properties of either corrosivity, reactivity, toxicity or flammability (CRIT). However, few efforts have been taken to analyze the economic value of electronic waste and its potential for recovery, which is necessary to promote self-management of these materials, as demonstrated in countries with conditions similar to ours, where through the initiation of public-private partnerships and other mechanisms, e-waste management has been incorporated into the existing formal channels through various mechanisms of policy [3, 13, 15, 21 and 22].

The Mexican General Law on the Prevention and Integral Management of Wastes (LGPGIR) defines electronic wastes as those from the computer industry, manufacturers of electronic products and automotive vehicles and others that might need a special management at the end of their life. However, it is necessary to develop a National Standard to establish requirements and responsibilities for developing special wastes management plans [5, 20].

To complement this, the delineation of responsibilities is necessary, regarding the handling of electronic waste by authorities of the three levels of government, business and society. But in order to produce schemes of shared differentiated responsibility, it is necessary to measure the national problem through the development of regional, detailed diagnostics and life cycle assessments. This will give decision makers a comprehensive view of the benefits and problems associated with the various options available for recycling of electronic waste, as well as their socio-economic implications.

Electronic wastes life-cycle assessment, based on material flow analysis, considers processes that have successfully been used in developing countries, particularly on the flow of materials related to consumption needs, economic structures and technological development. On the other hand, it might generate indicators for the system features (a.g. recycling rates), performance (a.g. efficiency in reducing resources), and impacts (a.g. available resources and capacity) [23].

Policy and economic recommendations

The development of policies for the sound management of electronic waste is being discussed by all countries in the world. Public attention has been focused on reducing disposal and increasing recycling rates. However, the benefits and problems that involve such measures have not been thoroughly evaluated [24-25].

Regarding the associated costs, there are two major schemes for electronic waste management: 1) the first is the *deposit-refund* scheme, which may have implications regarding the initial purchase and the disposal, recycling or storage when products reach the end of their useful life; 2) the second implies the use of widespread programs of return to manufacturers, which may have some complications such as transferring the costs to consumers; this model has been widely used in countries with a high per capita income [24].

It should be noted that for developing policies related to the handling of such waste, it is necessary to develop training programs, since many people are unaware of the problems related to the improper disposal of electronic waste [25], which translates into a sub dimensioning of the problem.

It is important to consider that the best results on electronic wastes management programs are those that enable the development of public-private partnerships [25]. It is also necessary to finish the environmental legislation framework to support the development of infrastructure for the recycling of electronic products at the end of their life, considering the recovery of high value items on a cost-effective way, and to control the entry of second-hand goods that may become an environmental problem in the short term.

Life cycle assessment (LCA) is a useful tool to understand this problem, by depicting the consumption of resources, environmental impacts and waste generation associated with the life cycle of products, processes and services, including: 1) Extraction and processing of raw materials and energy; 2) Manufacturing, transport and distribution; 3) Use, reuse and maintenance, 4) Recycling and disposal [13, 26]. The importance of the concept of Life Cycle lies in the estimation of an aggregate indicator (as a unit of environmental performance), based on various environmental problems and determined by their different variables (impacts) to compare the impacts related with the different options available for environmental management of electronic wastes in order to identify environmental priorities as a basis for improving environmental performance.

