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Compact Discard: Finding Environmentally Responsible Ways to Manage Discarded Household CDs and DVDs

Alan W. Biehn
University of Pennsylvania

Presented to the Faculties of the University of Pennsylvania in Partial Fulfillment of the Requirements for the Degree of Master of Environmental Studies 2008.

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Abstract

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This study examines the possibilities for responsible environmental management of the growing waste stream of optical discs from households around the world. It reviews options for reducing materials used in disc manufacture, models for collection and processing of waste discs, and the differing policies and practices of various countries with respect to e-waste in general and optical discs in particular.

The study concludes that environmentally responsible management of optical discs is lacking in all nations, and that optimal implementation of best practices will require the cooperation of governments, corporations, and consumers. It recommends implementation of curbside pickup and corporate mail-in programs for unwanted discs. It also concludes that effective policy-making and process design will require more and better quantitative data about the efficacy of various regulatory models and responsibility structures, and about the environmental impacts of various waste processing and recycling methods.

Disciplines

Environmental Sciences | Physical Sciences and Mathematics

Comments

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COMPACT DISCARD

Finding Environmentally Responsible Ways to Manage Discarded Household CDs and DVDs

Alan W. Biehn

Master of Environmental Studies

University of Pennsylvania

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Stan Laskowski, Advisor

ABSTRACT

More than 200 billion optical discs have been manufactured and distributed worldwide. As electronic storage media evolve, these discs are becoming obsolete. Most unwanted household discs end up in landfills or incinerators. Recycling options for waste discs exist, but public awareness and participation are low.

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Contents

INTRODUCTION

Why This Study?

The motivation for this study springs from the proliferation of optical discs (CDs, DVDs, CD-Rs, software discs, etc.) in the author's home, workplace, and daily life. Herein, the various types of optical discs are collectively referred to as "discs" except where specificity is required. After buying his first CD player in 1987, the author purchased hundreds of pre-recorded CD albums. Single-use recordable CDs eclipsed reusable cassette tapes as a means for sharing music in recent years, and his work as a musician led to an additional accumulation of CD-Rs that contained only one or two songs each. The resulting mass of plastic seemed wasteful and unwieldy.

Still, why focus solely on household waste discs? Other forms of electronic waste ("e-waste") such as computer monitors contain large volumes of lead, cadmium, and other materials that are far more toxic than those found in optical discs, more toxic even than the by-products of optical disc incineration. And why address the waste discs that trickle into household garbage cans rather than the large quantities of waste discs regularly discarded *en masse* by manufacturers and retailers? Why not seek solutions that address the plastic "jewel cases" that house the discs, which (unlike the discs themselves) contain polyvinyl chloride (PVC), a troublesome plastic with toxic components (Chemical Heritage Foundation, n.d.) that contribute to the formation of dioxin and PCBs in incinerators? (Katami, Yasuhara, Okuda, & Shibamoto, 2002)

The reasons are as follows: First, there seems to be a dearth of attention and published information on the subject. The severe global health and environmental problems posed by increasing (non-disc) e-waste streams, on the other hand, are well-publicized, and related research and policy activity is already widespread. The high volumes of waste discs created by corporations are already being handled by recycling firms seeking economy of scale and by producers acting to guard their intellectual property. As for the plastic jewel cases, they are bulkier than discs, and they have easily breakable moving parts, so they are less amenable to reuse and compact shipping.

The light, flat, round, uniformly sized, durable, flexible, and reflective optical discs, on the other hand, appear to be well-suited for practical reuse options. These same qualities also make the discs easy to collect and ship to processing facilities. So why do most discarded household discs end up in landfills and incinerators? (Kaplan, 2002) It is estimated that 60% of the world's 200 billion discs (Koninklijke Philips Electronics N.V., 2007)—collectively weighing about 2.6 million tons, assuming 120 billion units at 20 grams each (Zevenhoven & Saeed, 2003, p. 2)—are distributed among private users (Fujita et al., 2007, p. S13), and that about 30 million discs per month are thrown away, with only a very small portion getting recycled (Kaplan, 2002). This contributes to the larger problem of plastic waste. According to the U.S. Environmental Protection Agency (USEPA), "the amount of plastic in municipal solid waste has increased from less than 1 percent of the total in 1960 to about 12 percent in 2006." (Consumers Union, 2008) In roughly the same years, annual global consumption of plastic materials increased from around 5.5 million tons to more than 100 million tons (Waste Watch, 2008, p. 3).

I have undertaken this study because it seems that, with relative ease, we ought to be able to find feasible ways to collect these discs when they are discarded and manage them in an environmentally responsible manner, thereby significantly reducing landfill volume, emissions from incineration, and environmental damage worldwide.

Purpose of Study

This study seeks to identify options for minimizing disc waste and best practices for maximizing recovery of discarded discs while it notes areas where further research is required to guide stakeholders in designing optimal end-of-life management processes. It is also intended to raise public awareness of the growing waste stream of discarded household discs so that we can learn to address the issue effectively before the volume peaks. The study works toward these goals by exploring contextual information and by comparing existing systems for managing plastic waste, e-waste, and optical discs. Analysis of these comparisons provides the basis for a set of recommendations, which are presented at the end of the study. It is hoped that these recommendations will act as catalysts, sparking activity that ultimately leads to better environmental management of optical discs worldwide.

Focus Areas of Study

The study begins with an overview of the history, evolution, and composition of optical discs, and continues with a discussion of the qualities and uses of polycarbonate plastic, their primary ingredient. The mechanical and optical properties of discs are then explored in a series of experiments that were carried out specifically for this project. The author hopes that this information will form a “disc profile” that inspires ideas for practical reuse applications.

In seeking the best options for managing the waste stream of optical discs, the study mainly analyzes three areas, comparing:

- Options for source reduction and pollution prevention, including improved disc design and manufacturing processes, and alternatives to disc use.
- Various disc collection models, seeking those that offer maximum volume with minimal environmental impact.
- Legislative models and waste management practices, which differ widely among countries around the world.

The study does not overlook the crucial end-of-life stage. It briefly discusses reuse options and compares disc recycling processes, identifying a need for information that will help stakeholders identify environmentally preferable solutions. The chemical and technical complexities of recycling and disposal practices preclude thorough analysis in this document. Whenever possible, the study uses quantitative data and life cycle analysis to inform the identification of best practices.

Contextual Information: E-Waste, Plastic Recycling, and Ownership

Before beginning the analysis, it is worthwhile to briefly review the context in which the waste stream of household discs is emerging. Examining broader issues related to e-waste, plastic recycling, and ownership of optical discs (and/or the data stored on them) will help the reader to better understand the challenges of managing discarded household discs.

Optical discs occupy a category that lies somewhere between e-waste and common plastic wastes like soft drink bottles and product packaging. On the one hand, disc use is inextricably linked with complex electronic devices that clearly constitute e-waste, like computers and DVD players, and unlike simple plastics, the discs contain small amounts of metal—usually aluminum, sometimes silver or gold—but none of the toxic lead, mercury, or cadmium that drive the major global concerns about e-waste. On the other hand, like many widely recycled plastic products, the discs are composed almost exclusively of one recyclable polymer and have no moving parts.

Most published materials categorize discs as e-waste, yet some important international laws do not, and many e-waste collection programs do not accept them. Therefore, this study examines both e-waste and plastic collection methods to see which is better suited to maximizing participation and ensuring responsible processing. It may be significant to note that while the demand for electronic devices shows no sign of slowing, the optical disc waste stream is likely to peak and decrease in the future as discs move toward obsolescence.

A survey on disc ownership that I undertook to support this research seems to corroborate the published evidence that discs are becoming obsolete. I asked 106 individuals in about 60 American households (mainly in Pennsylvania) how many discs they owned, and the average individual owned more than 200 discs. As shown below in Figure 1, average ownership varied drastically by age group. With an average of 416 discs per person, the 41- to 50-year-old participants owned roughly 25% more discs than those aged 31 to 40, and nearly twice as many as the average 21-to 30-year-old participant.

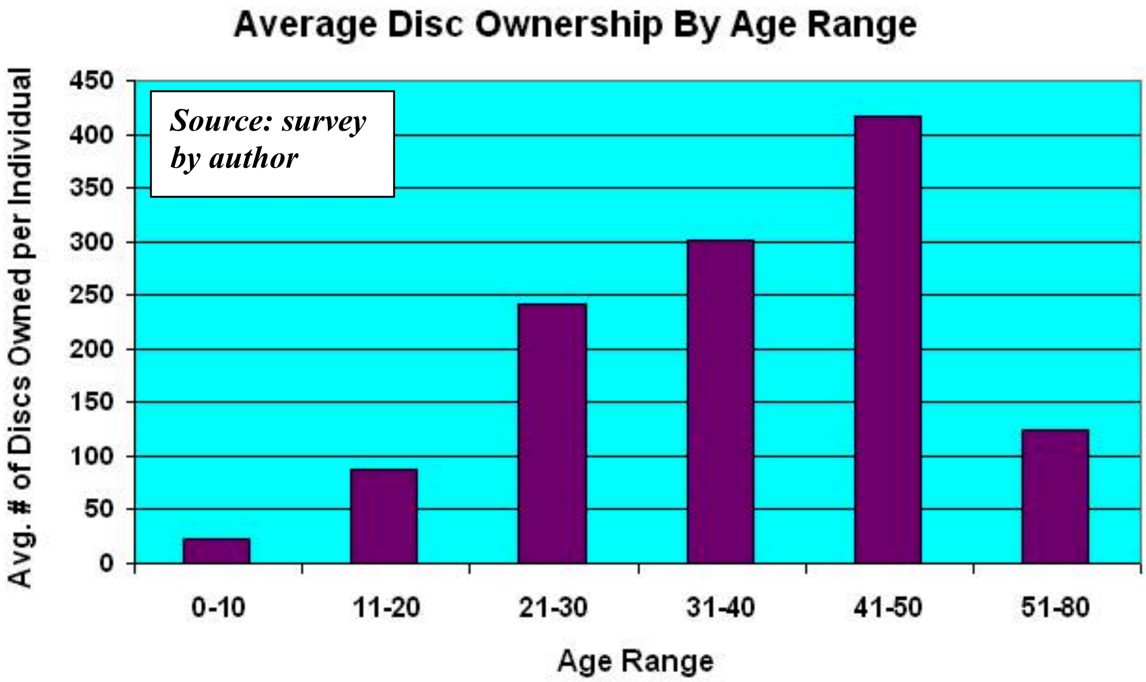


Figure 1: Graph of average disc ownership for various age groups.

