Design for Recycling: Influencing Product Design Using the Recyclability Index

by

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Abstract

The European Union recently passed the WEEE (Waste of Electrical and Electronic Equipment) Directive. This directive creates a law forcing Extended Producer Responsibility; that is, the original manufacturer is responsible for their products when the consumer no longer wants them. Starting in 2005, consumers can return used electronic devices free of charge within the European Union. The original producer must pay for collection and recycling of the product. In addition, there are specified methods and standards for recycling and recovery. Hewlett-Packard holds a significant part of the IT equipment market in Europe. The problem addressed in this thesis is how to design to reduce end-of-life costs and environmental impact and how to quantify the effects of those decisions. Because HP designs products for several years in the future, they must begin design change now. As part of this thesis work, the Recyclability Index tool was developed:

- To ensure WEEE Directive regulatory requirements for Europe are met
- To provide a way to make trade-offs with other design criteria
- To provide a metric which can be compared across time and printer generations
- To generate cost drivers, which can then be used to quantify end-of-life costs to evaluate recyclability and WEEE Directive compliance and assist in making design decisions.

The Recyclability Index tool is an Excel-based tool that assesses each product in terms of recyclability, hazardous materials, and ease of disassembly. HP's printing group has begun use of the Recyclability Index with new product designs, and it is being adapted for use through other groups in HP. The Recyclability Index Score has also been added as a measured metric for each new product design. In the future, the values generated by the Index will be used to estimate end-of-life costs.

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I am blessed with a career that allows me to help make the world a better place. I hope this thesis and my work at HP can in some way help to reduce our collective impact on the environment of this fragile planet.

We do not inherit the Earth from our parents; we borrow it from our children.
-Chief Seattle

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Chapter 1: Introduction

> "Nature recycles everything...This is the idea behind the nested cycling loops of the materials flow model. Rather than dumping valuable materials back into the environment, economic activities could be designed as closed systems that maximize the containment and recirculation of materials. As proponents of industrial ecology argue, one firm's wastes become raw materials for another firm's production." [1]

The concept of recycling is not new, and in fact, was far more common pre-Industrial Revolution. When resources were more difficult to acquire and move, people were more likely to save and reuse items. Even during World War II, people recycled many things for the war effort in America. Now, however, the links between designers, producers, and recycling are just beginning to develop. The industrial closed-loop system as described in the quote remains an ideal dream; however steps toward it have begun. Designers and engineers today face increasing constraints on design including assembly, warranty, marketing, and direct cost, among numerous others. With the advent of new environmental regulations and greater pressure from customers, environment and recyclability have been added to that list of criteria.

Much of the research that has been published on Design for Recyclability of electronic goods has been from an academic, technical perspective. The research answers the questions of "Is it technically possible to recycle?" or "What is the best method for recycling for a particular product?" Little of the existing research has been done working within a company; even less examines the implementation of changing the design process.

This thesis describes the process and results of an internship at Hewlett-Packard Company's Printer Development Team (PDT). The internship was to both create a Design for Recyclability tool, the Recyclability Index, and integrate it into the product design process. The implementation presented change management challenges. Hewlett-Packard's design organizations have traditionally enjoyed a large degree of autonomy, and many company initiatives are bottom-up as opposed to corporate mandated-down. For this reason, changing the design process or introducing new tools cannot succeed unless the engineers at the lowest levels accept and choose to use them.

Because of this unique position working within Hewlett-Packard with the design teams, as well as the approach of creating a useful design tool, not an academic environmental measurement tool, this research is new and of value. In addition, this project included both the design of a tool and the change management process inside a major corporation, not only the technical aspects. Thus, it will discuss both technical and managerial aspects of changing the product development process.

This thesis will explore many motivations for Hewlett-Packard to develop a recyclability tool and work to influence the design process. These motivations include legislation (discussed in Chapter 2), competitor practices (discussed in Chapter 3), and recycling technology (discussed in Chapter 4). However, the legislative requirements are the foremost driver in this initiative. These requirements can serve as barriers to entry in particular markets, and that is a barrier HP must cross. Compliance with these regulations for the lowest cost is a way to create competitive advantage out of a requirement.

In addition, beyond the legislation, there are additional motivations. One that is very important to Hewlett-Packard is brand recognition—acting in such a manner as to be recognized as an environmental leader. This eventually can translate in additional sales, particularly with government purchases of IT equipment.

The fifth chapter introduces the Recyclability Index and other recyclability models. The sixth chapter explains the implementation process and analysis through some organizational behavior frameworks. Finally, the seventh chapter shows the Recyclability Index results, analysis and some conclusions on the project as a whole.

Chapter 2: Legislation and Other Pressures

The primary motivation for this internship project is legislation, which is by far the leading basis for new environmental initiatives in the business world. In particular, this project was begun in response to regulations that force Extended Producer Responsibility; that is, the company whose name is on the product must now pay for its disposal and recycling. The impact of these laws on companies like Hewlett-Packard will be described in this chapter.

2.1 European Union

The European Union forces Extended Producer Responsibility through the Waste of Electronic and Electrical Equipment (WEEE) Directive. According to this legislation, the European Union (EU) believes the WEEE stream is a more immediate and significant problem than municipal waste for the following reasons:

- "The **rapid growth** of WEEE is of concern. In 1998, 6 million tons of waste electrical and electronic equipment were generated (4% of the municipal waste stream). The volume of WEEE is expected to increase at least 3-5% per annum. This means that in five years 16-28% more WEEE will be generated and in 12 years the amount will have doubled. The growth of WEEE is about three times higher than the growth of the average municipal waste.
- Because of their **hazardous content**, electrical and electronic equipment cause major environmental problems during the waste management phase if not properly pre-treated. As more than 90% of the WEEE is landfilled, incinerated, or recovered without any pre-treatment, a large portion of various pollutants found in the municipal waste stream comes from WEEE.
- The environmental burden due to the production of electrical and electronic products (**"ecological baggage"**) exceeds by far the environmental burden due to the production of materials constituting the other sub-streams of the municipal waste stream. As a consequence, enhanced recycling of WEEE should be a major factor in preserving resources, in particular energy." [2]

The EU chose to enact legislation to combat the above problems. In addition, the Proposal states that such standards are in line with the European Union's (Community's) policy on sustainable development ("Fifth Environmental Action Programme"). Germany and the Nordic countries are typically the first legislative bodies to enact major environmental laws, generally followed by the EU and Japan, and eventually the United States. Germany, Sweden, Norway, Holland, Belgium, Switzerland, Taiwan and Japan all previously had some type of extended producer responsibility laws. Extended Producer Responsibility means that the company who is defined as the "producer" becomes responsible for the takeback and recycling of all the products at the end of the useful consumer life. This will be explained in detail below.

The WEEE Directive defines a producer as:

> "any person who:
> (i) manufactures and sells electrical and electronic equipment under his own brand, irrespective of the selling technique used, including distance and electronic selling.
> (ii) resells under his own brand equipment produced by other suppliers, irrespective of the selling technique used, including distance and electronic selling, or
> (iii) imports electrical and electronic equipment on a professional basis into a member State" [3]

Thus, although a company like Hewlett-Packard may use subcontractors to build the equipment, Hewlett-Packard is still responsible at end-of-life in the EU. The goal of the EU proposal is to better protect the environment and human health through the following objectives:

- "Producers should take **responsibility for certain phases of the waste management** of their products. This financial or physical responsibility creates an economic incentive for producers to adapt the design of their products to the prerequisites of sound waste management. The financial responsibility of economic operators should also enable private households to return the equipment free of charge.
- **Separate collection of WEEE** has to be ensured through appropriate systems, so that users can return their electrical and electronic equipment. In order to create a common level playing field between the Member States, a "soft" target collection date is provided for.
- In order to ensure **improved treatment and re-use/recycling of WEEE**, producers have to set up appropriate systems. Certain requirements are prescribed as a minimum standard for the treatment of WEEE. Treatment plants must be certified by the Member State. Targets are laid down for the obligation to re-use, recycled WEEE and recover energy thereof.
- In order to achieve high collection rates and to facilitate recovery of WEEE, **users of electrical and electronic equipment** must be informed

> about their role in this system. The proposed Directive contains a labeling requirement for equipment that might easily end up in a dustbin. In addition, it will be necessary for producers to inform recyclers about certain aspects of the content of such equipment." [2]

The first objective means that companies like Hewlett-Packard, who were previously only responsible for the product until point-of-sale, are now responsible after the consumer no longer needs the product. In addition, the consumers must be able to return the products free of charge. The actual structure of the takeback and recycling processes is not stipulated in the WEEE Directive itself; each country will determine a system. For example, electronics may be picked up curbside along with trash, or consumers may need to take them to a special drop-off station that separates electronics goods by brand. Most of these details are not yet determined.

The second objective mentions the "soft" collection date—this is the point by which countries are expected to meet minimum targets of electronic equipment collected per person. This target is 4 kg per year per inhabitant. "It represents a typical average collection yield that has been achieved by several countries of the European Union in the course of pilot production schemes and corresponds to the collection achieved in practice under the Dutch WEEE legislation." [4] That target is for the country as whole; the country then needs to ensure the manufacturers are acting accordingly to achieve that target. The deadline for compliance is "soft" and varies among the various member nations of the EU.

The third objective listed above directly impacts the manufacturers' product designs. Annex I of the WEEE Directive lists the various products that fall under the law, and groups them in categories. This full Annex is in Appendix A of this thesis. Information technology equipment like personal computers, printers, and mainframes fall under Category 3. The Directive then stipulates minimum targets for each category:

> "For WEEE falling under category 3 of Annex I A, with the exception of equipment that contains cathode ray tubes, the rate of recovery shall be increased to a minimum of 75% by weight of the appliances and component, material and substance re-use and recycling shall be increased to a minimum of 65% by the weight of the appliances;" [5]

According to the Directive, "recycling" means: "the reprocessing in a production process of the waste materials for the original purpose or other purposes, but excluding energy recovery." [3]. "Recovery" includes both recycling and waste-to-energy incineration. For example, painted plastics cannot be recycled because of the paint, but they can be burned in incinerators for energy recovery. Annex II lists the various components and substances that must be removed from WEEE. This list includes such things as batteries, printed circuit boards, and cathode ray tubes.

Finally, as per the fourth objective, the producer will now have to label all products, convey disassembly information to recyclers, and provide for return and pre-treatment of all its products. Based on this framework, the Commission lays out specific standards and practices for the takeback and recycling of WEEE. Although the proposal was modified, and had to be integrated with the Council's version, the legislation was ratified by the EU Member States.

The WEEE Directive went into effect in February 2003. By August 2004, Member States must have laws in place. Producers will be responsible for their own goods marketed after August 13, 2005. [6] In the initial years, it is likely that each manufacturer's liability will be based on current market share for the collection and recycling. This is to cover for "orphans", products made by companies that have since gone out of business and therefore cannot pay for treatment today. Beginning in 2005, companies must establish annuities to ensure there will be significant funds to pay for treatment if the company folds.

Although the WEEE Directive establishes overarching objectives and goals, each individual Member State must implement policies to meet the Directive requirements. The Member States may choose how to meet the requirements. Countries who already had takeback systems in place, like Germany and the Netherlands, will most likely continue with the same systems. Other nations are attempting to build new systems. Political pressures and lobbyist groups have different levels of power in each of the

Member States, which may result in a variety of system structures across the EU. The result could be a difficult logistics and management problem for electronics producers. However, it is too soon to pass judgment on the collection and recycling systems.

The EU legislation has received more prominence over other nations' systems because it has the potential to be the most broad and affect the largest number of products. In addition, it has actually been promulgated, unlike systems in the United States, which will be described below in Section 2.3.

2.2 Other National Regulatory Programs

2.2.1 Australia

Australia is formulating a takeback program. A stakeholder group was convened and released a report with potential frameworks and the resulting environmental and financial impacts of each. In addition, trial takeback programs have begun in New South Wales for the population of Sydney.

2.2.2 Japan

Japanese regulation required recycling beginning in 2001 for major appliances, televisions, monitors, refrigerators, and air conditioners. Consumers pay the recycling fees for this. Additionally, takeback laws for computer equipment are in initial stages and will likely be in place by 2010. Japan faces the same issues as Europe—there is no landfill space left and minimal natural resources. For this reason, recycling has become a major concern.

2.2.3 Taiwan

Taiwan was one of the first countries to mandate takeback and recycling of electronics equipment. Since 1998, desktops, laptops, and monitors have been collected through takeback stations, municipal facilities, and recycling companies. Printers were added in 2001. "As of October 2000, roughly 1.4 million used computers had been recycled, and officials at Taiwan's Environmental Protection Agency said they were achieving a recycling rate of about 75 percent of all used computers." [7]

2.2.3 Switzerland

Switzerland, who is not a member of the European Union, enacted takeback legislation in 1998. This legislation requires consumers to return used electronic goods and requires retailers and manufacturers to take these goods back free of charge. There are no recycling or collection targets. In addition, financing methods are left to the individual companies. [8]

2.2.3 Other Countries

Legislation has also been implemented in Denmark, Sweden, Hungary, and Norway. These systems all vary slightly, particularly in financial responsibility.

2.3 United States

Extended Producer Responsibility Laws, while advocated by some environmental organizations, are not currently being drafted in the United States. There are several reasons for this: confusion over jurisdiction, limited public interest, unlimited landfill space, political party in power, pro-business mentality, and electronics manufacturer power.

