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The Challenge of Hazardous Waste Management in a Sustainable Environment: Insights from Electronic Recovery Laws

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ABSTRACT
New and pending regulations requiring product take-back by manufacturers at the time of disposal are intended to create a new era of industrial ecology and environmental sustainability. However, the intended benefits of the current legislation can be confounded by obsolescence in product design based upon advances in science and technology and also by the introduction of more environmentally benign product designs. Recent changes in legislation are identified and, based upon an extensive industry survey, their resultant likely impacts on consumer electronics are considered. This industry study illustrates that unless the impacted products simultaneously possess both stable designs and input requirements then significant secondary environmental issues related to the waste storage will be encountered. Inherently, these issues cause serious societal problems when hazardous substances are involved – which is the case with many products from the electronics industry. Copyright © 2005 John Wiley & Sons, Ltd and ERP Environment.

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Introduction

THE ESCALATING ENVIRONMENTAL FOCI OF THE PAST 20 YEARS HAVE DIRECTED CONSIDERABLE attention toward the disparate issues arising from the disposal of durable consumer goods. The resultant pressures from both governments and environmental groups have forced manufacturers to reduce, recycle and reuse their industrial waste products, thereby forcing a subsequent pro-

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gression toward both closed-loop production systems and an industrial ecology focus within their practices. The enaction of several pieces of legislation has required companies to 'take back' their discarded products (Rose *et al.*, 1998) and has banned outright the landfilling and incineration of numerous products containing certain hazardous materials. Several jurisdictions have also established requirements that minimum proportions of reclaimed and reprocessed waste must be specifically used as raw material input in the manufacture of new products. These environmental concerns have been clearly exemplified by numerous recent take-back and recovery regulations for the electronics industry in Europe, Asia and North America (CA, 2003; EPA, 1998; EU, 2003; Federal Register, 2002; MN, 2003; Shih, 2001). The electronics sector has been designated as the first target for such legislation since purchases and disposal of electronic products are increasing significantly on a global scale; electronic products generally contain several hazardous substances; electronic products become obsolete prior to their natural operating life; electronic products are difficult to bulk recycle or incinerate and electronic products have a high value relative to the value of the composition of their constituent materials at the time of sale.

National Regulation Affecting Disposal of Electronics

Disposed electronic products can cause health concerns because they contain a wide spectrum of hazardous materials, ranging from lead, phosphorus, cadmium, chromium and barium to mercury. The list of human health risks resulting from improper contact with these materials includes breathing difficulties, coughing, choking, respiratory irritation, pneumonitis, tremors, neuropsychiatric problems, convulsions, comas and even death. Hence, health risks associated with improperly managing and disposing of these toxic substances are significant, if not deadly (Linton, 1999), and the legislated prevention of their disposal seems to establish logical environmental policy. However, electronic products, in general, are affected not only by the variety of new and pending regulations, but also by their rapid technological obsolescence. Consequently, the European Union (EU) has recently approved an electronic recovery directive applicable to all EU member states, requiring the recovery of a significant proportion of electronic products (EU, 2003). These EU regulations will be phased in progressively by requiring that a certain per capita quantity of electronic products be recovered by specified deadlines (EU, 2003). For hazardous components, recovery targets as high as 80% by weight have been established. The EU states an intent to incorporate sustainability (WCED, 1987) into society through environmental regulation. Recovery targets for different electronic products range from 50 to 80% by weight. This recovery will divert waste away from landfills and incineration into reuse, remanufacture and recycling. Due to a lag time between the introduction of a European Directive and the development of associated implementing regulation by member states, the gradual phase-in of recovery targets, and the short lifespan of many electronic products, the anticipated effect of the regulation is to promote *design-for-environment* methodologies for new electronics products. Firms will most probably pursue design-for-environment strategies to reduce the burdens associated with regulation compliance.

Likewise, both Taiwan and Japan have enforced active take-back regulations (Shih, 2001). For example, Taiwanese retail stores must take back an old electronic product whenever a new product is purchased. In fact, Taiwan has required the take-back of computers since 1998 and Japan has required the take-back of appliances and televisions since 2001.