One reasonable interpretation of this chart is that people over age 50 store the majority of their music and movies on formats that existed before optical discs, that those aged 31 to 50 favor optical disc storage, and that people below age 30 store theirs on newer media. The survey data may have been skewed by the following factors: the thirty participants aged 18 to 21 were all African-American university students in a science course at Cheyney University, there were only six respondees aged between 51 and 80 (which is why this group was not divided by decade), and the majority of the participants were middle-class Caucasians living on the Eastern seaboard of the United States. While the chart's simple display of ownership is not conclusive, its interpretation is supported by plastic recyclers and industry reports that cite new storage media as a cause for the declining optical disc market.

To close the topic of ownership and end the introduction to this study, let us examine the differences between household disc ownership and corporate disc ownership. One fundamental difference is that while a small portion of household discs contain sensitive personal information like Social Security numbers, passwords, and account numbers, nearly all software and entertainment discs that are produced for sale contain intellectual property that the corporate owner is willing to pay to protect, according to David Beschen, president of GreenDisk (telephone interview, October 17, 2008). This concern for intellectual property is demonstrated in the FBI piracy warning message that appears at the beginning of many DVD movies.

Entertainment discs are often housed by retailers or rental firms like Blockbuster. When a new movie or video game is released on disc, many rental firms guarantee immediate availability to consumers. This practice requires massive overproduction of discs and results in huge surpluses when demand falls (McClain, 2008, p. 11). The lightly used surplus discs are then offered for sale at prices that decrease over time. Similarly, software companies produce more discs than they expect to sell, and retailers attempt to clear out remaining inventory before updated versions arrive. In both cases, large quantities of discs usually remain unsold in the end.

Beschen says that the willingness of corporations to pay for destruction of their unsold intellectual property and recycling of waste discs, driven by artists' rights and corporate interest in the public relations value of environmental responsibility (among other things), has created a market for recyclers who can certify disc data destruction (telephone interview, October 17, 2008). In addition, it is estimated that 10% of discs are rejected in the manufacturing process (Zevenhoven & Saeed, 2003, p. 2), creating large aggregate volumes of waste discs that can be efficiently shipped and profitably processed.

Household discs, on the other hand, are not concentrated in stores or warehouses. They are dispersed among hundreds of millions of consumers, each of whom will discard perhaps a few hundred discs over a lifetime. These individuals are generally not willing to pay for certification of data destruction, and few of them have a financial interest in the public's opinion of their environmental practices. Therefore, improving the management of discarded household discs (and possibly integrating them into the corporate disc processing systems) involves challenges of funding, collection, and public participation.

OPTICAL DISC BASICS

History, Evolution, and Pending Obsolescence

In 1970, the company known as Philips began working on an audio disc system using laser technology. In 1977, as the project progressed, the corporation chose the name "Compact Disc" for the new product, intending to capitalize on the past success of the Compact Cassette. In 1979, Philips teamed with Sony to complete the project, and in 1980 the two published the "Red Book" which codified all the standards for compact discs (BBC News, 2007).

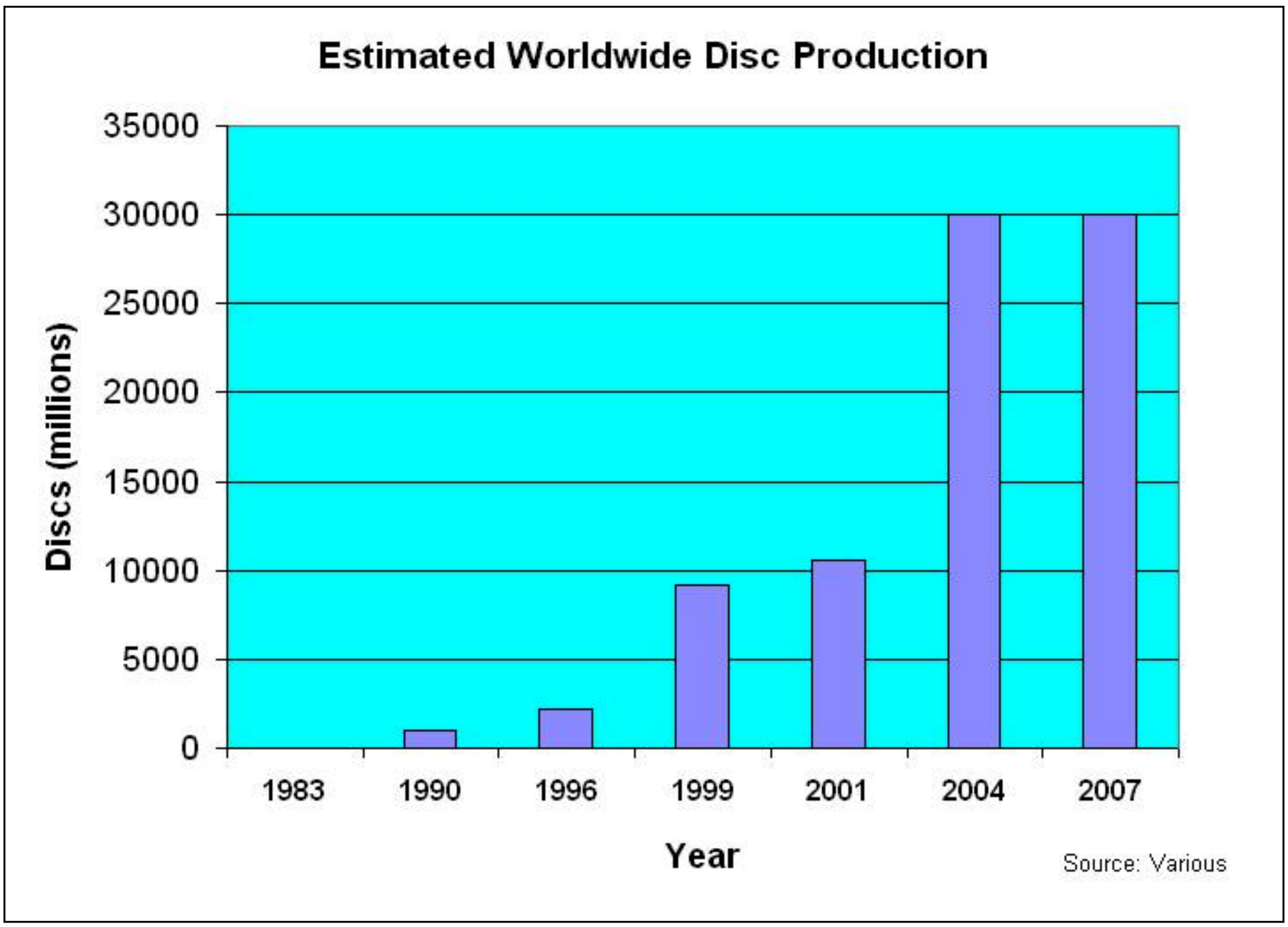


Fig. 2: Collected estimates of worldwide optical disc production in various years (includes, CD, CD-R, CD-RW, DVD, etc.)

As shown in Figure 2 above, annual disc production grew from less than 1 million in 1983 to more than 30 billion in 2004 (Compact Disc, 2008). CD album sales grew quickly, surpassing cassette album sales by 1992 (Perlich, 2008). Optical discs also opened new markets for distributing movies and storing photographs, and the disc itself evolved as demand arose for increased storage capacity. Where CDs were able to hold 74 minutes of music with about 650 megabytes (MB) of storage, and standard recordable CDs offer 700 MB, the race to offer movies and video games on disc resulted in the release of 4.7-MB DVDs in 1996 (Chapin, 1999). The development of dual layer recording technology increased DVD storage capacity to 17 MB, and in 2006, the 25-50 MB Blu-Ray format permitted the distribution of high-definition video on disc (Blu-ray Disc Association, n.d.).

Despite these advances, the optical disc is on the path to obsolescence. A representative of Custom Polymers, Inc., one of several plastic recycling firms interviewed for this study, asserted that DVDs and video game discs were the only products keeping the disc manufacturing industry alive (telephone interview, October 27, 2008). Other interviewees also predicted a waning market for optical discs.

Industry activity appears to support this view. Figure 2 shows that total annual disc production grew consistently from 1983 to 2004; since then it has remained steady at about 30 billion units. Global sales of CD albums peaked in 2000 at 2.455 billion units, dropping to 1.755 billion by 2006 (BBC News, 2007). After mailing out an estimated 1 billion free discs (and creating a backlash of frustration from unwilling recipients) America Online stopped the mass mailing of its software discs in 2006 (AOLcollecting.com, n.d.). E-waste recycler GreenDisk of Issaquah, Washington claims to have handled 60 million AOL discs in one year (McClain, 2008, p.11). The Digital Entertainment group reports that in 2007, consumers spent 3% less on DVDs than they had in 2006, the first annual decline since the DVD format was introduced in 1997 (Snider, 2008).

Increasing numbers of consumers now obtain music and movies by downloading files from internet websites like iTunes and Blockbuster Online. They store music and video files on their home computers or on portable entertainment devices like the Apple® iPod. Many people are copying their CD collections to computer hard drives that can hold up to 1,000 GB of information, or to their pocket-sized iPods, each of which can hold thousands of songs, and selling or discarding their CDs. And while discs have only competed with photographic prints for a few years, consumers are rapidly embracing the free online photo storage and sharing offered by websites like Facebook and Flickr. In October 2008, Facebook announced that it hosted some 10 billion photos.

In addition, much computer software is available by download, and leading email providers now offer free and unlimited online storage. These trends suggest that consumers will require fewer and fewer data storage units in their homes. A corresponding reduction in disc manufacturing, packaging, and shipping is likely to create a net environmental benefit. (The impacts of disc use and alternative data storage methods will be compared later in this document.) But we must still consider what will become of the more than 200 billion discs that have already been manufactured (Koninklijke Philips Electronics N.V., 2007).

Disc Dimensions, Component Materials, and Polycarbonate Applications

Each optical disc weighs about 20 grams and is about 1.2 millimeters thick, with a diameter of 120 millimeters and a center hole of 15 millimeters (Durrah, 2006, p. 6). Two layers of polycarbonate (PC) plastic comprise the vast majority of its mass. Its reflective layer, sandwiched between the two PC layers, is made of aluminum, silver, or gold, and the disc is covered with a coat of lacquer to prevent scratching.