One major issue is that of historical precedent and jurisdiction for waste issues:

> While materials scarcity has been a broad, national concern, concern over this other end of the materials cycle has been developed at the local level. Wastes had no military, commercial, or trade implications, so federal

> agencies saw no direct responsibilities for managing them. However, waste materials were a public issue. From the mid-nineteenth century on, the increasing volume of mining wastes, industrial discharges, and municipal refuse grew in public concern; the response, though was viewed as a local, not a national issue." [9]

In the United States, water and air pollution are regulated at the Federal level, although states may also have their own legislation. However, because waste, namely garbage, has been regulated historically at a municipal level, there is much debate about at which level EPR laws should be promulgated. Of course, each level (Federal, State, Municipal) believes they should have jurisdiction. However, none of them want to pay for the collection and treatment of these wastes. This is in part why municipalities and states have passed legislation that bans disposal of hazardous materials but does not necessarily finance a treatment system.

Massachusetts passed legislation that banned the disposal of televisions and monitors containing Cathode Ray Tubes in municipal landfills in 2000. The law does not establish Extended Producer Responsibility; consumers must now pay to recycle these products. Of course, because movement between states is free in the United States, Massachusetts residents can drive to Rhode Island or New York and dispose of their monitors. Laws like these have the potential for abuse and avoidance. Although many communities in Massachusetts have passed a Resolution Supporting Producer Takeback of Cathode Ray Tubes, Electronics, and Household Hazardous Products, it does officially establish EPR. [10]

In 2001, California also passed a law banning the disposal of Cathode Ray Tubes. There are also two bills currently in the California legislative process-- one that mandates Extended Producer Responsibility and one that mandates advanced disposal fees on Cathode Ray Tubes. In addition, many communities throughout California have adopted resolutions supporting Extended Producer Responsibility and electronics recycling.

The activist community has had little success pushing for takeback legislation at the federal level, and so has focused on local and state governments. Companies in the

United States are concerned that takeback legislation at a local level could mean thousands of separate laws. Compliance with all these laws would create a prohibitive financial and administrative burden. Although the electronics firms will not lobby for the additional burden of EPR, it is in their best interest to have legislation at the federal level.

A group called the National Electronics Product Stewardship Initiative (NEPSI) formed in Summer 2001 to design a proposal for a national law. NEPSI includes stakeholders from government, non-governmental organizations, and corporations. Progress has been slow in trying to reach a consensus, particularly on who pays for the recycling and takeback.

NEPSI's purpose is: "The development of a system, which includes a viable financing mechanism, to maximize the collection, reuse, and recycling of used electronics, while considering appropriate incentives to design products that facilitate source reduction, reuse and recycling; reduce toxicity; and increase recycled content." [11]

A similar organization, WEPSI (Western Electronic Product Stewardship Initiative) was organized in the western states of the US:

> "WEPSI is a project designed to find a more effective and fair solution to this problem. WEPSI will organize multi-stakeholder dialogues throughout the Western States, which engage manufacturers, suppliers, distributors, recyclers, non-profit organizations, government and consumers. Through a collaborative process the groups will explore product stewardship models, environmentally preferable purchasing and collection infrastructure." [12]

In a paper at the IEEE 2002 conference, Rifer and Stitzhal discuss the WEPSI initiative and two of four major working groups (Market Drivers and Design). Rifer and Stitzhal have identified areas of potential convergence for these two groups in three different areas of need:

> "1. A methodology to measure DfEOL [Design for End-of-Life] attributes of a product: There is an extensive body of literature regarding DfE principles that relate to end-of-life management...In the European context, several eco-label schemes have defined specific DfE standards that products must meet as a condition of earning the label. However, there is

> no system that provides a tool to compare different products according to the degree to which they implement an end-of-life strategy in order to facilitate effective and efficient product management." [13]

Although the group then identifies some policies for setting these standards and measurements, no clear directive has been written in the United States. Rifer and Stitzhal identify the need for a way to measure the correlation between design decisions and end-of-life impact and recyclability. As will be discussed later, the Recyclability Index tool was developed through this internship to solve that very problem for Hewlett-Packard.

> "2. Methods for obtaining continual feedback from end-of-life managers: It is critical that information be made available to product designers regarding: how different design features impact the efficiency of the recycling process, the requirements for management of toxic and hazardous substances, and emerging recycling technologies that should be considered during product design." [13]

Establishing a link between the recyclers and the product designers is critical. The designers cannot design more recyclable products if they do not understand how design affects recycling. Sometimes design guidelines are not linked to impacts in the recycling stage, whereas other decisions may actually hinder the recycling process. For example, one recycler said that making an entire product of one polymer is irrelevant in his process—the products are all shredded together, thus the plastics are mixed regardless.

> "3. Mechanisms that translate DfEOL design attributes into financial benefits for product designers and manufacturers. As long as the economics of design/manufacturer and of end-of-life management are independent, the full life-cycle system will not achieve efficiency and lowest optimal cost." [13]

The European legislation endeavors to place the cost burden on the manufacturer. WEPSI and NEPSI are both looking at potential funding systems that create financial benefit for better environmental design without overburdening the manufacturer. The obvious challenge in doing this is a major reason why the process has slowed for both groups. The stakeholders all basically agreed that there are benefits to better Design for Recycling; however, there is little agreement on how to fund these initiatives.

The NEPSI process seems to have stalled—no official proposal has been agreed upon, and nothing new has been posted to their website since January 2002. WEPSI has continued to sponsor research projects and hold meeting with stakeholders in the Pacific Northwest, but has not produced any proposal.

The Non-Governmental Organizations believe the entire burden should be borne by the manufacturers or appear as an up-front fee (an additional charge paid by the consumer upon purchase as an additional cost, like a deposit on a bottle). In addition, there is a real possible that that money will no longer be available at the end-of-life to pay for recycling. To some of the regulatory community, the up-front fee is preferable because it is the easiest to regulate and enforce. For the manufacturers, an up-front fee is not desirable, as it allows no room for differentiation and no benefit to those manufacturers that design better for recycling. The details of those structures remain nearly impossible to hammer out, however. Reaching consensus in this type of organization, particularly when millions of dollars are at stake, is extremely difficult.

2.4 Silicon Valley Toxics Coalition—the Non-Governmental Organization Connection

In addition to legislative pressures, there can be extensive pressure from consumers and non-governmental organizations (NGOs). A company can put its own message out on the Internet, and nearly anyone can claim "environmental responsibility" as a value. The claiming of great environmental work occurs so often it even has its own term-"greenwashing." One way to combat greenwashing is to compare company data with reports from non-corporations, particularly NGOs. These provide a different perspective in the companies' policies and public statements. The NGOs are not unbiased, however—they have their own agendas. However, they can provide an alternative from the corporate opinion.

One of these organizations is the California-based Silicon Valley Toxics Coalition (SVTC). SVTC annually prepares a Computer Report Card ranking companies in the Information Technology hardware business. This report card rates each company in four categories: Extended Producer Responsibility, Use of Hazardous Materials, Worker Health & Safety, and Degree of Accessibility of Information. Then SVTC ranks all the companies with various grades (Passing, Needs Improvement, Poor, Failing). In 2002, SVTC evaluated 28 companies, of which only Fujitsu got a Passing score. Canon was ranked second overall, followed by IBM. HP received a rating of "poor" and was ranked eleventh. According to the report, HP's rating fell from the previous year as a result of the merger with Compaq, which had scored very low in 2001. However, SVTC lauded HP for publicly embracing Extended Producer Responsibility and expanding takeback services.

According to an article by Ted Smith, executive director of SVTC, the organization has chosen to focus on Extended Producer Responsibility in their Computer Take Back Campaign: "The goal of the campaign is to protect the health of electronics users, workers, and the communities where electronics are produced and discarded by requiring consumer electronics manufacturers and brand owners to take full responsibility for the life cycle of the products, through effective public policy requirements or enforceable agreements." [14] The SVTC works with NGOs around the nation to focus attention on these issues and tries to force companies to change. The impact of these NGO groups is easy to underestimate. However, as America learned from Nike's troubles, ignoring the activist organizations can be disastrous.

Other NGOs focused on the issue of computer equipment and the environment include the Clean Production Network, Southwest Network for Environmental and Economic Justice, Basel Action Network, Santa Clara Center for Occupational Safety and Health, Environmental Health Coalition, and the GrassRoots Recycling Network- Computer TakeBack Campaign. These groups have formed a coalition focused on electronic waste.

2.5 Eco-labels

Some organizations have been created to standardize environmental product claims. These organizations have particular criteria to evaluate various products; products that meet these criteria are then certified. The certified products can then show these labels, either on packaging or on the product itself. "Certified products can lead to higher prices and expanded market share as well as to satisfy consumers' concerns about the safety or environmental impacts of such products. Eco-labeling from environmental NGOs can also help overcome a potential credibility gap between business and consumers." [15] In addition, many large industrial or government contracts require a particular certification for any products they will purchase.

The first eco-label was the Blue Angel in Germany in 1978. The Blue Angel is considered the most important by many firms in the computer industry. It is the label that HP seeks most often, along with Energy Star. Other eco-labels include the Green Dot, U.S. Energy Star, Taiwan's Green Mark, Japan's Eco-Mark, TCO certification, and the Nordic Swan. These labels provide an instant symbol of being environmentally friendly to consumers, if the consumers understand the label.

> "Eco-labeling is not a perfect tool. For instance, eco-label schemes are not comprehensive, often choosing one environmental feature out of many as the basis for awarding the label. Some schemes only scratch the surface of the immensely complex interactions between a product and the environment. The lack of harmonization of global standards leads to criticism that eco-labels pose a barrier to trade...Despite these difficulties, eco-labels can increase sales. Flourishing programs in the Far East and Northern Europe suggest that eco-labeling does work." [15]

The criteria required by eco-labels such as Blue Angel often influence the product design. For example, a designer may choose a more efficient but more expensive power supply if it is needed to receive Blue Angel-certification.

2.6 Hewlett-Packard Motivation

Hewlett-Packard sees the legislation not only as yet another set of compliance tasks, but also an opportunity. By viewing this as not just an environmental issue or automatic cost to the business, Hewlett-Packard can potentially make end-of-life responsibility a competitive advantage. There is an opportunity here for first mover advantage and economies of scale. In "Clockspeed", Charles Fine discusses capabilities and temporary advantage:

> "In this age of temporary advantage, the ultimate core competency is the ability to choose capabilities well. A company may have a core competence in product design, brand marketing, custom manufacturing, or high-volume distribution. Each of these may be important capabilities in its competitive environment. But the overriding competency is the ability to determine which of those capabilities are going to be the commodity abilities—and for how long. Lasting success will go neither to the company that manages to find a great business opportunity nor to the firm that develops the best proprietary technology. Rather, we will see that the greatest rewards go to the companies that can anticipate, time after time, which capabilities are worth investing in and which should be outsourced; which should be cultivated and which should be discarded; which will be the levers of value chain control and which will be controlled by others." [16]

Environmental product design and takeback issues is one area that could become one of those capabilities that should be invested in. It is Hewlett-Packard's belief that HP is uniquely positioned to finding the lowest cost way to comply with the EU legislation and could potentially turn this into a competitive advantage. Many electrical equipment manufacturers will be forced to hire second-party recyclers simply because the manufacturers do not have enough volume of product to make owning their own recycling facilities cost-effective. A smaller firm, like Apple, has only one cost-effective option—to select a consortium or a particular recycler in Europe to comply with the WEEE Directive. Because HP has such great volumes of installed base and in market share in the EU, there is sufficient economy of scale to consider managing an HP-only recycling program. In addition, because of the merger with Compaq in 2002, HP now has responsibility for all former Compaq and Digital Equipment Corporation products.

One motivation for exploring separate recycling facilities is the potential for free-riders. If everyone pays in a central consortium on a per-product basis, there is limited benefit to designing more recyclable products. In order to exploit the savings from better designs, a different financial system may be needed.

To what extent this HP-only recycling program would cover is unclear; however, the entire idea is only advantageous if HP can recycle products and meet the law for less cost than its competition. Although there is a direct correlation between better Design for Recycling and cost to recycle, contracts with recyclers typically are based on weight and size, not product design. However, if HP were to own recycling facilities or at least part of the end-of-life value chain, there would be a direct and immediate financial benefit to better Design for Recycling. The questions then follow, "Can HP design better for a cost advantage?" and "How would HP link these cost benefits directly to the design process?" The Recyclability Index can help answer these questions. By using the Recyclability Index in the design process, changes can be made to make products faster to disassemble, encourage better material selection, and to decrease the amount of hazardous materials.

However this thesis does not address the design of HP's end-of-life strategy— this thesis will not determine an end-of-life process structure. That is out-of-scope. In addition, for proprietary reasons, long-term corporate strategy cannot be discussed here.

To better understand HP's approach to this project, it is helpful to understand the company history and culture.

2.5.1 Hewlett-Packard Company

Bill Hewlett and Dave Packard founded Hewlett-Packard Company (HP) in 1939 in a garage in Palo Alto, California. In a story that is Silicon Valley legend, HP grew into a $72 Billion company by 2002. In the late 1990's HP spun off the medical and testing equipment divisions as Agilent Technologies. The remaining HP then merged with Compaq Computer Corporation in May 2002. The new HP focuses on Information

Technology Solutions in four divisions: Enterprise Systems Group, Imaging & Printing Group, Personal Systems Group, and HP Services. The Imaging & Printing Group is by far the most profitable in the company, and much of HP's revenue comes from inkjet printers and, particularly, supplies.

The Printer Development Team is where HP designs new inkjet printers and mechanisms for printers and multi-function devices. The significant volumes of products produced by this division mean that regulations like WEEE that force extended producer responsibility are definitely a concern and a huge potential liability.

HP's official website includes this quote from CEO Carly Fiorina: "Environmental protection is a complex undertaking, but the laws of nature are simple. We will provide leadership on the journey to an environmentally sustainable future, with efficient products and creative recycling solutions." Innovation and "doing well by doing good" have both been tenets of Hewlett-Packard since the company was founded. Thus, the company culture is already receptive to positive social responsibility initiatives.