References

1. Widmer, R.; Oswald-Krapf, H.; Sinha-Khetriwal, D.; Schnellmann, M.; Boni, H. Global perspectives on e-waste. *Environmental Impact Assessment Review* **2005**, *25*, 436-458.
2. Puckett J. and Smith T. Exporting harm: the high-tech trashing of Asia. 2002. The Basel Action Network. Seattle/ Silicon Valley Toxics Coalition.
3. Instituto Nacional de Ecología. Diagnóstico sobre la Generación de Residuos Electrónicos en México. 2006. SEMARNAT.
4. Culver, J. **2005**. The life cycle of a CPU. http://www.cpushack.net/life-cycle-of-cpu.html.
5. SEMARNAT. **2003**. Ley General para la Prevención y Gestión Integral de los Residuos. Diario Oficial de la Federación. 8 de octubre de 2003.
6. Weiyue, Q.; Xinhui, B.; Guoying, S.; Shaoyou, L.; Jiamo, F.; Jing, Y.; Liping, L. Exposure to polybrominated diphenyl ethers among workers at an electronic waste dismantling region in Guangdong, China. *Environment International* **2007**, *33*, 1029-1034.
7. Wong, M.; Wu, S.; Deng, W.; Yu, X.; Luo, Q.; Leung, A.; Wong, C.; Luksemburg, W.; Wong, A. Export of toxic chemicals - A review of the case of uncontrolled electronic-waste recycling. *Environmental Pollution* **2007**, *149*, 131-140.
8. Yu, X.; Gao, Y.; Wu, S.; Zhang, H.; Cheung, K.; Wong, M. Distribution of polycyclic aromatic hydrocarbons in soils at Guiyu area of China, affected by recycling of electronic waste using primitive technologies. *Chemosphere* **2005**, *65*, 1500-1509.
9. Sinha, D. The management of electronic waste: a comparative study on India and Switzerland. **2005**. St. Gallen, University of St. Gallen. Master Thesis.
10. Zhang, S.; Forssberg, E.; Van Houwelingen, J.; Rem, P.; Wei, L. End-of-life electric and electronic equipment management towards the 21st century. *Waste Manage. Res.* **2000**, *18*, 73-85.
11. USGS Fact Sheet FS-060-01. Obsolete Computers, "Gold Mine," or High-Tech Trash? **2001**. Resource Recovery from Recycling. US Department of the interior.
12. UNEP. **1989**. Basel convention on the control of transboundary movements of hazardous wastes and their disposal, United Nations Environment Programme/Secretariat of the Basel Convention. http://www.basel.int/text/documents.html.
13. Barba-Gutiérrez, Y.; Adenso-Díaz, B.; Hopp, M. An analysis of some environmental consequences of European electrical and electronic waste regulation. *Resources, Conservation and Recycling* **2008**, *52*, 481-495.
14. Kang, H.; Schoenung, J. Electronic waste recycling: A review of U.S. infrastructure and technology options. *Resources, Conservation and Recycling* **2005**, *45* (4), 368-400.
15. C-Tech Innovation. An Integrated Approach to Electronic Waste (WEEE) Recycling. **2007**. DEFRA Waste and Resources Research Programme. United Kingdom.
16. Mark, F.; Lehner, T. Plastics recovery from waste electrical & electronics equipment in non-ferrous metal processes. **2001**. Association of Plastics Manufacturers in Europe (APME).
17. Kang, H.; Schoenung, J. Estimation of future outflows and infrastructure needed to recycle personal computer systems in California. *Journal of Hazardous Materials* **2006**, *B137*, 1165-1174.
18. Yarto-Ramírez, M.; Gavilán-García, A.; Castro-Díaz, J. Contaminación por basura electrónica en México. **2006**. Calidad Ambiental, Febrero.
19. CANIETI. Instrumentación del Programa de Competitividad de la Industria Electrónica. **2004**. FOA Consultores.
20. Instituto Nacional de Ecología. Memorias de la 1er reunión de trabajo del proyecto "Programa modelo de plan de manejo para los residuos electrónicos en México". **2007.** Hotel Gran Meliá. SEMARNAT.
21. NOM-052-SEMARNAT-2005, que establece las características de los residuos peligrosos, el listado de los mismos y los límites que hacen a un residuo peligroso por su toxicidad al ambiente. SEMARNAT.
22. Biddle D. End-of-Life Computer and Electronics Recovery Policy Options for the Mid-Atlantic States. **2000.** 2nd Edition. Mid-Atlantic Consortium of Recycling and Economic. United States.
23. Streicher-Porte, M.; Widmer, R.; Jain, A.; Bader, H.; Scheidegger, R.; Kytzia, S. Key drivers of the e-waste recycling system: Assessing and modelling e-waste processing in the informal sector in Delhi. *Environmental Impact Assessment Review* **2005**, *25*, 472-491.
24. Macauley, M.; Palmer, K.; Shih, J. Dealing with electronic waste: modeling the costs and environmental benefits of computer monitor disposal. *Journal of Environmental Management* **2003**, *68*, 13-22.
25. Nixon, H.; Saphores, J. Financing electronic waste recycling Californian households' willingness to pay advanced recycling fees. *Journal of Environmental Management* **2007**, *84*, 547-559.
26. Suppen & van Hoof. Conceptos básicos del Análisis de Ciclo de Vida y su aplicación en el Ecodiseño. **2005**. Centro de Análisis de Ciclo de Vida y Diseño Sustentable.