Virgin PC is used to make discs because of its optical clarity, which is crucial to disc operation. David Beschen, president of Greendisk, describes PC as "strong as well as scratch- and break-resistant." He says that these properties hold up well through multiple iterations of recycling, making recycled PC a valuable and renewable addition to many resins (telephone interview, October 17, 2008). The optical clarity of virgin PC, however, is lost in the recycling process, so recycled discs cannot be made into new discs. It is possible, however, to separate and *reuse* the original PC layers from unsold, unused discs without *recycling* those layers first.

Its strength, rigidity, and resistance to scratching and breaking make PC quite suitable for many applications. Beschen says there is a sizable market for recycled PC among manufacturers of appliances, automotive parts, toys, and building materials (telephone interview, October 17, 2008). Virgin PC is used for a variety of medical applications that exploit its toughness, optical clarity, and compatibility with all major methods of sterilization, but according to Bruce Bennett, founder of The CD Recycling Center of America, the Food and Drug Administration does not currently permit the use of recycled PC in medical devices (telephone interview, October 15, 2008).

Mechanical Properties

Flexibility

Discs are quite flexible, and some can be bent nearly in half without breaking. In the experiments that I arranged for this study, participants essentially attempted to fold discs in half with gloved hands, as shown in Figure 3 below. Adhesive labels seemed to play a role in preventing breakage. Discs with such labels bent further without breaking and immediately sprang back to near flatness. When they broke, they tended to break into halves along the line of maximum curvature. The extreme flexibility of labeled discs could prove beneficial in any number of reuse applications. Discs without adhesive labels broke more easily and tended to shatter into more random shapes.

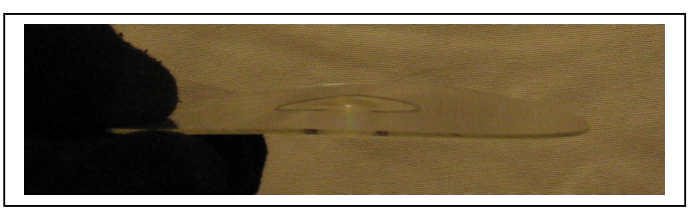
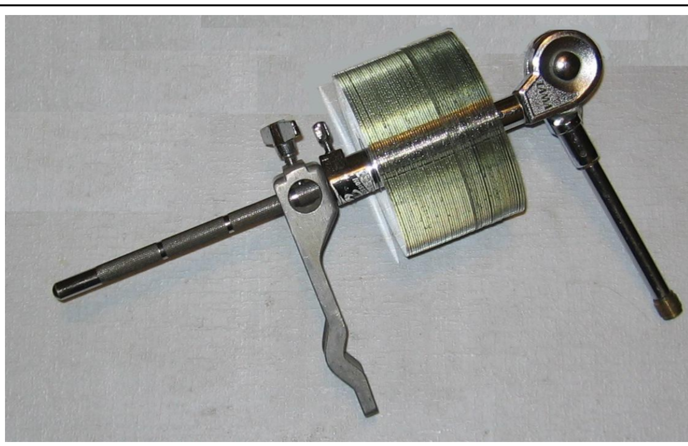


Figure 3. A disc with a label on the unseen side (at left) bent nearly in half without breaking, and sprang back to near flatness.

The unlabeled disc above broke into several irregularly-shaped pieces.
(Photos by author)

Load Support

Standing on edge and clamped closely together on an axle, groups of discs can be used as wheels or rollers, and are capable of bearing significant weight. In another experiment performed for this study, a stack of 20 discs (about an inch wide) were placed on an axle about one-half inch in diameter and one foot long. The 180-lb. weight of the author standing on the axle caused the discs to bend significantly, and several of them broke after rolling just a few inches on a smooth floor. But a stack of 50 discs (shown in Figure 4 on the axle) supported me easily as I rolled a distance of several feet on a gritty sidewalk. None of the discs cracked or broke in the process, nor did the disc edges show significant wear. The durability, load capacity and wheel-like shape of optical discs suggest a potential reuse option in conveyor devices like the one shown below in Figure 5.



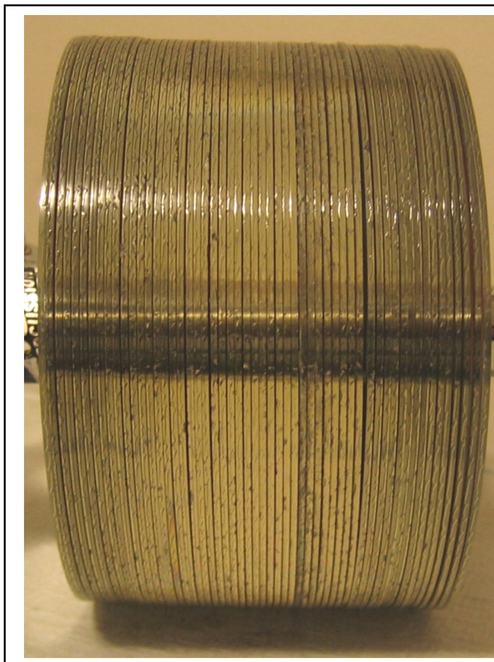


Figure 4. Above, 50 discs on an axle with perpendicular bars approximately 6 inches apart on which a person stood. At right, disc edge wear after bearing the 180-lb. person several feet over a pebbly sidewalk. (Photos by author)

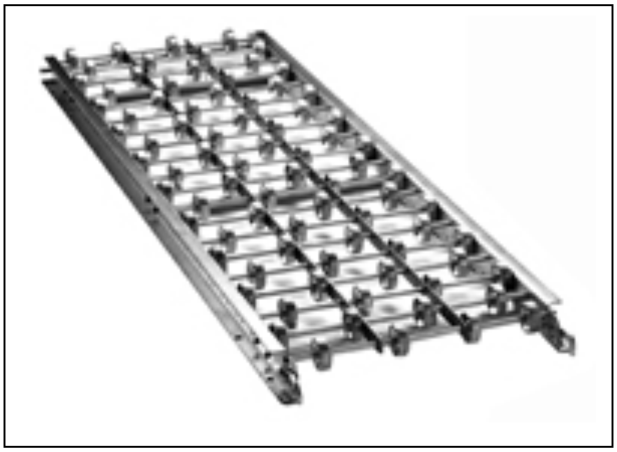


Figure 5.
Waste optical discs could be used in place of the rollers on this gravity conveyor.
(Image: www.ashlandconveyor.com)

Reflective Properties

One immediately striking visual trait of optical discs is their prismatic reflectivity (see Figure 6). This quality implies the potential for reuse applications that exploit the discs' reflective properties.

Figure 6.
Optical discs create multicolored reflections.
(Image: store.regionsports.com)

In an experiment performed for this study in a dark room, the author positioned a flashlight to shine into a glass mirror that reflected the beam directly onto the light sensor of an Extech 407026 Heavy Duty Light Meter, which was located about twelve inches from the mirror. The resulting meter reading was compared to readings obtained when the mirror was replaced with an optical disc and then with dull bricks, similarly positioned to reflect the beam directly onto the sensor. The configuration is shown in Figure 7.

Figure 7: Testing disc reflectivity with a flashlight and a light meter. (Image by author)

The baseline meter reading in the dark room was 0.0 candlepower, while the late afternoon sun, measured outdoors in Philadelphia on October 20, 2008, generated a reading of 114.0 candlepower. The maximum achievable reading from the flashlight and mirror was 15.9 candlepower, while the reflection from the bricks peaked at only 0.1 candlepower. The measured reflection of the beam from the disc reached 8.4 candlepower, indicating that the human eye would perceive the reflection of the flashlight beam from the disc to be about 50% as bright as that from the mirror over a twelve-inch distance. The author was surprised to find that disc reflectivity has been exploited almost exclusively for novelty purposes; no evidence of widespread practical applications was apparent.

SOURCE REDUCTION OPTIONS

Overview

This section of the study focuses on pollution prevention opportunities, noting the options that exist for reducing

a) the volume and/or toxicity of materials that go into disc manufacture
b) the number of discs produced, and
c) the number of discs that enter the waste stream.

The section begins with an overview of the disc manufacturing process and explores the application of life cycle analysis (LCA) and sustainable design principles. It also discusses the environmental impacts of some alternative data storage options.

Disc Manufacturing Process

The authors from The Green Initiative (2005) and Helsinki University of Technology (Zevenhoven & Saeed, 2003) explain the disc manufacturing process neatly in their published works. Figures 8 and 9 follow the quotations to illustrate the results.

> This is the most commonly used method of manufacturing compact discs:
> 1. An injection molding machine creates the core of the disc—a 1-millimeter thick piece of polycarbonate (plastic). With several tons of pressure, a stamper embeds tiny indentations, or pits, with digital information into the plastic mold. A CD-player's laser reads these pits when playing a CD;
>
> 2. The plastic molds then go through the "metallizer" machine, which coats the CDs with a thin metal reflective layer (usually aluminum) through a process called "sputtering." The playback laser reads the information off of the reflective aluminum surface;
>
> 3. The CD then receives a layer of lacquer (acrylic) as a protective coating against scratching and corrosion;

4. Most CDs are screen printed with one to five different colors for a decorative label. Screen printing involves the use of many materials, including stencils, squeegees, and inks. (Green Initiative, 2005, p. 8)

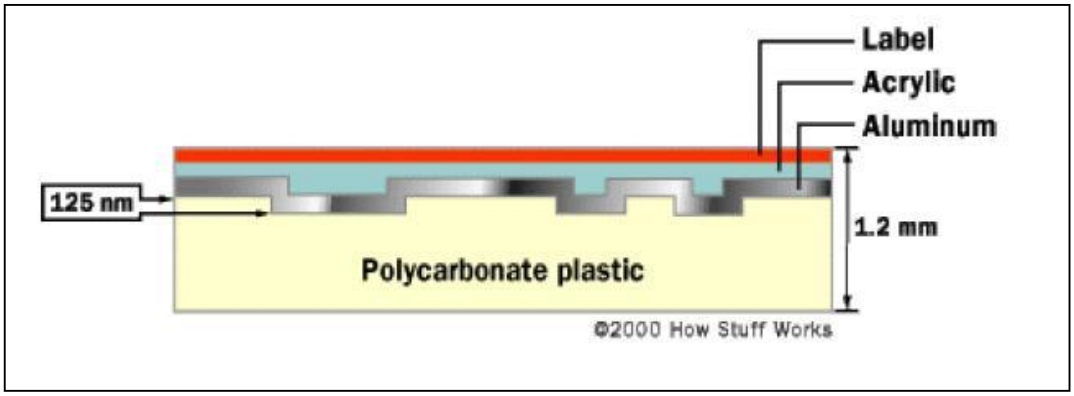


Figure 8: Cross-sectional view of a compact disc. (Image: How Stuff Works)