One area where Hewlett-Packard has been a leader, at least among American information technology firms, is environmental responsibility, evidenced by numerous awards and Hewlett-Packard has Product Stewardship programs in place throughout the company, and generally regards this as a positive for Hewlett-Packard. As with most companies, however, saying something is much easier than actually doing it. This thesis will discuss in detail the process of moving from talking about environmental product design to actually doing it.

Traditionally, regulatory requirements have been the primary motivator for environmental change within major corporations. However, companies like Hewlett-Packard are beginning to find ways to turn these requirements into competitive advantages. "Practicing green product design can produce direct bottom-line benefits such as reduced material costs and an improved product, which often results in increased market share, access to broader global markets, and decreased compliance fees. Less tangible benefits include enhanced corporate image, improved community relations, and increased access to investor capital." [17] The fifth chapter of this thesis will discuss the development and implementation of the Recyclability Index, which Hewlett-Packard plans to use to assist in Design for Recycling.

Legislation is mandatory; it motivates change at any company that wants to comply with the law. However, there is a distinct difference between minimum compliance and looking at regulation as an opportunity. HP's cultural and technical starting situation is unique and better positioned than many of its competitors to become a "green" leader. The competitors' Design for Environment programs will be explained in the following chapter.

Chapter 3: Drivers for Change and Product Design

3.1 Unifying the Technology, Regulatory, and Economic Drivers

For real design change to happen, there must be motivation; this may come from regulatory requirements, economic incentive, or better technology. Bauer and Sheng developed a model of the alignment of these factors.

> "Most effective activities, both from an industrial and from an environmental policy perspective, require alignment of technology (such as pollution prevention and environmentally benign materials), cost (such as for resource acquisition and disposal) and regulatory drivers (such as limitations on air, water, and solid waste emissions). Each of these areas has its own modes for information transmission, as well." [18]

Their model contains the criteria shown in Table 3-1. This model illustrates the concept that there are often many overlapping factors that drive environmental change.

Table 3-1 Bauer and Sheng Drivers for Change [18]

Technology	Regulations and Incentives	Economic Drivers
Key Elements: • Environmentally benign materials • Energy efficiency • Dry processes • Recycling processes	Key Elements: • Air, water, and solid emissions regulations • International standards (e.g. ISO-14001) • Eco-labeling incentives	Key Elements: • Total life-cycle cost for product stewardship • Waste disposal and abatement cost reduction • Revenue streams from manufacturing • Reduction in liability and risk management cost
Information Transmission: • Technology transfer • Environmental metrics • Design for Environment tools	Information Transmission: • Industry roadmaps • Environmental management systems • Education programs/ public dialogue	Information Transmission: • Environmental accounting • Cost-of-ownership modeling

Traditionally, regulations were the key driver, and were supported by technological advances. However, as attitudes shift, environmental change is being driven by other factors, such as management of risk and public perception. Often regulation provides the initial impetus for change, but then technology and economic drivers enable companies to move beyond the regulations. For HP and the Recyclability Index, this is the case—the WEEE Directive regulations initially motivated the project, but then the technology of the Recyclability Index enabled the economic driver of potentially turning compliance into a competitive advantage.

3.2 Design for X

Once those drivers are established, the next concern is translating them to design. As manufactured goods have proliferated, and constraints have become more prolific, designers can no longer design for only one criteria. There are numerous factors to consider in the design process, and the Design for X process has become the standard for integrating these factors. One of the most common is Design for Assembly (DfA)—designing products so that they can be assembled as quickly, easily, and inexpensively as possible. Other "X" include Manufacturability, Warranty, Serviceability, Supply Chain, Warranty, Environment, etc.

3.2.1 Design for Environment

One of these Design for "X" that is of concern here is Design for Environment.

> "Design for Environment (DfE) is defined as the systematic consideration of design performance with respect to environmental objectives over the full product and process life cycle. DFE takes place early in a product's design phase to ensure that the environmental consequences of a product's life cycle are taken into account before any manufacturing decisions are committed." [19]

There are published "design guidelines" that pertain directly to more environmental design.

> "Green product design, also known as design for environment (DfE), design for eco-efficiency or sustainable product design, is a proactive business approach to addressing environmental considerations in the earliest stages of product development process in order to minimize negative environmental impacts throughout the product's life cycle...It is not a stand-alone methodology but one that must be integrated with a company's existing product design approaches so that environmental parameters can be balanced with traditional product attributes such as quality, producibility, and functionality." [20]

Design for Environment is a relatively new concept. It varies dramatically depending on the product, and may include recycling, air pollution, hazardous substances, energy efficiency, and a host of other concerns. Design for Environment may also include measures to extend the useful life of products, like:

- Design for Upgrading and Adaptation
- Design for Reconditioning and Remanufacture
- Design for Repair and Reuse [21]

3.2.2 Design for Recycling

A further specialization within Design for Environment is Design for Recycling. There are many specific design decisions that help recycling processes. This is particularly relevant when the actual recycling process being utilized is fully understood, and when the information about that process is conveyed to the product designers.

> "As manufacturers come to rely more on recycled materials, they begin to alter their processes to facilitate recycling. Aircraft manufacturers stamp the alloy composition on parts during manufacture so that they can be easily identified during disassembly in order to facilitate recycling. Some leading automobile companies have been designing car components that can be easily removed and recycled when the car is discarded." [22]

Computer manufacturers like Hewlett-Packard have begun to design their products with end-of-life treatment and recycling in mind. In the following sections, the various Design for Recycling and Design for Environment programs of several electronics equipment manufacturers are discussed.

3.3 Design for Environment Programs at Electronics Firms

Information about Design for Environment programs has recently appeared in many companies' publications or on their websites. This chapter will discuss some of the programs and various firms' attitudes toward environmental responsibility and product design.

Traditionally, Scandinavian firms have enjoyed a well-deserved reputation for environmental leadership. As the rest of the world catches up, these firms have continued to push environmental product design with varying degrees of success. Nokia, a Scandinavian cellular phone and communications company, has a very informative website about their DfE program. On that site, they state, "Design for Environment (DfE) is an integral part of our environmental work—aimed at improving our products' impact through their whole life cycle." Nokia focuses on reducing material use and hazardous substances, reducing energy use, and recycling as much as possible. They provide a recycling assessment of a cellular phone as well.

Major competitors to HP include Canon, Epson, IBM, Sony and Lexmark. Canon and Epson, being Japanese firms, have fairly well established Design for Environment programs. Japan's culture and limited geographical area encourage environmental product decisions, and much of the initial Design for Environment work has come from Japan.

3.3.1 Hewlett-Packard

Hewlett-Packard posts Design for Environment guidelines on its public website:

> "HP's DfE guidelines recommend that its product designers consider the following:
>
> - Place environmental stewards on every design team to identify design changes that may reduce environmental impact throughout the product's life cycle.
> - Eliminate the use of polybrominated biphenyl (PBB) and polybrominated diphenyl ether (PBDE) flame-retardants where applicable.
> - Reduce the number and types of materials used, and standardize on the types of plastic resins used.
> - Use molded-in colors and finishes instead of paint, coatings or plating whenever possible.

- Help customers use resources responsibly by minimizing the energy consumption of HP's printing, imaging and computing products.
- Increase the use of pre-and post-consumer recycled materials in product packaging.
- Minimize customer waste burdens by using fewer product or packaging materials overall.
- Design for disassembly and recyclability by implementing solutions such as the ISO 11469 plastics labeling standard, minimizing the number of fasteners and the number of tools necessary for disassembly." [23]

All of the above are included in the Imaging and Printing Group's Design for Environment guidelines. The Recyclability Index includes those that are directly related to recyclability, like molded-in finished instead of paint. Coordination with corporate-level policy is important to long-term success of any Design for Environment initiative.

3.3.2 Canon

Canon shows "Environmental Activities" as a major link on their homepage (www.canon.com). This shows that environmental issues are very important to the company, or at least Canon recognizes the importance of environmental information to the public. The major company philosophy is "Kyosei", which means "living and working together for the common good". The resulting impact of Kyosei on Canon is described in the following paragraph from their website:

> "Canon first announced its kyosei corporate philosophy in 1988. Since then, we have taken the lead in tackling environmental problems. Our environmental initiatives, including a global recycling program for cartridges, symbolize our efforts to realize the kyosei corporate philosophy. The world is undergoing a major transformation from a "throwaway" to a "recycling" society. Not satisfied with the progress made to date, Canon is making progressive efforts for the next generation, including the creation of a total cyclical system unifying the development, manufacturing and sales functions, while supplying products that are increasingly friendly to the environment. Canon will continue its quest to become a truly global corporation by fulfilling its environmental responsibilities." [24]

Canon uses Life Cycle Assessment to identify areas to focus on in product development. They have identified energy use as the major environmental impact of most of their products. In addition, Canon says they have an Eco-Design System, which includes both design standards from suppliers and for recycling; and product assessment standards. The information available on their website suggests there is no significant feedback to product design. Canon uses Product Assessment Committees to evaluate designs and measure whether product divisions are meeting their goals.

3.3.3 Epson

Epson focuses on what they call "co-existence" of business and the environment. According to the company's 2002 Environmental Report, one major initiative is the development of eco-products. Epson has developed its own Eco-label for products that meet several criteria in the areas of energy-saving design, resource savings, and elimination of hazardous substances. In 2001, Seiko Epson (the parent company) published an environmental product design guide. Epson has begun using Life Cycle Assessment to quantify the environmental impact of their products.

Epson has recycling programs in seven countries and sets aggressive targets for recyclability of all finished products. This recyclability target was set at 65% in FY2001, and 70% for FY2003.

3.3.4 IBM

IBM publishes an extensive "Environment and Well-Being Report" and was one of the first IT companies to offer recycling to customers for a fee. The 2002 version of this report lists several Design for Environment initiatives, including energy efficiency, powder coatings, materials substitution, and plastics. Of note is that IBM uses large quantities of recycled plastics in its products—over 10% of total raw plastic polymer purchased is recycled material.

IBM established an Environmentally Conscious Products (ECP) program in 1991 with the following goals:

- "Develop products with consideration for their upgradeability to extend product life.
- Develop products with consideration for their reuse and recyclability at the end of product life.
- Develop products that can be safely disposed of at the end of product life.
- Develop and manufacture products that use recycled materials where they are economically and technically justifiable.
- Develop products that will provide improvements in energy efficiency and/or reduced consumption of energy.
- Develop products that minimize resource use and environmental impacts through selection of environmentally preferred materials and finishes." [25]

These objectives are integrated into IBM's Integrated Product Development guide. However, IBM does not give information about specific tools or metrics used for Design for Environment.

3.3.5 Sony

Sony has, like many other Japanese firms, identified the environment as very important to the company. This is visible in Green Management 2005, their most recent environmental action program. "Green Management 2005 comprises 16 chapters, each containing detailed and concrete goals to be accomplished by fiscal year 2005." [26] These include specific numerical targets in product and packaging material use, waste, energy use, and pollution. Sony has received numerous awards for various environmental activities.

Sony uses Environmental Accounting methods to evaluate the environmental impact in relation to sales for both individual products and the company as a whole. In the United States, Sony has started takeback recycling programs in Minnesota and Connecticut for electronic goods. These are test programs that may eventually be rolled out across the United States.

3.3.6 Lexmark

Lexmark, a manufacturer of printers and printing supplies, posts limited information on their website. They state that some of their laser printers have achieved Blue Angel status and that they are part of the Energy Star Program. There is no mention of any Design for Environment program. Although Lexmark has recycling programs for cartridges, there is no mention of recycling for printer hardware.

3.3.7 Summary

The companies all list goals as "recommended" or "whenever possible." In many of these guidelines and company information, nothing is definite. Because these areas are not much regulated yet and are still being developed, very few companies are willing to commit to absolutes. In addition, the effects on the bottom line are unknown, and in the short-term may appear as costs. For these reasons, many companies are yet unwilling to totally commit to absolute environmental guidelines.

3.4 Conclusion

Along with the legislative impacts of the Chapter 2, this chapter sets the stage for the current situation Hewlett-Packard faces. As discussed, the recycling processes and related challenges, the Design for Environment movement, and the competitors' programs all play a critical role in shaping HP's solution to adjusting to and facing these challenges. The following Chapter will discuss electronics recycling processes and some established models for determining end-of-life treatments.

Chapter 4: End-of-Life Treatment of Electronic Waste and Models

When a consumer has finished using an electronic product, such as a printer, and wishes to dispose of it, there are several options: recycling, reuse, landfill, and incineration. Reuse allows the product to be used without any processing, whereas recycling requires processing but reuses the materials. Landfill and incineration do not allow for any recovery of the original product.

Boks lists six types of technological development relevant to end-of-life processing:

- "**Sorting and handling technologies-** these refer to the way product streams are sorted and divided in useful batches of WEEE upon arrival at a recycling facility...
- **Disassembly technologies-** these refer to technologies, which are used to separate components from the main product and from other components. Disassembly technologies are usually manual operations, although in recent years much research has been devoted to automated technologies...
- **Shredding technologies-** these refer to processes that are used for shredding products or parts of products that remain after disassembly into smaller particles. Shredding is a necessary step before separation technologies can be used.
- **Separation technologies-** these refer to processes that are used to separate a particle mix consisting of various materials into fractions of (almost) the same materials. Separation technologies include separation on basis of for examples density, conductivity, colour, and weight.
- **Smelting technologies-** these refer to technologies that are used to obtain as pure as possible material from material fractions that result from shredding and/or separation processes. Smelting is for example used to obtain secondary copper and precious metals.
- **Incineration and landfilling-** these refer to burning and dumping of WEEE, or of any remaining fractions that may be left after the use of previous processing steps." [27]

This thesis will discuss some of these technologies in the following sections.