As the responsibility for the disposal of spent products increasingly shifts back to the manufacturers, companies have been forced to incorporate these take-back requirements into their strategic planning processes and product design strategies (Rose *et al.*, 1998; Blue *et al.*, 1999; Ferrer and Ayres, 2000). The paramount objective in the practice of industrial ecology and sustainable manufacturing is to create an industrial ecosystem in which all discarded, returned or otherwise spent products become the raw material inputs for new products. In an idyllic closed-loop industrial ecosystem, the raw material input requirements of the manufacturing processes are exactly balanced by the waste supplied from the discarded products. The motivation behind reusing 'post-consumer' waste as an input for new production is environmentally and ecologically pure, and the initiative for undertaking an industrial ecology approach represents sound policy. However, the enforced introduction of these well intentioned industrial ecology practices can subsequently create very negative, unintended environmental consequences, particularly for electronic products.

CRT Disposal

Numerous non-electronic products such as vehicle tires represent ideal candidates for enforced product take-back schemes, since their stable, predictable and relatively benign waste streams are readily conducive to managed industrial ecosystems. Conversely, many electronic products are not suitable for end-of-life industrial eco-system practices, since they contain materials that engender considerable public health concerns, are in the declining-market stage of their lifecycles and are considerably threatened by technological obsolescence. The waste recovery from televisions illustrates a prime example of the negative attributes arising from the new electronic anti-dumping and take-back regulations, with the cathode ray tube (CRT) encapsulating many of the challenges posed in establishing such industrial eco-systems. CRTs provide the viewing portion of most existing television monitors and contain significant quantities of identified hazardous materials – primarily lead. The disposal of CRTs has become controlled within the United States (EPA, 1998; DEP, 1998, 2002), Asia (Linton, 1999) and the European Union (EU, 2003) through the passage of extremely stringent legislation.

To better understand the challenges facing electronic take-back legislation, the waste streams from CRTs have recently undergone considerable scrutiny (Halluite, unpublished master thesis; Linton *et al.*, 2002; Linton and Yeomans, 2003). In Europe and Asia, the legislation governing the end-of-life disposition of television CRTs is integrated with legislation on electronics take-back. However, in the United States legislation governing disposal of CRTs has been initiated at a local or state level, partially in response to changes at the federal level (Federal Register, 2002). These local efforts are driven by concerns regarding the volume of waste involved and the possibility of lead leaching out of the CRT glass contaminating both soil and ground water. The leading jurisdictions to ban CRTs from landfills are California (CA, 2003), Florida (DEP, 2002), Massachusetts (DEP, 1998) and Minnesota (MN, 2003).

However, the complexity of this disposal issue has been compounded further with the impending technological obsolescence of CRTs through replacement by flat-panel displays and by the FCC-mandated switch from analog to digital broadcasting. In spite of the possible technological obsolescence issues, the research has indicated that, under all future scenarios, the trajectory of leaded waste disposal from existing televisions will continue to flow into the waste stream in significant quantities over the course of several decades (up to 50 years), *even if all CRT-based production ceased immediately* (Linton *et al.*, 2002; Linton and Yeomans, 2003).

The apparently beneficial net effect of these findings, therefore, is that significant quantities of lead will be continuously entering the waste stream over a protracted period of time in a form that is ideal for post-consumer remanufacturing applications. Thus, the legislation banning CRT disposal together with mandated remanufacturing requirements should lead to numerous potentially attractive business ventures for reprocessing and recycling the high lead content found in this CRT waste (Linton *et al.*, 2002; Linton and Yeomans, 2003). Unfortunately, an extensive industrial study of manufacturing practices in the United States (Halluite, unpublished master thesis) has discovered that, over the past decade, companies have discreetly moved away from the use of lead as a production input. As a result, the current demand for leaded input in any newly manufactured product is essentially zero (Halluite, unpublished master thesis).