DVDs have the same diameter and thickness as CDs, and they are made using some of the same materials and manufacturing methods. The DVD, however, is made of several layers of injection molded polycarbonate plastic. Aluminum is used for protection behind the inner layers, but a semi-reflective gold layer is used for the outer layers, allowing for the laser to focus through the outer and onto the inner layers. Each layer is individually coated with lacquer, all are then squeezed together and cured under infrared light to make a single disc. (Zevenhoven & Saeed, 2003, p. 46)

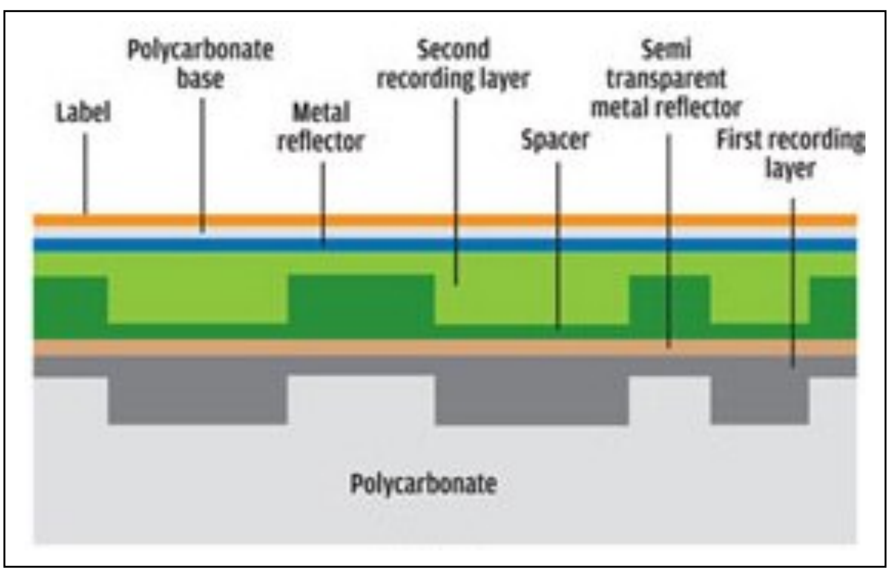


Figure 9: Cross-sectional view of a DVD. (Image: www.choice.com.au)

Reducing the Impact of the Manufacturing Process

In its clear and detailed life cycle analysis of compact discs, the *Carbon-Free CD Project* estimates that the manufacturing portion of each CD's life cycle produces 0.5 Kg of CO_2 equivalent (Green Initiative, 2005, p. 19). In addition to greenhouse gas emissions, use of fossil fuel reserves is also a life cycle concern for discs.

> …[P]lastics production requires significant quantities of resources, primarily fossil fuels, both as a raw material and to deliver energy for the manufacturing process. It is estimated that 4% of the world's annual oil production is used as a feedstock for plastics production and an additional 3-4% during manufacture. (Waste Watch, 2008, p. 6)

Thus the growing pressure to conserve petroleum resources supplies an important incentive to move from optical discs to alternative storage media.

Thanks to increasing environmental awareness, the concept of life cycle design is becoming more widely understood and applied, and environmental impact and end-of-life issues are being addressed earlier in the product design process. Having prioritized source reduction in manufacturing, Wewow Ltd. produces an 8-gram, 4.7-GB DVD called EcoDisc that (according to its own claims) contains only 50% of the polycarbonate used in standard DVDs and uses "40% less energy during manufacture" (Wewow Ltd., 2007).

In an interesting twist related to carbon footprint analysis, the substitution of carbon dioxide for the monomer bisphenol-a (a major ingredient in polycarbonate production) is on the cutting edge of plastics research in 2008, according to Acronym Required, a website that professes to "observe and analyze science and technology" (AcronymRequired.com, 2008). If successful, this change will reduce global exposure to the monomer (which some studies show is an endocrine disruptor) and offset greenhouse emissions by sequestering carbon dioxide in plastic. But the mass production of polycarbonate as a means for offsetting global emissions seems inherently suspect. In any case, the disc format itself appears to be on the road to obsolescence, so even if the EcoDisc design modifications and the use of carbon dioxide in disc production become standard practices, they are unlikely to become widespread soon enough to provide a significant environmental benefit.

Reducing Production Volumes via Online Storage and Alternative Media

It is not easy to define the online storage equivalent of a typical 800 MB optical disc, and it is therefore difficult to quantitatively compare their ecological footprints. The annual energy use of a typical 144-GB server in a data center, multiplied by the 1/180th of its total memory that 800 MB represents, is a starting point. But should the resulting figure be multiplied over the disc's 50-100 year life expectancy (Fujita et al., 2007, p. S12), during which online storage technology will undoubtedly undergo major changes?

> The overall number of data centres in the EU is growing fast, albeit not as fast as the data capacity, which is doubling approximately every 18 months… High density design now enables expansion to five times current capacity… using only 15% of the original data centre space. (European Information, Communications and Consumer Electronics Technology Industry Association [EICTA], 2008, p. 15)

Should the manufacturing and shipping impacts of the server be considered? What about the life cycles of the building materials of the data center? And how much are evolving technologies actually being implemented to reduce servers' physical space requirements and lessen their electrical cooling load?

Excluding these factors, we can calculate a very rough figure and compare it to The Green Initiative's estimated single-disc footprint of 1.8 Kg of CO_2 equivalent over its suggested useful lifetime of 10 years (Green Initiative, 2005, p. 19). Using information provided by Robert D. Hicks, COO of DBSi of Bethlehem, PA (personal communication, October 29, 2008), we assume the annual consumption of 28,063 kWh of electricity by a constantly operating server capable of storing 144 GB, multiply it by 10 years of disc life (to parallel The Green Initiative's study), and allocate proportionate energy consumption to an 800-MB "area" (1/180th of the server's memory capacity). Doing so, we find that the online storage of the disc information uses a total of 1,559 kWh over 10 years. Applying the Carbon Trust's conversion factor of 0.537 Kg of CO_2 equivalent generated per kWh of grid electricity (Carbon Trust, 2008) results in a figure of 837.2 Kg of CO_2. I was surprised to find that this compares very unfavorably with the disc's own 1.8-Kg footprint, creating more than 450 times as much CO_2 equivalent.

But the chosen comparison may be poor for many reasons. The disc's carbon footprint might better be compared with that of the energy used to store 800 MB on an iPod, on a 1,000-GB hard drive that can be turned off when not in use, or on a portable memory device, which uses virtually no electricity at all. Given the growing global importance and volume of electronic data storage, there is a need for more thorough LCA information about all data storage media (including their energy and water consumption, their inclusion of toxic component materials, and their disposal impacts) in order to inform a meaningful comparison.

In fact, we can completely reverse the result of the first comparison (even if we change the baseline optical disc from an 800-MB CD to a *more* data-intensive 5-GB DVD), by making a few very plausible assumptions. First, if server operation becomes just five times as efficient in the next ten years, then storing one 5-GB movie on a server for ten years would create about 1,046 Kg of CO_2 equivalent. (The existing trend is for servers to store more data while consuming less space and energy.) If online movie viewing continues to take market share from DVD sales (which may benefit film studios if the costs of producing and shipping plastic discs continue to increase), and if the online accessibility of that movie to consumers worldwide prevents the production of just 250,000 DVDs (the first shipment of *Spider-Man* DVDs to North America in 2002 was 11 million), then the tables are turned, and that 1,046-Kg footprint offsets 450,000 Kg of CO_2 equivalent related to those 250,000 unmanufactured DVDs.

Some in the industry, including Philips (the primary creator of the optical disc format), already assert that electronic storage is a more environmentally responsible option. In a 2008 report, the European Information, Communications and Consumer Electronics Technology Industry Association (EICTA) makes the following statement:

> There is… a clear environmental benefit from music and video downloads which do not require physical disks to be made, distributed, retailed, purchased, and re-distributed. Philips estimates that using video on demand instead of renting or buying physical disks could save around 120,000 tonnes of CO_2 a year across the EU. (EICTA, 2008, p. 28)

Further information from Philips in the report indicates that

> …electronic delivery of entertainment content through Video on Demand (VOD) is substituting disc-based distribution (DVD), saving materials (paper, plastic, ink, etc.), plus the physical distribution of the DVDs via the stores to homes. Philips has estimated that in Europe people travel around 33 million km per year to buy or rent DVDs and that VOD can therefore reduce annual CO_2 emissions by around 6.6 million kg. VOD also obviates the need to produce 2 million or so DVDs a year, a further saving of at least 181,900 kg of CO_2. Moreover, VOD does not require a DVD player which reduces the energy required for viewing over a physical video or DVD, a further saving of around 113.5 million kg of CO_2 emissions per year. (EICTA, 2008, p. 49)

This “obviating [of] the need to produce” has become a phenomenon associated with advancing technology. Known as “virtualization”, the process is described well on page 24 of EICTA’s report.

Reducing the Disc Waste Stream

Reducing disc mass and production volume will inevitably lead to reductions in disposal volume, but perhaps only after decades have elapsed. The author believes that, like VHS tapes, the billions of discs residing in consumer households will enter the waste stream only as they become unusable or unwanted. And like vinyl LPs, many will be discarded only after their owner's demise. (Recall that the ownership survey on page 10 showed that 21- to 30-year old participants owned an average of nearly 250 discs, which might easily remain undiscarded for another 60 years.)

A damaged disc does not necessarily need to enter the waste stream. Minor scratches can often be repaired with a mild abrasive like toothpaste, and some companies will attempt to repair discs for a nominal fee. But given the low cost of disc replacement, it is unlikely that many consumers will opt to repair damaged discs. Disc repair will therefore have little impact on the volume of this waste stream.

While industry indicators and comments from recyclers both suggest that disc production and use will decline steeply within a few decades, it is difficult to predict just how this will impact the waste stream volume over time. All sources indicate that the waste stream is currently increasing. Bruce Bennett, founder of the CD Recycling Center of America, estimates that about 100,000 pounds of CDs per month end up in landfills and incinerators (Compact Disc Recycling Center of America, n.d.).

Perhaps the waste stream volume will peak in about 20 to 30 years as software and game discs become obsolete and CDs and DVDs from the era of maximum production wear out. The author suspects that after the peak, the stream of discarded discs will slow very gradually, remaining roughly stable for several more decades as entire collections of discs are discarded upon the demise of their owners. It is hoped that this study will foster the development of effective, environmentally responsible solutions before the disc waste stream peaks.