4.1 Reuse

Product reuse does not require any reprocessing or remanufacture; in the case of a printer, it can be used by a different owner as is. Reuse in theory sounds like a great alternative to disposal; however, "Reuse is a fuzzy concept. From a materials perspective, there is not much distinction between continued use and reuse." [28] In addition, reuse only prolongs disposal of electronic goods. In addition, to some extent, firms discourage reuse because the more used computers being sold in the market, the fewer new computers required, and the lower the sales. Thus, reuse is somewhat of a double-edged sword for the manufacturers.

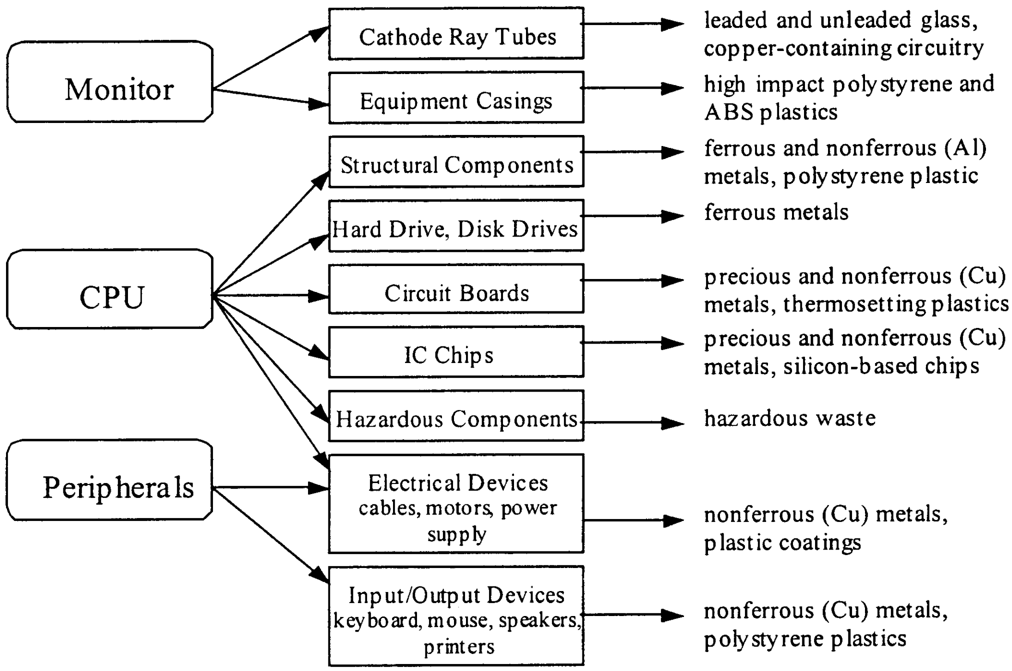
4.2 Recycling

Recycling is the reprocessing in a production process of the waste materials for the original purpose or other equivalent purposes. "Primary recycling recycles the material back into the same and a similar product, with minimal dissipation in the quality of the material (low entropy generation). Secondary recycling involves reprocessing the material into a product of lower quality, which means that there is some material dissipation (some entropy generation)." [29] Secondary recycling is also referred to as downcycling.

4.2.1 Material Composition of Electronics

There are many potentially valuable materials that can be recycled in computer electronics. These include ferrous materials, precious metals, plastics, glass, and others. These are shown in the figure below:

Figure 4-1: Recoverable Materials from Electronic Goods [30]



"There are seven primary categories of materials recovered from computers (eight if packaging is included): ferrous metals, aluminum, copper, precious metals (e.g. gold, palladium, and silver), glass, plastics, and hazardous wastes." [30] These materials can be recovered with varying degrees of success, depending on the recycling process.

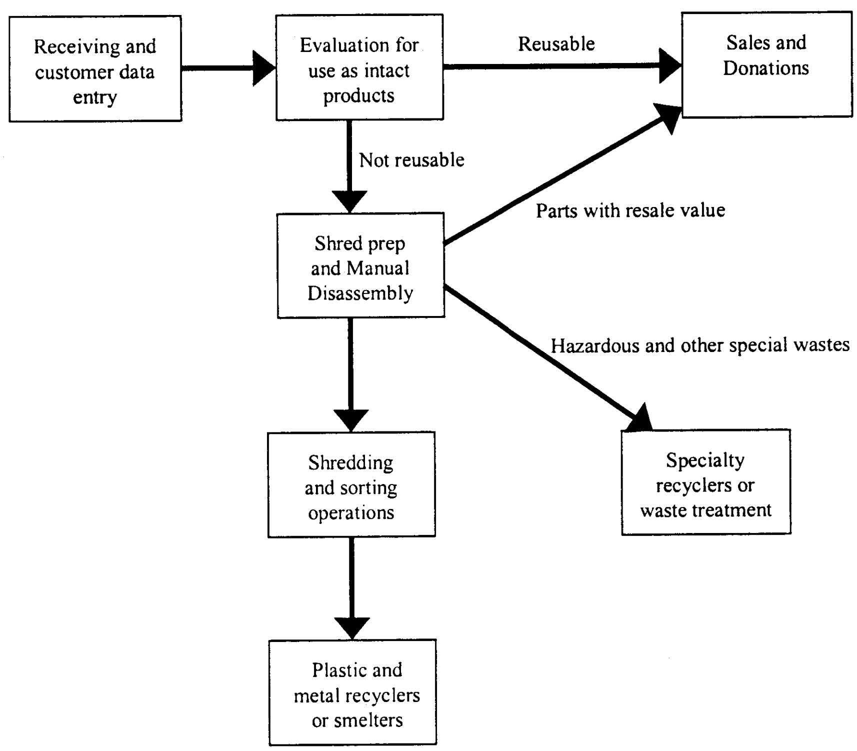
4.2.2 Electronics Recycling Process

Recycling of electronic goods has occurred for many years, but still relies on manual separation or basic principles of mechanical separation. In many places, recycling is a completely manual process; use of mechanical separation signifies a fairly sophisticated system. As a result of regulations and level of development, recycling techniques vary widely across the world. For example, in China, most disassembly is done manually, while in the United States and other more developed nations, machines do most of the work. However, because of input variability, completely automating the process is extremely difficult.

To create a tool that evaluates a printer's recyclability, one needs first to understand how to recycle electronics. A link between design decisions and better recyclability needs to be established. Unfortunately, the previous research on this topic is not extensive. There has been limited work published, mainly because the concept of recycling electronic goods on a mass scale is relatively new. In contrast, automobile recycling has existed for many decades and has evolved to the point where most cars are recycled in the United States.

The following is a typical flow of a major OEM recycler:

Figure 4-2: Recycling Process



Although giant "shredder" machines and mechanical separation techniques are used in the United States, there is also some manual disassembly done prior to shredding. This is for one of two reasons: 1) there are valuable components that can be removed and resold (like an processor), or 2) there are hazardous substances, which must be removed and treated separately.

Often manual disassembly is done before shredding. On an ink jet printer, the cover is generally removed first. The cover may be attached with snap fits and/or screws. If the cover is made of a single polymer, it is sometimes thrown into a separate bin for just that polymer, thus enabling pure plastics recycling. The next step is to remove those components that are either valuable or hazardous. Generally an ink jet printer will not have any components that are resalable as is. The ink cartridges are removed because ink can sometimes be hazardous and in large amounts can disturb the shredding process. In addition, cartridges are recycled separately. There are also some hazardous materials that must be manually removed before shredding in the European Union. As mentioned in the legislation section in Chapter 2, these include: printed circuit boards, batteries, mercury-scanner lamps in multi-function devices, and LCD displays over 100 cm^2.

As each of these things are removed, they are placed in appropriate bins. The printed circuit boards are generally sent to smelters to recover the copper and sometimes recover the other precious metals. Batteries are most often Nickel-cadmium or Nickel-Metal-Hydride. They are generally recycled through thermal processes where the metals are melted in a furnace and recovered. Mercury scanner lamps are recycled through high-temperature processes to recover the mercury, which can then be reused in other products. LCD displays can be recycled to recover the valuable materials contained in the display, like mercury.

Many other things are returned in the boxes as well, like users' manuals, CDs, Styrofoam, and cardboard. These are separated and sent to appropriate specialty recyclers.

The printer is then thrown into a shredder. A shredder is a giant machine with steel "teeth" that break apart the equipment into small pieces (generally from ½" to 3" squares, depending on the machine.) The materials are then mechanically separated after shredding. The machines require a huge initial capital investment of several million dollars, but greatly speed the recycling process and reduce the need for manual labor.

After the shredding process, which may occur all in one machine or in a series of machines, the material goes through a series of mechanical separation techniques. A typical process in the United States is the one used at PRS, HP's Recycling Center in Roseville, California. The first step after the shredder is a screen through which the copper and glass pieces are separated. Because they are the most fragile materials, they are generally broken into very tiny pieces by the shredder, even if the average material piece size is an inch or two square. This copper-glass mixture is sent to the smelter, and the glass is actually beneficial to the smelting process because it helps maintain the necessary high smelter temperature. This copper is then sold for use in new copper products.

Next a magnet is used to remove ferrous metals and separate them. Metals are generally very easy to recycle compared to other substances, both because of chemical structure and recycling technology. Thus, they are profitable to recover.

An eddy-current separator is used to charge the scrap so that the paper, foam, and other light pieces actually "jump" over the conveyer into a separate bin. Plastics are then separated and sent either for recycling or for incineration. That is, plastics are grouped together—separation by polymer is very unusual.

4.2.3 Challenges in Electronics Recycling

Some more complex recycling systems appear in Europe, where it has been either mandated by law or has been more accepted by the people and integrated into their daily lives. Simpler systems are used both in the United States and other developed countries.

In contrast, developing nations generally do not possess shredder technology, and thus have much more labor-intensive processes. In developing nations like China where labor is cheap and capital is expensive, this actually has become a major human rights and environmental problem.

Entire cities in China have been decimated by contamination of the air, water, and soil by giant piles of used electronics devices. According to a groundbreaking report by the Silicon Valley Toxics Coalition (SVTC), the IT waste problem is destroying entire communities in Asia. This report, "Exporting Harm," showed pictures of children playing in great mounds of waste electronic equipment and stated:

> "Until now, nobody, not even many of the reputable recyclers, seemed to know the fate of these "Made-In-USA" wastes in Asia and what "recycling" there really looks like…the field investigation revealed extremely hazardous and dangerous E-waste "recycling" operations that pollute the air, water, and soil of Asian countries. These operations are very likely to be seriously harming human health. Vast amounts of E-waste material, both hazardous and simply trash, is burned or dumped in the rice fields, irrigation canals, or along waterways." [31]

The electronic waste is stored in giant piles outdoors with no protection from rain. "These practices have been documented in China, India, Pakistan, Korea, and several other countries throughout Asia. U.S. brokers ship massive amounts of e-waste to Asia since they can make more money by export than is possible through 'recycling' in the U.S." [32] Workers sort computers by hand with no protective equipment for as little as $1.50 per day. Young children and women are exposed to numerous toxins at these sites. In addition, the hazardous chemicals leach in to the groundwater; in many places, the water is undrinkable and must be brought in from other towns. Through response to "Exporting Harm" report and resulting press, many of these situations have been curtailed. However, as long as the economics are more favorable, illegal operations to export used computer equipment may continue.

A second major challenge is the variability of products received by the recyclers. Because products reach end-of-life after different amounts of time, the incoming product mix could include products from many different manufacturers, product lines, release dates, and states of disrepair. This results in variable flow. In addition, a minimum amount of material is typically needed to run the shredder, which may result in batch processing. "To buffer against the unpredictable nature of a batch retrieval process, computer recovery firms compensate for intermittent flows by developing multiple sources of equipment. A consequence of this approach can be an extremely heterogeneous feed stream, which requires more information, learning, and shop floor flexibility." [33]

Another major challenge is connecting the product design with the recyclers; little information is shared by the manufacturer. "...reverse manufacturing demands new technologies of disassembly, which in some cases reveal a need for new technologies for assemblies as well. Collaboration between assemblers and disassemblers is often desirable to facilitate such technological developments, as reflected by joint partnerships and vertical integration to improve communication and control along the supply chain." [33] Recyclers generally do not receive bills of materials or design schematics for products. Therefore, identification of valuable parts is done by trial-and-error or based on past experience.

Electronics recycling overall is evolving. Although the current systems face many challenges, the legal responsibility and resulting mass of returned goods will promote technical innovation and better recycling techniques.

4.2.4 Plastics Recycling

One of the major challenges in electronics recycling is plastics recycling. Plastics recycling is more complex and less efficient than metals recycling. There are a number of critical issues that limit the effectiveness of plastics recycling. First, plastics properties can be diminished during the recycling process:

> "Because remelting of plastics for reforming tends to damage the polymer chains, most plastics cannot be recycled back to their original quality. Instead they are "downcycled" to less demanding products. For instance,

> a plastic lumber can be made from commingled plastic wastes that can compete with wood for park benches, roof shingles, fencing, deck flooring, and boat docks, although it has poor structural characteristics and cannot be used for tension or compression members." [34]

Second, polymer separation technology is in its infancy and rarely done on a commercial scale. MBA Polymers and Salyp are two of the better-known companies, but neither works on a scale comparable to metals recycling. Because polymers cannot be easily separated by basic physical techniques, the only existing technologies are proprietary, expensive, and small-scale. The results of one research study concluded, "Due to the heterogeneity of the typical batch, it was found that it was generally not economical to sort all plastics for recycling. This study found that most often only the highest volume polymers in any given batch of computer plastics were being sorted for recycling." [35].