Hence, by eliminating the legal means for CRT disposal, concurrent with the limited and declining applications for lead reprocessing, any enforced introduction of industrial ecology practices in the electronics sector will result in large hazardous waste storage issues that could be considered akin to the experiences surrounding the permanent nuclear waste storage facility proposed for Yucca Mountain, the 'mobile storage' fiasco experienced by the Khian Sea barge (which traveled the world's ports in search of a location that would actually be willing to accept its waste) or the 'temporary' automobile tire waste storage facility located in Hagersville, Ontario (the site of a major environmental disaster when the stored tires ignited). Inhaber (1998) has stated that the only waste more difficult to dispose of than leaded waste is nuclear waste, so the byproduct storage challenges of radioactive waste already experienced by the nuclear industry could soon be similarly applied to the electronics sector.

Consequently, the best of environmental and ecological intentions established by regulations for the remanufacturing and reprocessing of electronic consumer goods becomes egregiously misplaced when all of the targeted practitioners of the industrial ecology directives have absolutely no propensity to engage in the re-use of the resultant waste materials.

Industrial Ecology Policies Highlighted by the CRT Disposal Example

The overarching environmental goal for industrial ecology policy is to reduce the negative impacts posed by the hazardous materials contained in the existing electronic products. Take-back regulations provide one appropriate solution, since they effectively prevent the incineration and landfilling of undesirable materials at the product's end of life. The intent in banning television CRTs from landfills and the requirement for CRT take-back in both Taiwan (Shih, 2001) and the EU (2003) is to prevent the lead from contaminating the soil and water surrounding landfill sites. However, in addition to the well publicized phase-out of lead from paint, automotive fuel and plumbing solder, there has been a continuing decline of lead in most of its other traditional applications, such as in ceramic glazes, material additives, solder for electronic products and commercial window glass. Hence, practices of benign manufacturing, sustainability and future-liability avoidance have resulted in a simultaneous elimination of hazardous materials from being used as inputs in the design of new products (Halluite, unpublished master thesis).

In the largest existing markets for lead, such as automotive batteries, recycling programs already recover substantial quantities of lead. Consequently, much of the lead currently in use (about 1.1 million tonnes) has already been reclaimed from secondary sources and the lead from primary sources has declined from 337 000 tons to 276 000 tons as it continues to be phased out of other applications (Halluite, unpublished master thesis). The banning of television CRT disposal would immediately inject a large new source of secondary lead into the 'marketplace'. This new secondary source would reduce the demand for lead from primary sources. Assuming that television CRTs are replaced in the near future as predicted by the Electronics Industry Association, the waste stream for leaded CRT glass under the scenario of an almost immediate cessation of CRT production (Linton *et al.*, 2002; Linton and Yeomans, 2003) is shown in Figure 1. Given the current rates of decline in industrial lead demand, the lead provided by these CRTs would far outstrip the demand for primary lead sometime between 2012 and 2013 (Halluite, unpublished master thesis; Linton *et al.*, 2002; Linton and Yeomans, 2003), leading to a supersaturation of the lead market. At this point in time, either new applications or storage locations for lead would be required.