INTERNATIONAL WASTE MANAGEMENT LAWS AND PRACTICES

Overview

Around the globe, local and national environmental policies and practices vary, as do people's attitudes toward them. Some nations and regions are known for designing innovative environmental solutions for the long term, and some have a reputation for valuing short-term profit over public and environmental health. As there is relatively little information specifically related to optical discs, this section of the study examines the disparate circumstances and challenges that coexist in the global fields of e-waste and environmental policy. It begins by discussing the most influential directives and concepts, and it subsequently profiles important geographical players. Information specific to optical discs is included wherever possible.

WEEE and RoHS

The European Union's Waste Electrical and Electronic Equipment Directive (known technically as Directive 2002/96/EC and commonly as WEEE) may be the single most influential piece of e-waste legislation in the world. It mandates the treatment, recovery and recycling of electric and electronic equipment (RoHS Guide, n.d.). All applicable products in the EU market have been subject to WEEE compliance since August 13, 2006. The directive stipulates that producers are responsible for taking back and recycling electrical and electronic equipment, and that consumers must be able to return such equipment free of charge (European Commission, 2008, *Environment: Waste Electrical and Electronic Equipment*). An exception for "consumables" excludes optical discs from WEEE compliance.

WEEE has global impact because it forces producers in other nations to meet its criteria in order to sell their products in the EU market. The related Restriction of Hazardous Substances directive (Directive 2002/95/EC, known as RoHS) bans the use of certain toxic substances in electronic equipment. China recently developed its own WEEE and RoHS legislation that expands somewhat on the EU's requirements (Franklin, 2006). These may force producers worldwide to make additional design modifications in order to access China's huge market. Notably, China's WEEE directives apply to products sold in China but not to those exported from China (Centre for Sustainable Design [CSD], n.d.).

Extended Producer Responsibility (EPR) and Life Cycle Design

Increasing waste volumes worldwide have led to product management concepts and laws that assign some responsibility for a product's disposal to its producer. The traditional practice of ceding all responsibility to the consumer has externalized environmental costs and promoted harmful patterns of consumption and disposal. EPR laws and practices are most advanced and entrenched in the European Union, while the U.S. has been slow to adopt them.

EPR often mandates that a producer must take back its products at the end of their useful life cycles. This presents businesses with unfamiliar logistics and new expenses related to the collection and processing of these items. New skill sets and partnerships are required, and according to Linda Barr of the USEPA's Office of Solid Waste, companies that implement takeback programs are concerned about controlling costs and employee safety (conference call, November 21, 2008). Mail-in programs for compact fluorescent light bulbs, for example, must consider the potential for mercury exposure if reclaimed bulbs break in transit. While they are interested in helping the environment (and boosting customer relations), Barr says that many U.S. firms are also concerned that implementing a product takeback program would result in their being classified as waste collection sites, which would subject them to extensive regulations that mandate expensive measures (conference call, November 21, 2008).

EPR encourages the development of life cycle design capabilities, because products that are designed for efficient reclaim and disassembly are better positioned to offset their own processing costs by reducing the producer's need to purchase raw materials. A number of global electronics firms including HP, Cisco, and Toshiba have implemented multinational takeback and recycling programs to comply with WEEE, but optical discs are often excluded, presumably because they are exempt from WEEE.

China

Thanks to highly publicized stories of babies sickened by melamine and toys contaminated with lead, China has developed an unwholesome reputation for seeking profit at the expense of public and environmental health. Its failure to enforce environmental regulations constitutes tacit support of a huge black market e-waste recycling trade, which subjects many of China's citizens to extended exposure to toxic lead and heavy metals at levels that are hundreds of times higher than the exposure limits permitted in the U.S. (CBS Interactive Inc., 2008). While China purchases a significant portion of the world's optical disc waste and recycles it, it does not appear that discs contribute in any important way to the tremendous e-waste problems in

China. Taiwan is reported to have begun the enforcement of polycarbonate disc recycling in April 2006 (Berghammer, 2006, p. 18).

European Union

The European Union is viewed as the global leader in developing and implementing innovative policies that protect the environment. Its citizens and lawmakers have a reputation for placing a high value on environmental quality and protection. Its EPR mandates are transforming business practices worldwide, forcing product life cycle issues to be considered earlier and earlier in the design process. There is evidence in the EU, however, of widespread WEEE noncompliance and illegal trade with non-EU countries (European Commission, 2008, *FAQ on Revised Directive on Waste Electrical, Electronic Equipment*).

The U.K. does not appear to be very successful in the field of plastic recycling. According to a 2001 Environment Agency report, 80% of post-consumer plastic waste is sent to landfill, while 8% is incinerated and only 7% is recycled. In addition, "…just over half of local authorities offer some form of plastic bottle collection service, and only an estimated 15% of UK households are served by kerbside collections that include plastic bottles." (Waste Watch, 2006)

As for optical discs, many are landfilled and incinerated in the U.K. (Waste Watch, 2006). A Finnish study found no evidence of disc waste processing in Finland, implying that discs there are treated as municipal waste (Zevenhoven & Saeed, 2003, p. 47). These examples suggest that inadequate management of waste discs in the EU presents a significant opportunity to reduce waste volumes and environmental damage.

United States

The U.S. has a poor environmental image in the global community. Known for its disproportionately high energy consumption and greenhouse gas emissions, the nation has a reputation for foot-dragging at environmental summits and for refusing to ratify agreements (like the Basel Convention and the Kyoto Protocol) that are espoused by other industrialized nations. Toxic U.S. e-waste fuels the “recycling” practices that are poisoning air, land, water, and people in China and other developing nations.

A search for “disc” on the USEPA’s own Waste Electronics web page underscores two important, disparate issues in this study. First, the relative unimportance assigned to recycling optical discs in relation to more toxic electronic wastes—which is not inappropriate—and second, the federal government’s (claimed) lack of influence on EPR issues in deference to state regulations.

The first search result link led to a poster displaying the life cycle of a CD. The document was clearly targeted for children, but it contained several calls to action:

> Call the company that produced your CD/DVD. Ask what the policy is for accepting its CDs/DVDs back for recycling or remanufacturing… Contact a local recycling center and ask if it accepts old CDs/DVDs… Contact your local waste management agency and ask what its policy is regarding discarded CDs/DVDs. (U.S. Environmental Protection Agency [USEPA], 2003)

The second link led to a 134-page report on EPR that contained a wealth of case studies of corporate and government pilot programs (but did not mention optical discs). The report conclusions ranged from inconclusive to cautiously positive (Davis, Wilt, Dillon, & Fishbein, 1997). According to Dan Barrett of the U.S. Postal Service, the Service is developing a free national collection program for small electronic items (conference call, November 21, 2008), but the USEPA website suggests that the U.S. federal government is not promoting its EPR views heavily in the public realm.

COLLECTION OPTIONS

Overview

This section of the study explores and compares collection options for optical discs. It begins by looking at household disc waste volumes and the challenges that face those who want to collect them. It then discusses issues of consumer participation and compares several collection models, including municipal collection events, public deposit kiosks, curbside recycling service, corporate takeback programs, and mail-in collection. The section concludes with two charts. The first compares several aspects of these models and the second offers the author's qualitative rating of each, based on its potential to achieve the highest possible disc collection volume.

Household Disc Waste Volume

While individual discs take up little space and pose a minor environmental threat compared to other types of solid waste, their collective volume and weight are significant. According to Bruce Bennett, founder of the CD Recycling Center of America, "Every month approximately 100,000 pounds of CDs become obsolete (outdated, useless, or unwanted)." (Compact Disc Recycling Center of America, n.d.) At roughly 20 grams per disc, and with an estimated 60% of the world's 200 billion discs distributed among private users (Fujita et al., 2007, p. S13), household discs represent a growing waste stream that currently stands at about 2.6 million tons.

Collection Challenges

Like many other household products, a major challenge to collecting waste discs is their geographic dispersal and slow rate of entry into the waste stream. Their aggregate volume is significant, but each disc is small and light, and each household discards only a small number (if any) at a given time. And as with any recycling program, full public participation cannot be guaranteed, even with legislative mandates. To maximize volumes, the collection process must be made simple and convenient for potential participants. In addition, “It has to be free for consumers or they won't do it,” says Barbara Kyle, national coordinator of the Electronics Take-Back Coalition.

But there are certainly costs associated with separating discs from other waste materials, transporting them to a recycler, and processing them. These costs represent another challenge to disc collection. According to David Beschen, it is currently cheaper for disc producers and consumers to treat waste discs like trash and send them to landfills or incinerators, due to the externalization of environmental costs (personal communication, December 10, 2008).

A final challenge to collection involves data security. While this is generally a lesser concern for individuals than for corporations, which often require certification of the destruction of corporate intellectual property from their disc recyclers, those individuals who store sensitive information on discs may be reluctant to release them into a system that does not offer such protection.

Participation and Collection Models

Participation

As Kirsten Allen of Supreme Asset Management Recovery noted in a recent telephone interview, “It is up to the consumer to be environmentally friendly.” (October 17, 2008) In other words, the success of any program for recycling household consumer goods is dependent upon the consumer’s willingness to participate. There are many ways to increase participation. Legislation that mandates recycling can help, but enforcement resources are not always available, and taking the time to inspect household trash bag contents would add significant time to the collection process.

Incentives such as those offered by RecycleBank can also increase collection volumes. RecycleBank (which does not yet accept waste discs) partners with local businesses to offer rewards to those who sign up for its collection service. Customers earn points according to the weight of recyclable material they place in the RecycleBank container, and the points can be redeemed for various rewards at the partnering businesses. This model allows businesses in many sectors to support recycling without dedicating the significant resources required to administer a recycling program.

Another way for businesses to offer recycling incentives is to set up an in-store collection kiosk and offer cash or store credit for deposited materials. The kiosk may fill some retail space, but lost sales may be offset by increased store traffic and customer loyalty. Best Buy and OfficeMax both offer recycling kiosks in many of their stores. It is significant to note, however, that in-store recycling programs are not as convenient as curbside collection—they require time and travel (with associated burning of fossil fuels), and consumers must remember to bring the items along even though their primary objective may be shopping, not recycling.

Municipal Collection Day

Another collection model often used by municipalities involves the organization and advertising of a special date and location for collecting hazardous household waste materials like paint. Some cities have begun to offer similar programs for e-waste (computers, printers, ink cartridges, cellular phones, etc.).