Third, because of the intense processing required to recycle plastics, and the current limited scale at which that is being done, recycled plastics are often more expensive than virgin material. Finally, the large plastics producers sometimes buy recycled plastics processors and therefore can limit the use and threat to the profitable virgin materials business. There has been intense chemical industry resistance to recycled plastics—the traditional chemical companies continually downplay the technology, argue that the decrease of polymer characteristics is substantial, and raise the prices. Even those plastics manufacturers that have a recycled plastics unit, like GE polymers, keep prices high, relative to virgin material. The limited supply means it is also difficult to purchase recycled resin on a large scale. Recycled plastic suppliers have difficulty guaranteeing quantity and consistency of supply.

4.3 Incineration and Landfilling

Incineration and landfilling are both disposal techniques for waste. In the United States, where open land is plentiful, landfills are preferred. In Europe, where available land is severely limited and expensive, incineration is generally used.

There are, of course, issues with each. Landfilling requires unoccupied space and has the potential for leakage of toxics.

> "Incineration is usually not complete and a residual product is left behind (slag). How this residual slag is to be treated in an environmentally responsible manner, is one of the most important cost factors...This applies to an even greater extent for the purification of flue gases released during incineration, especially aggressive chloride and bromide-based gases. Combined with organic residues, these compounds can be the basis for dioxin production." [36]

Incineration produces air pollution and leaves toxic residue. This residue then must be landfilled or treated. However, sometimes the incinerator's heat can be harnessed and used to produce electricity—this process is called energy recovery. Although energy recovery does not occur at every incinerator, it is becoming more common due to improving technology.

4.4 End-of-Life and Recyclability Models

Extensive research has focused on the most eco-efficient end-of-life treatment for electronics goods. Many different models, both general and specific, have been created. These models "are classified into two main categories: methodologies and tools for the quantitative analysis and assessment of the environmental impact of products, e.g. Life Cycle Assessment (LCA); and dedicated design support tools for environmental performance improvements." [37] This section will first discuss a few of these models. Life Cycle Assessment is the most thorough and complex tool for environmental analysis of products. It is the ideal standard if time and information availability are not issues. However, as will be explained later in this chapter, a complete LCA is not the appropriate tool for a recyclability assessment. LCA includes production of the product and all raw materials and actual environmental impact during life as well as end-of-life issues. The Recyclability Index and similar tools are much smaller, less complex, and faster to use. A complete LCA could be done for each product in addition to end-of-life assessment.

4.4.1 QWERTY

Several models were developed by the team of Ab Stevels, who is both an environmental manager at Philips Electronics and a professor at the Technical University of Delft (TU-Delft). In these models, eco-efficiency is determined based on two parameters—an economic index and an environmental index. To have a higher eco-efficiency, a process or design can improve on either of the two scales. However, the best scores come from getting high marks on both scales. Stevels, Huisman, and Stobbe list three goals of end-of-life processing used in their models:

- Reduction of materials going to landfill, minimizing landfill volumes.
- Recycling of materials in order to keep maximum economical and environmental value.
- Reduction of emissions of environmentally relevant substances; including leaching from landfill sites and incineration slags, etc. [38]

The team has used these goals, along with the eco-efficiency concept, to develop an approach to evaluating recycling efficiency called QWERTY (Quotes for Environmentally Weighted RecyclabiliTY). QWERTY's purpose is to integrate environmental and economic. "Generally it can be concluded that addressing economical costs and revenues in relation to environmental costs and revenues on a quantitative way, is a powerful concept in rethinking about eco-efficiency of the end-of-life of consumer electronic products. Furthermore, better insights in the performance and the demands and constraints of secondary material processors are obtained." [39]

The QWERTY methodology is:

1) The costs and revenues as well as environmental impacts in various end-of-life scenarios are determined.
2) Boundary conditions are set: "The minimum environmental impact and minimum costs are defined as all materials being recovered completely without any environmental impact or economics costs of end-of-life treatment steps," and

maximum environmental impact and maximum costs are set as worst-case scenario. For environmental impact, maximum may be landfill with no recovery.

3) The actual environmental impacts and costs are expressed as percentages of the maximum and minimum boundary conditions. [39]

This method requires a significant amount of detailed information and assumptions about processing technologies. Since the recycling infrastructure is rapidly changing, and thus the future state is unknown, this method assumes a specific end-of-life treatment is used.

4.4.2 End of Life Design Advisor

The End of Life Design Advisor (ELDA) was developed by Catherine Rose for her doctoral thesis at Stanford University in 2001. ELDA is a software tool that uses product design characteristics to recommend the optimal end-of-life solution. It is based on actual end-of-life treatments in place and attempts to identify recommendations based on data from early in the design cycle. ELDA was created to be a design tool, although its output is an end-of-life treatment process.

The major issue with ELDA is that it assumes designers care about the best end-of-life scenario. In reality, designers care minimally about end-of-life treatment of their products unless mandated. ELDA does not provide any unit of measure to enable tradeoffs with other design considerations and designing for optimum end-of-life treatment is not a major concerns at most electronics firms yet. ELDA is useful to determine the best course of action for end-of-life treatment for an existing product, but has very limited potential for use in the design process. This is especially true for low-margin products that are very cost-constrained. In addition, according to Rose's thesis, "ELDA does not address other characteristics such as legislation, infrastructure, supplier and secondary material recycling, since design and manufacturing engineers have limited control over these issues." [40]

4.4.3 WebVDM

A group of researchers at the New Jersey Institute of Technology developed a tool called WebVDM to analyze disassembly strategy. The tool produces disassembly plans based on a variety of criteria and specific strategies. These strategies range from minimal disassembly to complete disassembly. "The process planner module in WebVDM has several expert rules programmed into it. These rules analyze the disassembly state at the end of each step, and then make alternative suggestions for potential next steps. In each iteration, the use selects a suggestion, WebVDM updates the state vector, and the plan is iteratively generated." [41]

The recommended disassembly process is then given in chronological order of disassembly steps, along with the estimated time for the step. Disassembly Effort Index (DEI) score is also a model output:

> "The DEI score is representative of the indirect labor cost to disassemble a product. This score accounts for the complexity and difficulty associated with each step. The model was developed from a survey variety of commercial disassembly facilities. Based on these surveys, a multi-factor weighted estimation scheme was developed. The seven DEI factors are (i) direct time, (ii) tools required, (iii) fixture required, (iv) part/fastener accessibility, (v) disassembly instructions, (vi) operating hazards, (vii) disassembly force requirements." [42]

Some of these same factors are incorporated in the Recyclability Index. While WebVDM focuses exclusively on disassembly, the Recyclability Index was designed to cover other categories as well. However, many of the relationships between design and ease of disassembly that result from this tool are similar in the Recyclability Index.

The WebVDM project also included analysis of disassembly economics. Included were the cost of labor, the difficulty of disassembly (base on the DEI), the expected market for reusable parts, and the expected market value of materials. This model was a reference in developing the Recyclability Index's cost model, although the WebVDM does not include reverse logistics (shipping) costs because it is minimizing disassembly costs, not the total overall cost. The Recyclability Index financial model was refined based on actual HP cost structure for recycling. This financial model will be discussed in Chapter 6. The Recyclability Index, however, does not consider expected markets for reusable parts or materials.

4.4.4 Review of Recyclability Tools

As was mentioned previously, there are two types of design tools. The first category includes a full quantitative assessment of all environmental impacts from the entire life of the product from production through end-of-life, such as Life Cycle Assessment (LCA). LCAs examine the environmental impact of every stage of a product's life, from material extraction through disposal. Although there are many commercially available LCA models, their intent is so different from HP's needs that none are discussed here. Vezzoli lists several difficulties with using the LCA approach:

- "the nature of the choices and assumptions in a LCA are subjective
- the models are not able to describe the whole spectrum of the environmental impacts
- the models are not adaptable to all applications
- on a global level, the results and the criteria can be inappropriate for local applications
- the lack or the low quality of the data can limit the reliability of the results" [43]

The LCA methodology is useful to truly understand the big picture of a product's environmental impact. However, for the reasons listed above, it is difficult and often impractical to use for every product in a fast clockspeed industry, such as at HP. QWERTY, while not a full life cycle assessment, is based on similar concepts to these models. QWERTY was not developed as a design tool to examine the effect of individual decisions. It is a more comprehensive evaluation of end-of-life issues for a particular product in a particular scenario.

The second category includes "design tools...for the improvement of specific environmental performance (dedicated tools) particularly in relation to the 'end of life phase'." [43] This includes ELDA, WebVDM, and the Recyclability Index. One major difference between the other two tools and the Recyclability Index is that ELDA and

WebVDM are designed to evaluate end-of-life options for an already-designed product, whereas the Recyclability Index is designed to be used to influence a product design based on a specific end-of-life treatment.

> "A lack can be observed of methodological research to position Design for Environment as a part of existing managerial concepts and business practices. Rather, it is often described separately without positioning it within a business context, taking into account all usual business aspects…research focusing on end-of-life issues has traditionally been very design and technology-focused, a statement, which can be substantiated by the pointing out the lack of literature studying simultaneously the process for identification, solving, prioritisation, and implementation of environmental issues in business contexts. Only in the last two or three years, the focus is (slowly) shifting towards the incorporation of economical and managerial aspects as well." [44]

The difference between ELDA's approach and the approach of the Recyclability Index is the drivers of design change—the Recyclability Index is based on legislation and cost issues. The Recyclability Index's main objective is not to reach the optimal end-of-life treatment from an environmental perspective. Rather, it is designed to help HP meet legislative requirements, minimize costs, decrease environmental impact, and balance these with other design constraints. The Recyclability Index project was constructed through a business lens, that of Hewlett-Packard. It was not through an academic or purely environmental perspective.

In addition, the Recyclability Index is designed with the intention of being frequently updated and modified. It is constructed in Microsoft Excel so that only minor computer programming skills will be required to make modifications, and the Product Steward can update it to reflect changes in regulations, recycling technology, or HP policy.

The literature offers few examples of design-for-recycling tools. Although many companies claim to have them, the details are not publicly available, so there are only academically-designed tools for comparison. HP's competitors' Design for Recycling programs were discussed in Chapter 3.

Chapter 5: Recyclability Index

This chapter will then explain the Recyclability Index and the development of the tool. The Implementation Process for integrating into the product design structure at HP will be discussed in Chapter 6. Results and analysis of the Index will be discussed in Chapter 7.

5.1 Recyclability Index Concept

The Printer Development Team's Recycling Strategy committee initially conceived the concept of a recyclability tool. It was then offered as an LFM internship. The purposes of the Recyclability Index are:

- To ensure WEEE Directive and RoHS Directive requirements for Europe are met
- To provide a way to make trade-offs with other design criteria (material costs, assembly, etc)
- To provide a metric which can be compared across time and printer generations
- To generate cost drivers which can then be used to quantify end-of-life costs

The Recyclability Index is an Excel-based tool to evaluate printer designs in terms of recyclability and to enable designers to make informed decisions. The tool consists of several sheets:

- **Data entry-** Lists all the questions and has drop-down menus to select answers. Input page in the model.
- **Explanation-** includes all questions, answer choices and resulting scores as well as regulatory background on each question. Serves as the "look-up" source for data entry questions and the rest of the file.
- **Calculations-** all of the calculations for percent recyclability and other scores are done and explained here.

- **Summary**- output sheet which shows scores, graphs, and other data in one simplified page
- **Assumptions**- lists definitions, basic assumptions, and Blue Angel analysis.
- **Engineer**- guidelines with questions, answers, and goals to be used as a reference for designers and engineers.
- **Finance**- shows data inputs for financial model; provides space for financial analyst to enter results

The following sections of the thesis will explain the development of the Recyclability Index and discuss each of the above components in detail.

5.2 Development of the Recyclability Index

The first step in developing the actual Index itself was determining what the output should be. Through the interviews with engineers and designers, as well as the client, a basic idea of what output would be useful was sketched. This included the Percent Recyclable (by the WEEE Directive definition), an overall score, and the two categories that generated the most negative effect on the score.

In the initial project definition exercise a comparable potential format was suggested. When someone applies on-line for a mortgage to determine credit rating, he or she is given a score, an explanation of what that means, the two things that most boosted the rating, and the two things that most damaged the rating. This overall package of information is small enough to fully comprehend but broad enough to provide a good understanding of the whole situation for the user.

The beginning steps in the project were as follows:

1) Interviews with external experts
2) Interviews with internal stakeholders in customer assurance, corporate environmental, internal management consulting organization, packaging and other corporate standards groups, European teams

3) Interviews with engineers, designers, program managers, project managers, and procurement engineers in Printer Development Team
4) Data gathering from industry conferences, academic journals, competitors' websites, non-governmental organizations, government regulations

A sampling of the job functions interviewed in the initial data gathering are listed in the following table:

Table 5-1: Interviewees

Job Title
Customer Assurance Consultant
Packaging Coordinator
Plastics Procurement Specialist
Internal Strategy Consultant
Lead-free Initiative Coordinator
Design for Environment Expert
Europe Operations Director
Hardware Recycling Coordinator
European Lobbyist
United States Lobbyist
Product Steward, Supplies
Product Steward, Laser Jet
Product Steward, Large Format Printer
Corporate Design for Environment Coordinator
Program Manager
Industrial Designer
Electrical Systems Engineer
Procurement Engineer
Senior Financial Analyst

Each interviewee was asked three key questions: 1) What do you do in your job?, 2) What do you know about the WEEE Directive?, and 3) Who else should be interviewed?. In addition, each person was asked, "What can be done to ensure that the Recyclability Index is used and continued to be used after the internship?" The major suggestion of the design community was to "put it in dollars"; therefore, an estimate of end-of-life treatment costs was added to the output desirables. These ideas and suggestions were incorporated throughout the Index's development. The results of these meetings and comments from the stakeholders will be further discussed in Chapter 6.