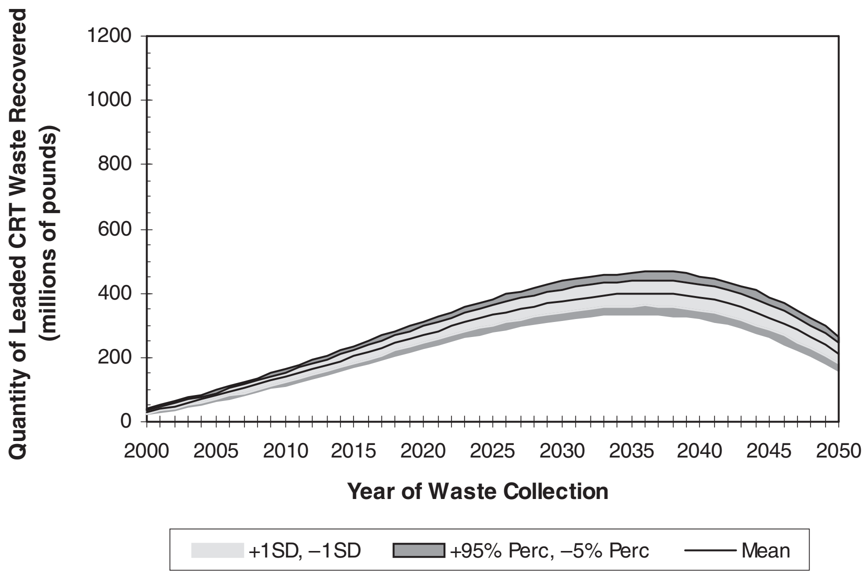

Figure 1. The quantity of lead CRT waste that would be recovered assuming diversion of televisions from municipal landfills and the rapid replacement of CRT-based technology by flat panel displays.

Alternatively, if CRT-based televisions actually remain in production and are sold at or above their current volumes over the next several decades, then the lead reclaimed from disposed televisions could be used in the manufacture of these new televisions. This reprocessing would somewhat ease the challenges created by banning the landfilling of CRTs.

Clearly, societal concerns regarding toxic materials and the subsequent trade-offs associated with their post-use disposition have to be addressed ahead of time, so that suitable decisions can be made and any supporting infrastructure can be sufficiently developed. Due to the widely encompassing nature of the EU legislative directives, the most significant challenges arising from CRT recovery will probably occur in Europe. In Germany the possibility of integrating leaded glass from CRTs into roadfill has been considered. While the use of leaded waste within such solutions would undoubtedly elevate several levels of environmental concern, the Yucca Mountain, Khian Sea and Hagersville disasters have clearly provided ample evidence of the environmental consequences that have arisen from situations in which insufficient forethought has been applied to the post-use disposition issue. Hence, the most pressing requirement surrounding CRT recovery must be the need to find acceptable alternative uses for the leaded glass wastes.

Consequently, what is readily evident for televisions, in particular, and for the electronics industry, in general, is that any changes in product composition, design or technological base will create significant problems for the well intentioned environmental policies that have been legislated. Under such circumstances, the regulations that are intended to encourage sustainability and industrial ecology will instead introduce unintended, but significant, secondary environmental consequences.

Conclusion

Environmental policies promoting sustainability and industrial ecology offer advantages in stable industrial settings, but such policies can be rapidly destabilized by shifts in science and technology. This observation highlights an important policy deviation from the environmental approaches of the past that looked to science and technology to assist in monitoring, detection, containment, remediation, end-of-pipe solutions, improving efficiency and reduction in toxic emissions. Regulations throughout the world that have banned the landfilling and incineration of electronic products are well intentioned, since their goal is to remove a major source of hazardous waste from entering the eco-system. However, the noble foundations of remanufacturing, reverse logistics and industrial ecology have all been based upon the premise that the resulting wastes can be economically directed into alternative products and this should be strived for (and enforced) wherever possible. Although such laws are all ecologically well intentioned, they become doomed to create alternative environmental problems when no market or outlet exists for the specific waste product. The regulatory paradox that must be resolved is that legislation requiring product take-back and reprocessing focuses on products and materials that are seen as undesirable components of landfills, but these products consequently all contain undesirable components that must somehow be used for raw materials input in some alternative product, and the manufacturing demand for such reclaimed noxious materials has already rapidly dissipated within much of the electronics industry. This incongruence results in the new environmental problem of finding a place to indefinitely store the unwanted, hazardous material similar to that experienced in the Yucca Mountain and Khian Sea storage dilemmas. While the electronics industry has been the first to encounter such reprocessing legislation on a global scale, similar consequences should also be expected to regulations directed toward other durable good manufacturing sectors. Therefore, it remains a significant open question as to how these secondary environmental consequences to the seemingly beneficial legislation can be successfully resolved.

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