The city of Lynchburg, VA began accepting e-waste (including CDs and DVDs) on designated days beginning in April 2008 (Petska, 2008). The city of Hercules, CA also accepts discs at its hazardous waste collection events, but many other cities only accept bulky electronic appliances. It would be impractical to accept the discs without the larger items, as the greenhouse gases created by transporting a small quantity of waste discs to a collection site would probably offset any environmental benefit. But the acceptance of discs at such events could reduce landfill volume considerably. No data was available on the quantities of discs collected by such programs.

School and Charity Programs

Since curbside e-waste recycling is not widespread, many environmentally conscious educational institutions create their own collection programs for staff and students. This arrangement is quite convenient and does not require burning of additional fossil fuels, because most students and employees already travel to their schools daily. The University of Massachusetts has offered free e-waste collection, including optical discs, since 1996 (Chaves, 1998). Sweet Briar College of Amherst, VA started a CD and DVD recycling program on its campus in fall 2007, and it has since expanded, placing collection boxes in two public library branches. Other nonprofits accept e-waste with the intention of raising awareness of their organizations and refurbishing the materials for constituent use, or selling them to raise funds.

In-Store Collection

In-store collection models like those described above are proliferating as retail competitors seek to “out-green” each other (and offset the e-waste stream that they help to create). Such models make the most sense when the collected materials are similar to those sold or used at the store. It is easier to remember to bring used plastic grocery bags back to your local supermarket, for example, than it would be to take them to a cellular phone store. Staples, Best Buy, and OfficeMax all offer free e-waste collection with store credit incentives, but none of them accept optical discs yet.

Curbside Recycling

The success of curbside recycling programs for common household wastes has varied widely throughout the United States. The highest published *sustained* participation rate is Wisconsin’s 90%, reported in 2005 (Paper Industry Management Association, 2005). The California cities of Garden Grove and Temecula have established curbside e-waste recycling options, but they are geared toward bulky items like computers, and they do not accept optical discs. Given their small size and flatness, discs would fit easily with other plastic products in standard-size recycling containers.

But this study found only one curbside recycling program that specifically mentioned disc acceptance—a private, fee-based service in Murfreesboro, Tennessee.

Many cities in California accept #7 plastic products in their curbside containers. Because polycarbonate belongs to this group of plastics, it seems likely that optical discs could also be accepted, although the additional component materials in the discs may disallow a common recycling process. Still, curbside collection of optical discs, perhaps mandated by e-waste legislation, would offer a convenient way to access the many discs that are dispersed throughout consumer households; and the minimal additional effort required of consumers suggests a potential for high collection volumes. Bruce Bennett of The CD Recycling Center of America, one of the major disc recycling firms in the nation, is lobbying for such legislation, which would almost certainly increase the company's business (telephone interview, October 15, 2008).

Mail-In Programs

Retailers are joining electronics producers and e-waste recyclers in offering mail-in programs for recycling. OfficeMax provides free shipping and free containers as well as store credit incentives for its "MaxPerks" members who are high-volume recyclers. (Note that this arrangement can facilitate school and nonprofit collection programs like those described above.) Part of GreenDisk's recycling model is based on the sale of an e-waste collection box, the price of which includes shipping of the filled container to GreenDisk, processing of the enclosed materials, and an audit certificate guaranteeing environmentally responsible recycling practices and destruction of all data (GreenDisk, 2005).

Chart 1: Comparison of Disc Collection Options

Collection Method / *Criterion*	Municipal E-Waste Collection Event	Charity Collection Event	In-Store Collection Kiosk with Customer Incentives	Public/University Collection Kiosk	Curbside Recycling Container	Mail-In Program– Corporate Takeback	Mail-In Program– Direct to Recycler
Consumer cost, convenience, and incentive to participate	Consumer • must be available at scheduled time and date. • must remember date and travel to event site. • may have to pay a fee. • Not convenient.	Consumer • must be available at scheduled time and date. • must remember date and travel to event site. • Not convenient.	• Dropoff is free. • Consumer must travel to store during business hours. • Consumer may receive store discount, credit or merchandise. • Convenient if consumer travels near store regularly.	Consumer • must travel to collection site. • must remember to bring discs. • Convenient if consumer passes kiosk regularly.	• Free to consumer (municipality pays). • Extremely convenient.	• Usually free to consumer. • Consumer must generally request a shipping envelope or box online. • High-volume recyclers may receive discount or store credit. • Supplies collection infrastructure for other businesses and charities. • Very convenient once package arrives.	Consumer • usually pays for shipping and/or processing. • usually must request (or buy) a shipping envelope or box online. • must follow packing guidelines. • Convenient once package arrives.
Potential Market	• Only reaches area residents.	• Only reaches area residents.	• Only reaches area residents. • Store may be too distant from rural consumers.	• Only reaches area residents. • Impractical in sparsely-populated areas.	• Only reaches area residents.	• Reaches all areas served by public and/or private postal carriers.	• Reaches all areas served by public and/or private postal carriers.
Sorting and Aggregation/ Shipping Logistics	• Discs probably sorted and aggregated at event site. • Must arrange one-time or infrequent shipment to disc recycler.	• Discs probably sorted and aggregated at event site. • Must arrange one-time or infrequent shipment to disc recycler.	• Discs aggregated in kiosk at store, sorted later. • May have an efficient, low-cost shipping arrangement with disc recycler.	• Discs aggregated in kiosk. • May be sorted at a local facility. • May have efficient, low-cost shipping arranged with disc recycler.	• Discs mixed with other accepted items. • May be aggregated and sorted at a local facility. • May have efficient, low-cost shipping arranged with disc recycler.	• Consumer may sort discs in return package. • Mail carriers will have efficient shipping logistics and optimally located hubs for aggregation and distribution.	• Consumer may sort discs in return package. • Mail carriers will have efficient systems and optimally located aggregation and distribution hubs.

Chart 1: Comparison of Disc Collection Options (cont.)

Collection Method / *Criterion*	**Municipal E-Waste Collection Event**	**Charity Collection Event**	**In-Store Collection Kiosk with Customer Incentives**	**Public/University Collection Kiosk**	**Curbside Recycling Container**	**Mail-In Program – Corporate Takeback**	**Mail-In Program – Direct to Recycler**
Need for Legislation	• May require local e-waste recycling policy.	• n/a	• n/a	• May require local e-waste or plastic recycling policy.	• May require local e-waste or plastic recycling policy.	• National legislation could increase corporate participation.	• National legislation could improve recycling infrastructure and increase collected volumes.
Involved Parties	• Consumer, local government, transporter, recycler • Possible: corporate sponsor	• Consumer, charity, transporter, recycler • Possible: corporate sponsor	• Consumer, corporate sponsor, transporter, recycler	• Consumer, local government or educational institution, collector, transporter, recycler • Possible: corporate sponsor	• Consumer, local government, collector, transporter, recycler	• Consumer, corporate sponsor, mail carrier, transporter, recycler. • Possible: federal and/or local government.	• Consumer, mail carrier, transporter, recycler. • Possible: corporate sponsor, federal and/or local government.
Environmental Impact*	• Excess fossil fuel burned as consumers drive cars to event location.	• Excess fossil fuel burned as consumers drive cars to event location.	• Excess fossil fuel burned as consumers drive cars to store.	• Proper placement reduces consumer dropoff miles driven. • Aggregation in kiosks reduces fuel burned for collection.	• No consumer travel required. • Very low increase in fossil fuel use for collection if curbside service already exists.	• No consumer travel required. • Low increase in fossil fuel use for collection if area served by public and/or private postal carriers.	• No consumer travel required. • Low increase in fossil fuel use for collection if area served by public and/or private postal carriers.
Public Awareness, Social Benefit	• May raise awareness of e-waste issues.	• May raise awareness of e-waste issues. Charity may use proceeds for additional public benefit.	• Likely to raise awareness of e-waste issues.	• Kiosk likely to raise awareness of e-waste issues.	• May raise awareness of e-waste issues.	• May raise awareness of e-waste issues.	• May raise awareness of e-waste issues.

**Environmental Impact: Note that all collection methods reduce landfill volumes and incinerator emissions in collection areas served. Full environmental impact assessment depends on the subsequent shipping and recycling processes, which vary.*

Chart 2: Assessment of Disc Collection Options

Collection Method / *Author's Assessment*	Municipal E-Waste Collection Event	Charity Collection Event	In-Store Collection Kiosk with Customer Incentives	Public/University Collection Kiosk	Curbside Recycling Container	Mail-In Program – Corporate Takeback	Mail-In Program – Direct to Recycler
Positive Aspects	• Municipal involvement.	• Better chance of salvage and reuse. • Some social benefit.	• Better than free. • Incentives benefit consumer. • Incentives increase participation, which benefits store. • Has proven successful in various locations including the U.K. and Japan.	• Convenient for locals. • Free. • Involves municipality. • Raises public awareness.	• Convenient. • Free. • Involves municipality. • Raises public awareness. • No added collection emissions. • Uses existing infrastructure for collecting and recycling plastics.	• Free and very convenient. • Maximum market accessibility with no added collection emissions. • Encourages corporate responsibility, promotes life cycle design. • Corporations have PR incentive to fund programs.	• Very convenient. • Maximum market accessibility. • No added collection emissions.
Negative Aspects	• Inconvenient. • Not free to consumer. • Low participation. • Excess emissions from dropoff drive.	• Inconvenient. • Low participation. • Excess emissions from dropoff drive.	• Contingent convenience. • Low market penetration (particularly in rural areas).	• Not feasible in areas of low population.	• Not feasible in areas of low population or where curbside programs do not exist.	• May require legislation to force corporate action.	• Not free for consumer. This will significantly reduce participation.
Overall Rating of Collection Method *(for achieving maximum collection volume of discarded household discs)*	**D**	**C-**	**B+**	**B**	**A–**	**A**	**B–**

POST-COLLECTION OPTIONS

Overview

Given the goals of this study, it would be inappropriate to ignore the ending portion of a disc's life cycle. A quantitative analysis of processing options, however, would be far beyond the limited chemical and technical expertise of the author. This section begins by noting the inconsistency of published information about disc behavior in landfills and incinerators, and the apparent lack of practical reuse options for discs. It then asserts the need for more information that will help to identify the best practices for recycling optical discs. While it briefly discusses some of the environmental issues related to disc recycling, it refers the reader to technical studies that more thoroughly explore the various recycling methods.

Impacts of Landfilling and Incineration

It is clear that a large percentage of discarded discs currently end up in landfills worldwide. The CD Recycling Center of America's website states that optical discs will not decompose in landfills, and another site claims that PC "…will not degrade to any products or by products that would contribute to soil or water contamination." (Brett Martin Ltd., n.d.) A 2003 Helsinki University of Technology study asserts that "the structure and composition of CDs and DVDs is such that when these end up on landfills or in waste incinerators not much harm will be done." (Zevenhoven & Saeed, 2003, p. 6) Not surprisingly, the European Polycarbonate Sheet Extruders (EPSE) agree.