5.3 Data Entry Questions

Although this gave a vision of the desired output, the most work-intensive portion of the development process was creating the Data Entry Questions. A long list of questions was compiled from Blue Angel guidelines, the WEEE and RoHS Directives, HP's own General Specification for the Environment (a document given to all subcontractors), industry recommended Design for Environment guidelines, and academic research. Blue Angel in particular was used because it has specific standards for ink jet printers, and HP applies for Blue Angel certification for most ink jet products. During the process, work was done in coordination with the HP Design for Recycling expert at HP's Product Recycling Solutions center. This is crucial because what the Index measures should correspond with what really is important at the recycling stage.

The questions cover four main categories: materials, disassembly, hazardous substances, and value recovery. The full list of questions is included and discussed later in this section.

From this master list of questions, the relationship between the design choice and the recycling process was determined. For example, if the cover is made of only High Impact Polystyrene (HIPS), does that make a pure recycling stream, which can be recovered and sold? Or is it irrelevant to the recycler because the printer is thrown in the shredder without disassembly anyway? Masanet, Auer, Tsuda, Barillot and Baynes followed the effect of design choices on computers through the recycling phase in research at Apple Computer Company. They found that some "traditional" Design for Environment guidelines were only helpful in conditions of purely manual recycling. They looked at six Design for Recycling guidelines in both pure manual recycling and auto-shredder recycling. The effectiveness of each is shown in the Table 5-2:

Table 5-2: Prioritization of DfR Guidelines for Plastic Components [45]

#	DfR Guideline	Effectiveness for Manual Systems	Effectiveness for Automated Systems	Design Priority
1	Use of ISO labels for parts > 25 g	High	Low	High
2	Use of one polymer for all large parts	Low	Low	Low
3	Limiting the use of paints	High	High	High
4	No molded-in or glued-on metal parts	High (molded-in only)	Low	High
5	Use of one color for each polymer type	Low	Low	Low
6	Use of snap fits where possible	Medium	None	Medium

As their research shows, some of the standard Design for Recycling guidelines are not relevant in certain recycling scenarios. Use of one polymer for all parts is a common suggestion; the research here shows it to be of low importance in recycling. Unfortunately, research in this area is very limited. In speaking with the author of this study, he was unaware of other similar research on other DfR guidelines. However, in the absence of academic research, conversations were held with recyclers in both the United States and Europe to ask about specific Design for Recycling guidelines during this internship.

In addition, the evolving nature of electronics recycling technology also affects the list of valuable questions. Visits to recyclers in Europe validated and negated some of the questions chosen for Version 1.0 of the Recyclability Index. For example, glass-filled plastics had been on the list of "unrecyclable materials" on Version 1.0. The thought was that, similar to painted plastics, the technical difficulties associated with recycling glass-filled plastics were significant enough to warrant a negative score. However, the German recycler Elektrocycling said glass-filled plastics do not hamper plastics recycling and therefore are not a concern. Although the glass fibers are damaged, and thus the material produced from recycling glass-filled plastic does not retain its properties, the overall impact on the greater plastic in negligible. After the discussions with the recycling companies, the question about glass-filled plastics was removed from the Recyclability Index.

The list of questions was narrowed down to those that: 1) have a direct effect on the recyclability of printers, technically and/or from a cost perspective; 2) can be changed or modified through the product design; and 3) can be measured, at least on a relative scale. The Index is designed for small, incremental design changes, not major shifts in the core architecture of products. There are some fundamental product changes that are not included in the Recyclability Index. For example, it is impossible to have an inkjet printer without some ink storage (like a cartridge); changes of that magnitude would not be included here.

That list was then checked for redundancy and separated into the four broad categories of Materials, Disassembly, Removal of Hazardous Substances, and Value Recovery.

5.3.1 Content of the Data Entry Questions

The questions were each chosen based on their direct relevance to recycling and the end-of-life treatment process. They are listed below, along with the supporting explanation, which frequently will include the regulatory citation.

1. How many types of plastic on the case parts?

At many recyclers, the case parts are removed and thrown in resin-specific bins. If there are many types of plastic in the case parts, it may be too time-consuming or impractical for manual separation. The Blue Angel Eco-label has a specific set of standards for ink jet printers. Per Blue Angel Annex 1, Paragraph 3.3, "Plastic cases are to be made at most of four separable polymers or polymer blends." [46] However, the "jewel" (the small plastic "HP" tag) should not be counted as a separate plastic.

2. How many types of plastic in the paper tray alone?

According to the Blue Angel Ink Jet printer standards section B.1: "Is the variety of materials forming plastic components of similar function limited to one polymer or polymer blend? The smaller the number of polymers and polymer blends the more efficient are isolation and separation processes." [46] For the same reasons as in question one above, the number of polymers should be limited.

3. Can the plastics be recycled (not just downcycled)?

A major concern in recycling operations is that products are turned into valuable raw materials, not downcycled. Per Blue Angel B.4: "Are the materials used recyclable by the material on a high level? [46] 'Recyclable by the material' stands for those materials which can be recycled on an industrial scale, hence technologically and economically useful. 'High level' means that a recyclable comparable with the original material (original utilization) can be achieved for a similar use." Recycling of plastics is highly dependent on the type of resin used and its after-recycled properties (e.g. polycarbonate can be sold and reused in similar products). The plastics that are most likely to be recycled for an equivalent use are those that are not painted, not filled with glass fibers, and have no labels. Also, those plastics with the highest virgin resin prices are the most likely to be recycled (PC > ABS > HIPS in 2002).

4. Are all plastics >25 g marked?

There is a basic International standard (DIN/ISO 11469) that requires all plastic pieces greater than 25 grams or with more than 200 square millimeters of available space to be labeled with the polymer type. This label is a requirement for ink jet printers per Blue Angel as well.

5. What percentage of the plastic is post-consumer recycled material?

Although using recycled material in a product does not affect the recyclability of that product, it "closes the loop." For recycling to work, there needs to be both supply and demand. According to Blue Angel B.5: "Is the proportional use of recyclate permitted and admissible according to the product specification? A real 'cycle' does not exist before the manufacturer actually uses recyclate goods." [46]

6. Are all major plastic parts (> 0.5 lb) uncontaminated by metal pieces, cork, adhesives, etc.?

Plastic pieces that are contaminated with too much of other materials will likely be sent to incineration or landfill because recycling is too difficult. To qualify for the IT ECO Declaration Voluntary Standards (P6.6), "Plastic parts are free from metal inlays that cannot be removed by one man alone with a standard tool." [47] In addition, per American Plastics Council, metal rivets are too difficult to remove. One small piece of another material will not prevent recycling; however, highly contaminated pieces are cost-prohibitive to recycle.

7. Is any plastic painted or coated?

Many recyclers will not accept painted plastics; generally painted plastic is landfilled or incinerated. It is not technically impossible to recycle, it is just too difficult and costly. As stated in Blue Angel guidelines B.3: "Is the coating of plastics components limited to a minimum? Large surfaces of lacquer, vacuum coatings, and printings on plastic components shall not be considered as printings." [46] Also, for the IT Eco-declaration Voluntary Criteria (P6.2), "Painting/varnishing of plastic materials has been avoided" is required. [47]

8. Are there molded-in labels?

Molded-in labels create no adverse effects on recycling. They are the ideal labeling method. Paper based labels can be dissolved and removed, although it does require work. Plastics of different resins than the plastic part they are attached to should be avoided. Per IT ECO Declaration Voluntary Standards (P6.7): If labels are required, they should be inherent and separable." [47]

9. If plastic labels are used, are they the same polymer as the part they are attached to?

If plastics are not the same polymer, they must be separated in order to recycle the plastic, which is very difficult. If they cannot be separated, the plastic piece and label will probably be incinerated.

10. How much must be done to remove the cover?

The cover must be removed in order to reach the hazardous components inside. If more time and effort is required to remove the cover, more labor is required, and the recycling process is more expensive.

11. How many plastic housing case parts are there? (excluding paper tray, keypad mechanisms, LCDs, and decals)

If there are more plastic case parts to remove, then more time and labor are required.

12. How many tools are required for disassembly? (count snapfit tool as one, plus each screwdriver separately-- each size of regular, Phillips, or specialty screwdrivers)

Switching tools takes time; and in manual disassembly, this switching time increases labor costs. This is also a Blue Angel requirement (A.7): "Standardized and uniform connecting elements make disassembly easier. The less the tools have to be changed the easier is disassembling." In addition, it is easier and less expensive when a standard set of tools can be used to disassembly everything. A second Blue Angel question (A.4) asks: "Can assembly be done with all-purpose tools exclusively?" [46]

13. Are there any issues of clearance for reaching a fastener or snap fit? How many snapfits or screws are difficult to access?

If it is more difficult to reach a fastener or snap fit, more time is required, which leads to higher labor costs. In addition, special tools or techniques may be necessary if the fasteners have clearance issues, potentially resulting in more time and expense.

14. Are at least half the plastic connections snap or plug fits?

This is a Blue Angel standard (A.8): "Are at least half the separable connections between plastics components plug or snap connections? The share of plug and snap connections forms the basis for the evaluation of the selection of dismountable connecting techniques." [46] Snap fits take less time to separate than screws, saving on labor costs and disassembly time.

15. Can disassembly/removal of hazardous components be done by a single person?

The cost of labor is higher for two workers than a single worker.

16. How many printed circuit boards > 10 cm2 are there?

Printed circuit boards are an issue mainly because of a WEEE Directive requirement: printed circuit boards greater than ten square centimeters must be removed prior to any mechanical processing. Each additional printed circuit board requires additional labor time to locate and remove.

17. After the casing has been removed, how long does it take to remove each Printed Circuit Board greater than 10 cm^2?

This is related to the previous question. Since each board must be removed, the more time it takes remove the board, the more labor is required, and thus the more expensive the equipment is to recycle. For example, a printed circuit board could be held in place with two screws or ten screws. With an estimate of six seconds to remove each screw, a few extra screws per printer can result in a fair bit of additional time per day.

18. Is a lead-based solder used?

Lead solders will be banned in the European Union in 2006 per the RoHS Directive. No product with lead solder can be imported into the European Union after that date.

19. How easy is it to trace the electronics module?

Per the Blue Angel requirements (A.2): "Are electronics modules easily traceable and removable? The minimum recycling strategy means: removal of the pollutant freight.

Electronics modules and components which involve the risk of ingredients containing harmful substances must be easily traceable and separable." [46] This again relates to labor time and potential for hazardous substances getting into the smelting and mechanical processes.

20. Are electronics modules attached to the case?

This is another Blue Angel requirement (A.11): "For the purpose of a quick removal of harmful substances and a quick and clean separation of the electronics fractions all electronics modules ought to be attached to the chassis. Control parts attached to the case and case parts serving as chassis are not considered as case parts." [46]

21. Is there a battery in the printer?

Per the WEEE directive, batteries must be removed prior to mechanical processing. Also, in both China and the EU, Hewlett-Packard must report all batteries, provide an MSDS, and pay fees based on the number of batteries sold. In addition, there are transportation regulations for lithium-containing batteries. These all create additional complexity and regulatory requirements.

22. Does the battery contain lead, cadmium, or mercury?

Cadmium, lead, and mercury must be phased out of all HP products between 2006 and 2008 under the RoHS Directive.

23. After removing cover, how difficult is it to remove battery?

The more difficult the battery is to remove, the more labor time is required, and thus the recycling is more expensive.

24. Is the battery location obvious?

The more time spent searching for the battery, the more labor is required, and thus the greater the costs.

25. Does the outside of printer have markings that there is a battery?

Batteries must be removed prior to mechanical processes. Recyclers need to know if there is a battery in a product. Per the IT ECO Declaration Mandatory Requirements (P2.1): "If batteries, defined as hazardous, are used in the product they are labeled." [47]

26. Is there a mercury lamp?

The WEEE directive mandates that mercury lamps be removed prior to mechanical processing. They are an exception to the RoHS mercury ban. Although PDT ink jet printers do not contain mercury lamps, HP does produce All-in-One devices on the same ink jet platforms. These All-in-One devices contain a printer, copier, and scanner. The scanners often use mercury lamp technology.

27. After removing cover, how difficult is it to remove the lamp?

The more difficult to remove the lamp, the more labor time is required, and thus the higher the cost.

28. Is there an LCD display greater than 100 cm2 or backlit with a gas discharge lamp?

Per the WEEE Directive, LCD displays that are greater than 100 square cm or backlit by gas-discharging lamps must be removed prior to mechanical processing, so this is an additional step in the disassembly process. Like the other steps mentioned above, it adds additional time and labor expense.

29. Can it be removed quickly?

The more difficult to remove the LCD, the more labor time is required, and thus it is higher the cost.

30. Is Cadmium used at a percentage greater than 0.01 % by weight in any coating or material?

RoHS Directive bans the use of Cadmium in the European Union starting in 2006.

31. Is Chromium used in any plating or elsewhere in the printer?

RoHS Directive bans the use of Chromium in the European Union starting in 2006.

32. How easy is it to remove the ink cartridges with the power off?

Cartridges must be removed before shredding processes. Sometimes, the cartridges lock when the power is off, and cannot be removed without removing the whole carriage. This requires additional effort and labor time.

33. After cartridge removal, how much plastic (by weight) is potentially contaminated with ink and spitting?

Contaminated plastics cannot really be recycled, and are generally sent for incineration or landfilling. Some of the inks are considered hazardous according to chemical legislation, and thus cannot be simply washed off into a waste stream.

34. Is ink contained and thus easily removable?

Too much excess ink can contaminate the materials during the shredding process, and some inks are even considered toxic, so it is preferable that the loose ink in the printer is separated and can be removed. This is frequently accomplished by including a sponge in the printer design.

35. Is there any part that would be of significant value to remove and re-sell?

Selling of recovered parts can provide revenue, which offsets some of the cost of recycling. Although this is uncommon for low-end ink jet printers, some examples of resalable parts are a microprocessor in a laptop computer or a fan in a large server.

Those are the thirty-five questions that were determined to have the greatest effect on recycling technical feasibility and costs. The Index is structured so that these questions can be changed as recycling technology, legislation, or cost considerations change.