But the City of Fresno in California reports that discs leach bisphenyl-A (2008, p. 3), a substance that the World Wildlife Federation calls "a known endocrine disruptor."

(Lyons, 2000). A 2008 headline in *Video Business* magazine announced that “Recyclers Help Keep Toxic Discs Out Of Landfills And Incinerators” (McClain, 2008, p.11). While the Helsinki study made it clear that if waste discs are burned for energy recovery, the PC content “will give a CD or DVD a heating value of the order of 25-31 MJ/kg”, consistent and conclusive information about the costs, toxicity, and environmental impacts of disc landfilling and incineration is needed so that we can assess clearly the relative costs and benefits of reuse and recycling.

Reuse Challenges

Comparing Options

Repurposing and recycling are good, but very conscientious consumers make sure that a product cannot be repaired in an environmentally friendly way before sending it to its secondary life. If a disc remains functional and marketable, but is simply unwanted, the owner can trade it for another item at a used CD/DVD store or via an online service like craigslist. The owner can also benefit society while keeping the disc in use (and out of the waste stream) by donating it to a library or to a charity retail store.

A current challenge to effective repurposing of discs is the dearth of published options that address a meaningful volume of waste in an environmentally responsible way. This may well be due to a real lack of viable uses, but this study will propose at least one, and perhaps inspire a search for more.

Many published reuse suggestions are worse than simple disposal. Using unwanted discs to make a “decorative” lamp, for example, requires electrical components and glue, which create more troublesome waste and toxic fumes, not to mention the danger of fire. Others, like using discs indoors as drink coasters or in gardens as reflective deterrents for hungry birds, are quite practical, but they will have little impact unless tens of millions of consumers choose to implement them.

<u>Outdoor Use Issues</u>

A major barrier to outdoor reuse options involving reflectivity is the quick degradation of this property caused by exposure to the elements. The disc pictured below in Figure 10 remained on a west-facing Philadelphia rooftop for about 3 months. The foil layer, which provides all of a disc's reflectivity, showed significant deterioration within this period.

August 27, 2008 ***September 30, 2008*** ***November 5, 2008***

Figure 10: Degradation of reflective layer of a disc that remained on a west-facing Philadelphia rooftop for less than three months. (Photos by author)

An environmental health issue also exists. This study cannot recommend any large-scale outdoor disc reuse options because, as mentioned earlier, some sources claim that polycarbonate can leach bisphenol-A. A 2002 study found that high doses of bisphenol-A, when administered daily to mice, caused changes in body weight and organ weights in three generations of offspring (Tyl et al., 2002). While the substance is not considered dangerous at low doses, any application that would involve significant numbers of discs being exposed to water might create a localized health hazard.

Recycling Challenges

Sorting

According to Jim Crater, founder of Recycling Services, Inc. in Pottstown, PA, it is necessary to separate CDs from DVDs before recycling them (telephone interview, October 10, 2008). Most recyclers also request that the discs be separated from their cases and paper inserts. Invariably, not everyone follows such directions properly, so recycling firms must be prepared to do some of the sorting. This involves the expense and administrative effort of employing laborers. (This practice can provide benefits to society when elderly, disabled, or prison workforces are utilized.) Advances in technology are automating the sorting of more and more recyclable materials, but equipment costs can be high.

Environmental Impacts of Recycling

It is crucial to remember that the recycling of any material uses energy and has its own environmental impact. In the case of disc recycling, the shipping of the discs to a recycling facility requires burning of fossil fuels, the crushing and heating equipment uses electricity, and chemical stripping processes (if used) require the production, shipping, use, and disposal of solvents.

For a clear technical comparison of some commonly used end-of-life disc processes, the author recommends *Automotive shredder residue (ASR) and compact* *disc (CD) waste: options for recovery of materials and energy*, a 2003 study by Ron Zevenhoven and Loay Saeed of the Helsinki University of Technology. A brief chart comparing the environmental impacts of those common processes follows.

Chart 3: Comparison and Rating of Disc Recycling Methods and Incineration

Process / ***Criterion***	**Chemical Stripping (Chemical Separation)**	**Melt Filtration**	**Mechanical Abrasion**	**Incineration**
Use of acids/solvents	Uses solvents and aggressive chemicals, acetic acid	No	No	No
Water Use	Stripped discs are washed	Unknown	Discs may be misted for cooling	Unknown
Electricity Use	Process requires elevated temperatures and hot air dryer	Process requires elevated temperatures	Requires elevated temperatures for drying	Not excessive
Health Issues	Harmful solvents	Unknown	Relatively safe	Conflicting information on health impacts
Emissions	Unknown (may be high due to heat)	Unknown (may be high due to heat)	Unknown (may be high due to heat)	Very high
Compromised Quality of Resulting Material?	Potential interaction of solvents and polymer	Possible total loss (material unrecoverable)	Very minor loss of quality	Possibly
Financial Feasibility for Vendor	Poor – High equipment cost. Pending legislation may make this practice more expensive.	Unknown	High – Low equipment cost, easy adaptability.	Unknown – Suspected high due to tax funding. Future legislation may make this practice more expensive.
Author's Relative Environmental Friendliness Rating and Comments	**D** Pending legislation may make this practice even more burdensome	**?** Study mentions many opportunities for degradation and contamination	**B** Found by study to be the best environmental recycling option	**C–** May be getting a bad rap

From this chart we can see that, perhaps surprisingly, incineration of optical discs may be more environmentally friendly than some recycling processes. Reclaimed polycarbonate, besides being recycled back into PC plastic, can also be used to form new polymers with different mechanical properties, or it can be depolymerized into its useful monomer components. Analysis of these options is beyond the scope of this study. (Helpful information about the latter can be found on pages 380-387 of *Green Chemistry*, the Royal Society of Chemistry's journal, in the 7th volume of 2005.) A process diagram of the chemical stripping method appears below in Figure 11.

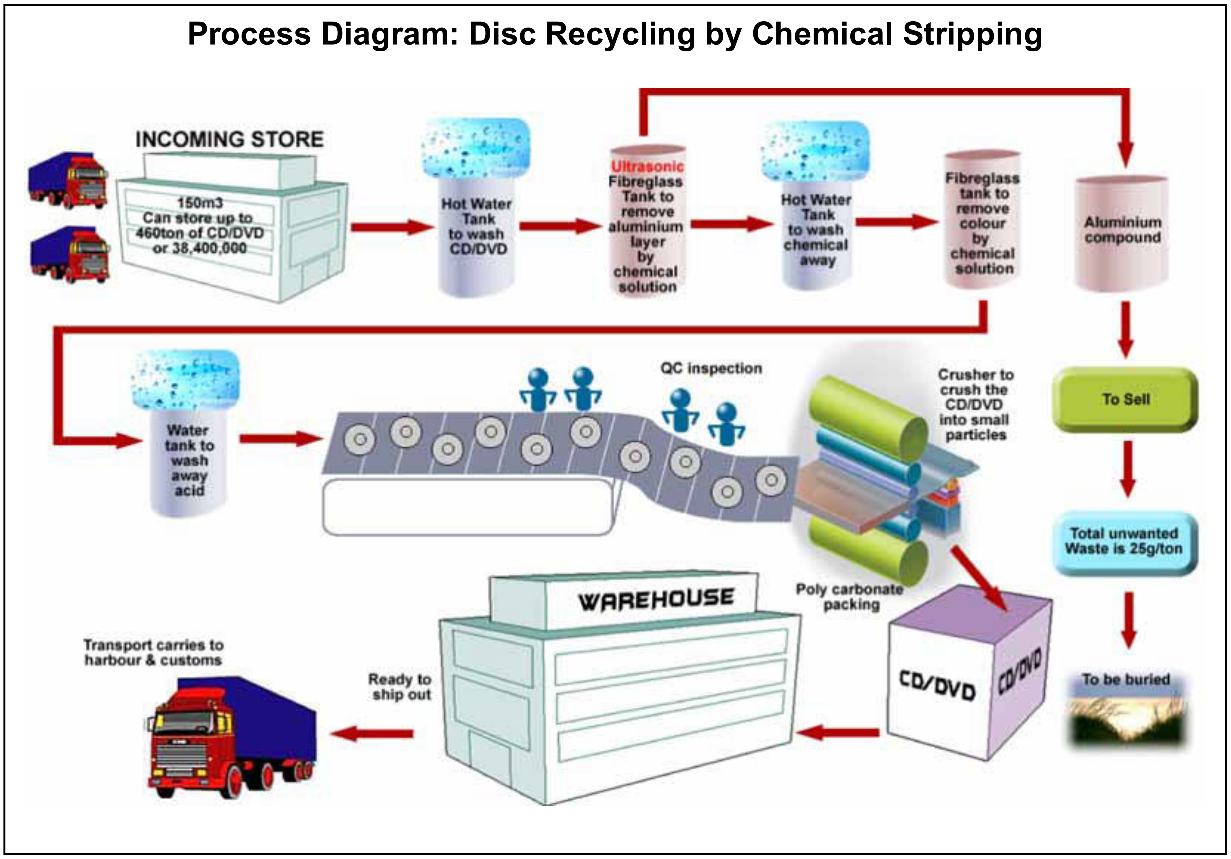


Figure 11: This disc recycling process diagram from a recycling firm in California illustrates steps involving use of chemicals and acid, and seems to imply that the crushed discs will be shipped overseas for further processing. (Image: www.freerecycling.com)

<u>Chemical Use and Employee Health</u>

Most disc recycling processes involve separation of the disc into its component materials. Some use nitric acid, which is highly toxic and corrosive, to dissolve the metal components (Fujita, Dodbiba, Murata, & Ihashi, n.d.). Production and disposal of nitric acid can damage the environment, and its use creates a risk of severe harm to recycling employees. Another method uses cyanide, which carries very similar concerns. A study performed by the Kyoto Institute of Technology in Japan suggests that less harmful chemicals can be used to create self-sustaining reactions that separate the disc materials (Hata, Goto, Yamada, & Oku, 2001), but the methods still involve the use of many chemicals, including the endocrine disruptor bisphenol-A and skin irritant dimethyl-2-imidazolidinone. As stated earlier, this study seeks recycling options that avoid unnecessary chemical use and health risks.

CONCLUSIONS AND RECOMMENDATIONS

Overview

To reiterate, this study is intended to identify best practices for minimizing disc waste and maximizing recovery of discarded discs while it notes areas where further research is required to guide stakeholders in designing environmentally optimal management processes. With the information presented here, the author also hopes to raise awareness of the growing waste stream of discarded household discs and inspire a search for solutions. This final section begins by noting some of the study's limitations, and then it presents the author's conclusions and recommendations with regard to source reduction and pollution prevention options, disc collection models, international waste management practices, potential reuse applications, and other post-collection management processes. It concludes with a brief summary of some of the study's most salient points.

Study Limitations and Opportunities

The efficacy of the study was limited by the difficulty of obtaining quantitative data on several topics, particularly the environmental impacts of various disc transportation and recycling systems. Also, there was not enough time to thoroughly test the collection and reuse options that are described below. The paucity of LCA data on PC recycling creates opportunities for future expansion of the study, which the author hopes will lead to definition of best practices for managing waste optical discs. The cursory experiments leave room for additional testing of the suggested applications, and the author may well continue this work after the study is published.

Source Reduction

When considering a product's environmental impact, source reduction is always an important topic. While there are some gains to be achieved by improving disc design, it is likely that the real keys to reducing disc-related pollution and petroleum consumption are alternative storage media and virtualization, both of which can supplant the production of vast quantities of discs, and are in fact doing so already. Data suggest that the optical disc format is becoming obsolete, and the author predicts that disc source reduction concerns will be irrelevant in twenty years because production will cease almost entirely by then. But billions of additional discs will still be manufactured, so design improvements that can be implemented quickly and widely could deliver significant benefits.

Collection

The models for optical disc collection, both extant and proposed, highlight a diverse array of challenges and opportunities. The publishing of more quantitative data on costs and collected volumes of various models would be helpful. Based on the analysis herein, the author recommends that all businesses related to the production, distribution, and sale of optical discs should immediately explore the feasibility of launching a mail-based disc takeback program. If unable to administer their own takeback programs, disc manufacturers should support existing programs with funding, or by providing postage-paid collection boxes upon request, or by installing collection kiosks in stores. While I would suggest the placement of more such kiosks, they seem to be proliferating on their own. The U.S. Postal Service has experience supporting takeback programs and Ground Shipping Manager Dan Barrett claims that the Service is eager to facilitate more of them (conference call, November 21, 2008).

Similarly, all municipalities with curbside recycling programs should consider accepting optical discs in curbside recycling containers (and subsequently recycling them) wherever they can be integrated into the existing plastic recycling infrastructure. Passing of local or national legislation targeted at optical discs might increase collection volumes, but the costs of developing and enforcing such legislation could offset the environmental benefits provided by disc recycling alone.

NetFlix Collection Proposal

While searching for inroads to the volume of discs dispersed among households in the U.S., the author of this study noted that Netflix regularly mails DVDs to its 8.7 million subscribers, and provides for each DVD a pre-addressed return envelope that actually has room for two discs. If Netflix were to permit the inclusion of one waste disc for recycling with each rental return, it could provide the convenient, cost-free recycling process that consumers demand.

Implementing such a program would probably incur a small postage increase for Netflix, perhaps a jump from $0.83 to $1.00 for each envelope so used. (It is quite possible that Netflix receives a discount from these standard postal rates, which are based on average disc weights.) There would be a cost for the labor of separating and aggregating the waste discs upon their arrival. With sufficient volume, however, Netflix would not have to pay to ship or recycle the collected waste discs. In fact, it might be able to recoup costs by selling them to a waste broker or recycler. In addition, the company would probably improve its brand image and customer loyalty by taking the opportunity to pioneer environmental stewardship in the online movie rental industry.

The author discussed the idea with David Beschen, president of GreenDisk, a company that has been recycling optical discs and other e-waste for 15 years. The company recycles discs and certifies the destruction of intellectual property for major DVD and software distributors. Mr. Beschen expressed interest in contacting Netflix to introduce the idea. Working with a company like GreenDisk would allow Netflix to provide a guarantee to its subscribers that their discs would be recycled in an environmentally responsible manner, and that all data on the discs would be destroyed. The author sent letters describing the proposal to two Netflix executives, but received no response in the brief time before this study was published.

International Waste Management Practices

While compact discs are a relatively minor hazardous waste concern, the United States should ratify the 1989 Basel Convention or establish a similar set of regulations that demand accountability and prohibit e-waste trade that supports the kind of black market e-waste recycling that is severely damaging human and environmental health in developing countries. 60 Minutes has published striking video coverage of Guiyu, China, where mounds of computer waste from the U.S. are releasing toxins into the water, soil, and air (CBS Interactive Inc., 2008). The U.S. should also improve its global environmental citizenship by embracing attitudes and legislative models that support life cycle design and EPR. For their part, developing nations (especially China) must do what they can to enact and enforce laws that protect their citizens from the health hazards of e-waste.

American nonprofits and government organizations should seek ways to remove the barrier that prevents the federal government from enacting WEEE legislation that is binding for all states. If the USEPA can partner with the Departments of Energy and Transportation to set minimum Corporate Average Fuel Economy standards for cars nationwide, then it seems that the federal government should be able to find a way to implement national WEEE laws. Perhaps these laws could even go beyond the requirements of the EU and China in a few areas, thus helping to polish America's tarnished environmental image.

Global awareness and implementation of EPR and sustainable design concepts must be promoted so that we avoid creating similar waste issues in the future. Enforcement of e-waste regulations must be improved in developed and developing countries alike. And finally, the availability of more quantitative data comparing the successes and failures of various regulatory and enforcement models could foster a quicker determination of common best practices.

Reuses

The reflectivity and flexibility of optical discs suggests that they could be used for a variety of practical applications. However, the variety is severely limited by the discs' susceptibility to weathering and their potential to leach bisphenol-A when exposed to water. This indicates the preferability of dry indoor applications, such as placing waste discs in dimly lit areas to reflect the available light and maximize its coverage.

Another possibility, given the discs' load-bearing capacity and wheel-like shape, is to use them for conveyance purposes. Their 12-cm diameter might cause them to perform poorly on rough surfaces as load-bearing wheels, and small obstacles like pebbles could cause the plastic to wear or break. But waste discs might perform quite well as conveyor belt components, particularly as substitutes for the roller wheels used in gravity conveyors. If a suitable waste material (such as aluminum ladders) could be found to build the gravity conveyor framework, it might be possible to manufacture and sell a line of gravity conveyors made entirely from recovered waste materials. Doing so might add the social value of jobs and profit to the environmental value of diverting these materials from landfills.

Given the optical disc's simple, consistent shape and desirable mechanical and optical properties, it is frustrating that high-volume, environmentally friendly reuse options remain elusive. A university or environmental nonprofit organization might generate creative ideas for practical disc reuses by sponsoring a contest with rewards for the best submissions.

Recycling and Other Management Options

Relatively few programs and businesses exist to serve individuals who wish to recycle small quantities of waste discs, and few (if any) of these are free, convenient, and able to guarantee data destruction and environmentally friendly processing. In the many areas where municipal and corporate collection programs are unavailable or poorly promoted, a conscientious consumer must usually pay a shipping or processing fee to recycle waste discs. Several of the recycling firms interviewed for this study would not accept quantities smaller than a truckload.

In addition, the plastic recycling industry as a whole exemplifies the practice of “downcycling”, where wastes are recycled into materials of lower quality that do not reduce the demand for virgin raw materials. This practice fails to maximize the environmental benefit for which the consumer expended effort and expense. A superior recycling firm would employ “upcycling” to create a new and more durable product out of materials like plastic that are often treated as if they are disposable.

Trumping these concerns is the possibility that recycling discs actually creates more health and environmental risks than landfilling or incinerating them. The use of hazardous solvents and chemicals in disc recycling is particularly undesirable. Determination of best practices for managing waste discs is hindered by a lack of quantitative, comparative LCA data for the various options.

Despite their relatively low toxicity compared to other forms of e-waste, the author hesitates to include landfill or incineration as acceptable methods for managing waste optical discs. This study seeks options that create a net environmental benefit. Before utilizing landfill or incineration, I would recommend storing collected discs safely until more environmentally friendly and financially viable management options are developed. And once they are defined, the most environmentally beneficial options should be employed—and supported with tax incentives or other financial mechanisms—wherever possible.

Summary

In the realm of waste management, discarded household optical discs represent a unique set of challenges and opportunities. Compared with most forms of e-waste, they are benign, compact, uniform, and easy to recycle. While they are not dissimilar to many commonly recycled plastic wastes, they contain small quantities of metal and must therefore be recycled differently. And unlike discs that are rejected during the manufacturing process or that remain unsold after distribution, household waste discs are discarded in low, widely dispersed volumes, and their owners have little or no incentive to recycle them.

Evidence indicates that optical discs are becoming obsolete and that widespread production will cease within a few decades. This will cause an eventual decline in the household disc waste stream (which is currently increasing by all accounts), but it is difficult to predict the timing of the peak and the subsequent rate of decline. The author hopes that environmentally friendly options for managing this waste stream will be identified and implemented before the waste stream peaks.

Optical discs have some mechanical and optical properties that appear well-suited for practical reuse options, but few seem to have been found. The author encourages a diligent search. Polycarbonate plastic also has many desirable qualities, many of which persist through multiple iterations of recycling. There is a looming question, however, as to whether current disc recycling processes cause more environmental harm than landfilling or incineration. Practical reuse applications and alternative data storage options that preclude disc manufacturing may well be the best potential solutions in terms of pollution prevention.

> But when producers design products so as to use less material, to extend product life or to be recyclable, the users of the products and the waste management sector must also share responsibility for sorting, collection, recycling, and proper disposal. Also, users of products must take responsibility for carefully choosing recycled and recyclable products and for generating less waste in the first place by buying less or finding reuse or repair options for products that they no longer use. (Davis et al., 1997)

Optimal environmental management of waste household discs (and e-waste in general) will be possible when *all* of the following parties are involved: governments, producers, consumers, waste management firms *and* organizations with shipping and distribution infrastructure. Partnership is key to maximizing efficacy, and the importance of the consumer's participation cannot be overstated.

A central theme of this study is the need for more quantitative LCA data that will allow stakeholders to identify best environmental practices for collecting and processing waste discs. Such data will undoubtedly inform the management of other waste materials as well. Implementation of WEEE legislation and EPR concepts still varies widely among nations, as do public and corporate attitudes about them. Collection and publication of data about the strengths and weaknesses of various WEEE and EPR models will also help move us toward better environmental management of optical discs and other waste streams, and will hopefully diminish the frequency and complexity of future waste management issues.

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