5.3.2 Assigning Values to the Answers

Particularly challenging was assigning numerical values to the answer choices. Engineers overwhelmingly requested numerical metrics and not just qualitative data. Therefore, it was decided to calculate an overall Recyclability Index Score in addition to percent recyclable. After considering several methods, the method chosen for assigning value was:

1) Create a list of potential answers for each question
2) Determine which answer is "status quo": what would be the typical answer for an average printer in 2002.
3) Assign that answer a value of zero.
4) Assign positive and negative values for those answers that are better and worse than status quo.
5) Assign the magnitude of the positive and negative values based on an evaluation of their impact on the cost and ease of recycling, as well as overall recyclability.

The interrelations of design decisions are seen in the Index; one decision can be reflected in multiple questions. For example, using a different type of plastic polymer for a case part so that it can be painted affects questions about materials, paint, and potentially labels since labels cannot be molded in to painted plastic pieces.

The scoring system is the most qualitative part of the Recyclability Index. Whereas the weight of parts can be measured, the value of using molded-in labels instead of plastic ones is much more difficult to quantify. Although a detailed cost analysis of the recycling process could theoretically have been done to determine a financial cost of each individual change, for three reasons this is not value-add. First, it puts all the value in the cost of recycling or the theoretical recovery of a material; ignoring the relevance to other factors. Second, because recycling technology and methodology is far from uniform, the translatability of these values is suspect. Finally, these kind of detailed numbers are too specific for the designers and engineers to care about; simply, it is too much information that provides no real value. Essentially, the result would be very precise but not very accurate.

For these reasons, the Recyclability Index score was created. While imperfect by its very definition, it provides a simple, recognizable metric that can be used by HP to quantify recyclability, recycling costs, and overall Design for Recyclability in a single number.

5.4 Calculations

The calculations that appear on the Summary sheet are all done on the sheet labeled Calculations, including: scaling the score, category scores, percent recyclable, and disassembly times.

5.4.1 Scaling the Score

The data entry questions are added to get a raw score. These numbers are not easy to relate to other metrics, so, at the suggestion of an HP Product Steward, the numbers have been scaled to a −100 to +100 scale. The scaling is done to preserve the concept that "zero" is a status quo printer with positives being better and negatives being worse; the scaling function keeps the score on the same side of zero. This scaling occurs automatically in the Excel file calculations, and thus only the official score appears on the Summary sheet.

5.4.2 Category Scores

The 35 questions were separated into four major categories and thirteen sub-categories, which are used to identify the areas for improvement. These four major categories are Materials, Disassembly, Removal of Hazardous Substances, and Value Recovery.

Each of these categories and subcategories' actual and maximum raw scores are calculated and then compared on the Calculations tab. A simple Visual Basic program is used to sort this list and identify the two subcategories where the actual score is furthest from the maximum score. These two subcategories then appear on the Summary sheet.

This identifies to the user the two areas where small changes can make the most substantial impact.

5.4.3 Percent Recyclable and Recoverable Calculations

Percent recyclable is a difficult calculation because there is no official legal or even generally accepted methodology available. Therefore, this calculation was developed based on interpretation of the WEEE Directive, advice from the Hewlett-Packard Product Recycling Solutions, and HP's European organization.

The calculation is shown below:

Percent Recyclable

Mass of recyclable portion of the mechanism + Mass of recyclable plastics + Mass of clean metal + Recyclable portion of printed circuit boards = Total Mass Recyclable

Total Mass Recyclable / Total Mass of Printer = % Recyclable

Several key assumptions are required. First, it is assumed that it is possible to recycle all clean metal, all clean plastics, and the copper and precious metals portion of printed circuit boards. Painted and contaminated plastics are considered unrecyclable, which is a conservative assumption. Also, it is assumed that the majority of the printer mechanism by weight is recyclable metals; a small portion is unrecyclable (plastic, foam, or other materials.) The percentage used in the Recyclability Index, based on data from recycling centers, is 20% non-recyclable, 80% recyclable.

The definition of recoverable is recyclable plus that which can be burned for waste-to-energy. It is assumed that the plastic portion of printed circuit boards will be burned in the smelting process but cannot be recycled. Thus, this plastic portion is considered to be recoverable but not recyclable in these calculations. Painted and contaminated plastics can also be incinerated. The resulting calculation is as follows:

Percent Recoverable

Total Mass Recyclable + Remaining Mass of Printed Circuit Boards + Contaminated Plastic + Painted Plastic = Total Mass Recoverable

Total Mass Recoverable / Total Mass of Printer = % Recoverable

These calculations are fairly conservative—for examples, painted plastics are technically recyclable but are considered unrecyclable here since major recyclers do not accept painted plastics. The Recyclability Index percent calculations can be modified if the EU establishes an official methodology.

5.5 Financial Models

The end-of-life cost model is an integral part of the Recyclability Index's broader use. In order to compare with other costs, like materials and assembly labor, there has to be a dollar figure. For this reason, an HP Financial Analyst has developed a model.

Important cost data to consider in recycling are:

1. "Sorting, registering, transportation, and buffer storage costs
2. Integral costs for shredding and separation
3. Costs at primary copper smelting:
    a. Treatment charges, analysis and administration costs, as well as price adjustments percentages for recovered metals.
    b. Refining charges and unit deductions for copper, silver, gold, and palladium (including concentration dependencies).
    c. Costs for penalty elements like arsenic, chlorine, mercury, lead, antimony, and bismuth.
4. Costs at ferro and aluminum smelter processes
5. Costs at incineration sites, both MSW incineration and special waste incineration, also including charges for all environmentally relevant materials (concentration dependent)
6. Costs at landfill sites, also including charges for all environmentally relevant elements occurring in disposed consumer electronics (concentration dependent).
7. Costs for plastics recycling including cleaning and upgrading, color sorting.
8. Disassembly costs based on disassembly times for standard operations.
9. Revenues paid for all recovered materials." [48]

This data is easy to find after end-of-life but is incredibly difficult to estimate with any accuracy for three to five years in the future. In addition, it would be excessively time consuming to gather all the data. Because of the rapid pace of change in the industry, the costs would likely change dramatically before the products currently in design actually reached the end-of-life.

The Recyclability Index generates factors, which then can be used by the Finance Department in their models. The financial estimates can be used to understand the effects of design decisions on the bottom line.

5.6 Additional Sheets: Engineering Guidelines

After looking at Version 1.0 of the Recyclability Index, one designer requested a simple set of guidelines so designers know on what they are being evaluated. These guidelines print out to less than three pages, and list the Recyclability Index questions, answer choices, and a brief explanation of the question and why it is important. The answer choices are designated then with goal levels. This helps identify the importance of the factor and connection to the overall goals. The Recyclability Index guidelines appear on the tab "Engineer" in the Excel file.

5.7 Additional Sheets: Assumptions

One tab in the Excel file ("assumptions") lists many of the assumptions made in the file as well as definitions of many key words. Part of this sheet, the working definitions, is shown in Appendix A. Many of the assumptions are listed on the individual sheets (particularly Calculations) and are identifiable throughout the file by blue shading. Also included on this page is a Blue Angel analysis, listing all of the Blue Angel requirements for ink jet printers and how and where the requirement was incorporated into the Recyclability Index.

5.8 Outputs of the Model

The Recyclability Index returns several things based on the input data. To easily convey these results, the output is organized into a Summary sheet, which is shown in Figure 5-1.

Figure 5-1: Summary Sheet Output

Recyclability Index Tool

invent

Results Summary for: Brand A- Printer 3 **3-Oct-02**

The total score was **24**

out of 100 possible

And the Impacts (from each category):

category	score	out of
Materials	36	100
Disassembly	10	100
Removal of Hazardous Substances	0	100
Value Recovery	0	100

The two criteria that most negatively impact the total score:

1 Plastics polymer selection
2 Disassembly casing/cover

WEEE Compliance

Minimum of 65% Recyclable and 75% Recoverable by weight

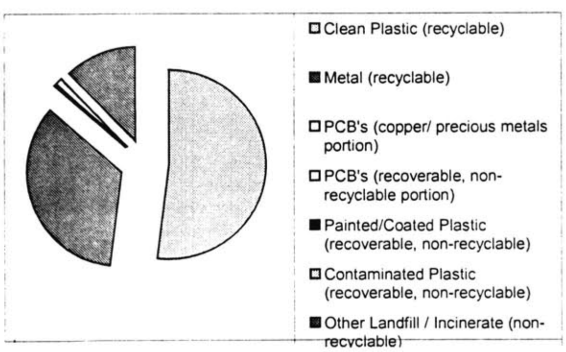
This product is	87% Recyclable	**COMPLIANT**
This product is	88% Recoverable	**COMPLIANT**

88% Recoverable

1% Waste to Energy

87% Recyclable

12% Landfilled



End-of-Life Costs

This works out to cost of recycling of

	per printer	total
EU		
North America		
Japan		
Asia		

This sheet first gives the overall score on the –100 to +100 scale. On the left side, the scores in each of the four categories are shown, along with the maximum possible score for each. If then lists the two subcategories, chosen from the list of thirteen, which are furthest from ideal. These are the areas where making a design change would have the greatest impact on the overall score. Below that is a pie chart of the materials in the printer by weight. On the right side, there is a result of the WEEE Compliance test and a simple graphic to illustrate recyclable, recoverable, and waste portions of the product. Below that are the financial estimates for the cost of end-of-life treatment. For confidentiality reasons, none of the actual financial data will be shown in this thesis. Finally, the bottom of the page summarizes major assumptions and methodology.

The goal is to have a simple one-page sheet for the design teams summarizing only what they need to know. If the engineers want more detail, they can always open the whole Excel file. However, this provides a "quick and dirty" summary and allows for trade-offs with other criteria. The process for using this Summary sheet and the tool as a whole is explained in Section 5.10.

5.9 The Environmental Question

One question that must be addressed is that of the environmental result of design changes. There are many environmental issues with IT equipment. Many of the hazardous components may be fairly benign during the product's use, but become particularly dangerous if the product is landfilled or incinerated. In landfilling there is always the possibility of leaching and contamination from hazardous materials. With incineration, air pollution and the production of toxic gases are serious human health issues.

The substances that are of particular concern in electronic equipment are described in Table 5-3:

Table 5-3: Environmental Issues with Electronic Equipment [49]

Substance	IT Source	Human Health Effects	Environmental Effects
Cadmium	Semiconductors, batteries, older Cathode Ray Tubes, stabilizer for PVC	Causes renal dysfunction, skeletal damage, and reproductive problems. Also suspected to be carcinogenic.	Toxic to aquatic life, cause growth-related problems in mammals
Lead	Printed circuit boards, soldering, batteries, glass for Cathode Ray Tubes	General poison, especially to children and pregnant women. Damages the nervous system and circulatory system.	Chronic toxicity for plants and microorganisms. Bioaccumulates in shellfish.
Mercury	Batteries, thermostats, scanner lamps, relays and switches	Can damage the brain and cause birth defects and mental disability.	Bioaccumulates in certain types of fish. Poisons birds.
Chromium VI	Batteries, stabilizers	Carcinogenic. Less information available than other heavy metals.	Insoluble in water, can become concentrated in the food chain.
Brominated Flame Retardants	Printed Circuit Boards, Plastic Connectors and Casings, Cables	Can damage the liver and thyroid.	Bioaccumulates in animals like fish, causes liver and other damage to animals.

Often these substances are released into the environment as a result of landfilling or incineration. Therefore, European legislation either bans the chemicals entirely or requires separation and treatment prior to disposal. The attitude toward environmental issues is very different in the United States than Europe. Much of this stems from the difference in availability of resources and land for disposal. "Indeed there is little evidence of materials scarcity in the United States...The easy solution has not extended to the problem of wastes. Historically, wastes have been less of a factor in determining materials development because for a long time they were so easily discharged to the environment with little economic cost." [50] Since HP is based in the United States and must work under American business pressures, financially, it would not be viable for HP to focus only on environmental issues and not on other business concerns.

On a smaller scale, this issue plays out with individual products: to make a "perfectly environmental" product is not feasible and certainly not practical. As a bottom line, the product must sell and make money. Being excessively green at a very high cost may not allow the company to make enough profit to stay in business.

Any environmental decision at HP related to product design must be made relative to all of the other important factors, hence trading off with Assembly, Warranty, etc. Painted plastics are generally not recycled; this is a trade-off the designers need to make. A second example is the use of steel for the printer base and structural parts. From a recycling perspective, steel is much easier and cost-effective to recycle than plastic pieces. However, steel is also more expensive to purchase, resulting in higher direct material costs; and steel is much heavier, resulting in higher shipping costs.

It is highly unlikely a design will ever score a perfect 100 on the Recyclability Index, nor is it necessarily a good idea to do so. Most likely a perfect-scoring printer would be very expensive to produce and potentially have no market. If design changes can be done without significant adverse changes in cost or other factors, then they may be something to reach for. However, a perfectly green printer would probably be expensive and potentially unattractive to a customer.

5.10 How the Recyclability Index Will Be Used

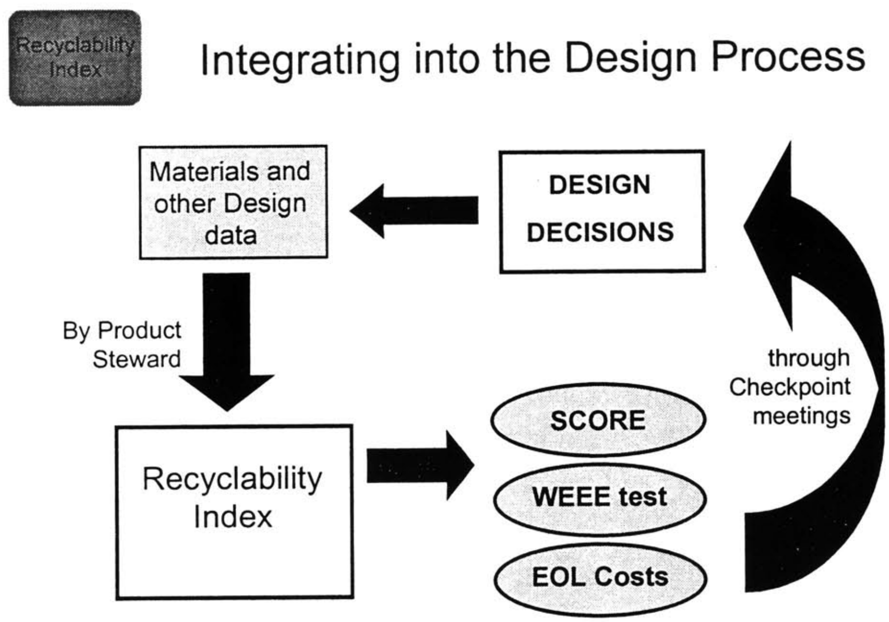
The process at Hewlett-Packard for using the Recyclability Index depends on the Product Steward. One important result of the interviews with the design community was that they did not want another task or responsibility. For this reason, the Product Steward will own the tool.

There are generally five major checkpoints in the design cycle for each product. At the initial goal-setting checkpoint, the Product Steward will identify the scores of competitor and previous-generation HP products as well as set recyclability percentage and overall Recyclability Index score objectives. Before each checkpoint, the Product Steward will collect design information from the engineers and industrial designers, and then enter this data in the Recyclability Index. She will then report the expected score at the checkpoint meeting. These meetings are the forum to make tradeoffs between various criteria. Environmental and recyclability issues have only been discussed qualitatively at these meetings in the past. However, with the Recyclability Index and the resulting quantitative data, including expected recycling cost, the Product Steward will be able to discuss tradeoffs on an equal level with other criteria.

In addition, using the Recyclability Index Summary sheet, the Product Steward can recommend design changes. The team's knowledge and experience can then potentially identify changes which can be made at no additional cost. For example, on a recent printer design (Printer Y), the printed circuit board was placed under the mechanism in a difficult-to-access location. Although this is a negative from a Warranty and Assembly standpoint, it saved an inch in the overall printer height. That decrease in overall size results in lower direct material cost and shipping cost. However, this printer circuit board is now very difficult to remove in disassembly for recycling. Perhaps if the Product Steward had been able to offer quantitative cost data at that meeting, the location of the board would have been moved to the top. On the other hand, it is possible that the direct material cost savings would still have outweighed the total serviceability, assembly, and recycling cost savings from moving the board. However, now that conversation can take place. The Product Steward will have a tool and actual data to support any design change requests.

Figure 5-2 shows the process vision for using the Recyclability Index. As is illustrated, after each checkpoint meeting, there will be design changes, which will then be incorporated the next time the Recyclability Index is run.

Figure 5-2: Design Process



After a product's design is finalized, the Recyclability Index score will be calculated and recorded for historical comparison. Although expected recycling costs may not be comparable over time, due to changing market and technology changes, the overall Recyclability Index Score should be comparable across printer generations. This allows the PDT to track improvement. The various printer models can also be compared. In working with the engineers during the initial baseline evaluations, the internal competition was evident. Every engineer wanted to know how their printer compared to the other current designs. This internal competitiveness could be used as motivation to improve the product designs.

In December 2002, the pilot printer model was begun with the Recyclability Index. This new printer, Printer Z, was between checkpoints one and two of the design cycle at that time. A meeting was held with the Project Managers and Product Steward. Together, the group walked through the Recyclability Index and answered the questions to the best of their knowledge. Although some design details, particularly the industrial design, had not yet been determined, most of the Index could be filled out with relative certainty. Printer Z is using the same mechanism as a previous printer and similar design to another previous printer, so much as the data was assumed to be the same as the prior products. A meeting was then held with the electronics engineer to complete the form. The Recyclability Index then produced a Summary sheet for Printer Z, which was emailed to and discussed with the members of the Printer Z project team. Based on this data, PDT can be fairly certain Printer Z will meet the WEEE Directive requirements. However, some recommendations were made to the design team, such as switching from a plastic label to molded-in labels, which the team accepted. As Printer Z approaches the next checkpoint, the Product Steward will update the Recyclability Index and share the results.

5.11 Conclusions

The Recyclability Index tool is unique because it has been designed specifically for the Printer Development Team of HP and encompasses both technical and managerial issues. It is very specific to HP's needs, simple to use, quick, and was created with input and involvement from many stakeholders. However, it is also easy to understand and easy to adapt, so it can be modified for other HP products.

The creation of the Index was a major project; however, the implementation was equally important and more difficult. This Implementation process will be discussed in Chapter 6.

Chapter 6: Implementation of the Recyclability Index

A tool has no value if it is not actually used. The development of the Recyclability Index is only half the internship project; the second half is implementation—integrating the Recyclability Index into the design process and institutionalizing it at Hewlett-Packard. This project is only successful if the Recyclability Index is used after the internship concludes.

The following are objectives of the Implementation process:

1) helping engineers understand how their design decisions impact recyclability
2) establishing the Index score as a measured objective on the Metric Sheet
3) making tradeoffs with other considerations (assembly, etc)
4) gaining visibility with different levels of management
5) gaining buy-in from designers and engineers
6) establishing processes to continue after internship concludes
7) spreading the Index to other divisions of HP

This chapter will discuss the process of implementation and the resistance encountered.

6.1 Input During the Development Process

As the project began, it became apparent that the project needed early and frequent involvement from the stakeholders. There are several reasons for this: 1) the stakeholders know and understand the product development process and the company, 2) their inputs ensure the tool is actually something of value, 3) they become personally involved and thus less resistant to change, 4) the tool will more likely be used after the internship finished, 5) stakeholder involvement creates opportunities for learning in both directions.

The stakeholders interviewed are listed in Section 5.2, and their interests will be discussed later in this chapter. This section will focus on the creation of a process for use and integration into the design process, in contrast to creation of the tool itself. At the initial stage of the project, before the Index was envisioned as little more than an amorphous concept, engineers and designers were approached. They were all asked about changing the design process to make more environmentally and recyclability-conscious decisions.

A common response received from the engineers was "we would be happy to do it if we knew how." The engineers did not understand the impact of their design choices on recycling and the environment because that information had not been conveyed, partly because it is not available or definite. However, they did not want yet another list of "guidelines"— guidelines already exist for a number of areas. In addition, designers must optimize numerous criteria. The design criteria for new product designs, particularly in low-margin products like ink jet printers, include:

- Direct material costs,
- Assembly process and costs,
- Competition,
- Features,
- Marketing recommendations,
- Technological advances (i.e. dots per inch (dpi), pages per minute (ppm))
- Warranty concerns,
- Schedules,
- Other products in HP's line,
- Compatibility with HP hardware,
- Software engineering, etc.

With so many forces pushing the design in different directions, the addition of another criteria is often met with resistance. This resistance is often unrelated to the criteria itself; it is resistance to yet another constraint. For that reason, the process of integration into the design process and overcoming that resistance was equally important as the development of the Recyclability Index itself.

Interviews were held with engineers, industrial designers, project managers, and program managers before construction of the Recyclability Index began. These meetings served two purposes: 1) education about upcoming legislation and the recyclability question and 2) gathering ideas and suggestions from them as to how to develop the Index and what it should look like. Because these stakeholders were asked for opinion at the very beginning of the project, they were personally invested, and more likely to be supportive of the Recyclability Index. In addition, a great concern for any internship or short-term project by a temporary person is that it will be furloughed and not be used once the creator is gone. Every interviewee was asked, "What can be done to ensure this is a valuable and actually used tool?" Their answers were extremely helpful:

- "Put it in dollar terms. That is a unit everyone understands."
- "Make it simple and easy to understand."
- "Give interim updates of process so people are in the loop."
- "Make scales relative rather than absolute so it can adapt with a changing market."
- "Don't make the engineers enter the data in the database themselves."
- "Explain simply where the numbers come from."
- "Don't be too Europe-focused."
- "Split out an Assumptions page and put assumptions on the Summary sheet."
- "Be explicit about what is good and what it bad (i.e. positive score is better)."
- "List goals and targets for each question."
- "Make the tool 'easy to be relatively' accurate." [51]

Several key decisions in format and structure of the Recyclability Index were made as a result of these conversations. In addition to the above comments on tool structure, many people offered suggestions for implementation and gathering support. These will be discussed in the following section.

6.2 Hewlett-Packard Cultural Change

Many of the stakeholders offered suggestions for managing change at Hewlett-Packard and specifically on the Printer Development Team. In particular, the internship was sponsored by an internal consulting organization that assists people in the divisions in creating roadmaps, designing and instituting new processes, and managing change. Their experience proved invaluable in this process. Suggestions from colleagues in this consulting organization included specifics about change in PDT in particular:

- "Entire group is very relationship-driven at PDT, not hierarchical."
- "Most processes are implicit, not explicit and may be hard to discover."
- "Job positions do not mean influence—there are a lot of informal leaders."
- "Find passionate people to champion implementation."
- "Look at environmental issues as a Sales/Marketing issue."

As a result of these early discussions, emphasis was placed on finding the informal leaders and gaining their buy-in on the project. A significant amount of time was spent talking to people at PDT and trying to better understand the product development processes there. Also, the first topic in these discussions with engineers was always recyclability as a legal and as a sales issue. Overall, it was much easier to gain support by talking to the right people, not necessarily the people with the most senior job titles.

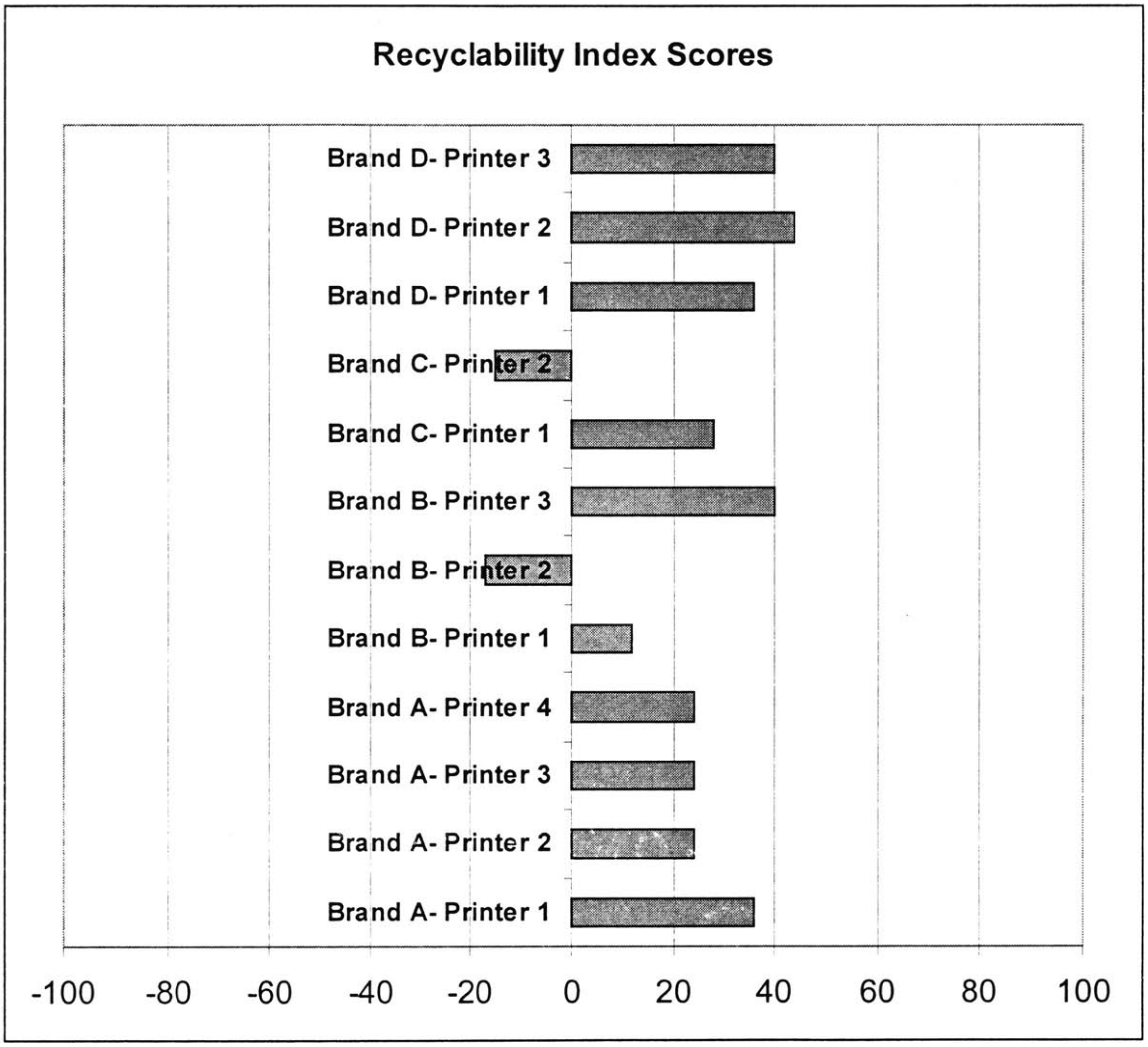
In meeting with some of the informal leaders and the influential Program Managers, several key ideas were discussed for implementation. These people have brought about change in a division that is used to financial success, technological leadership, and a position of power within Hewlett-Packard. It is more difficult to change a successful organization than one in crisis.

One important recommendation was: "It has to be something they are measured on or they won't care." For engineers to consider recyclability as more than an afterthought, it has to be on their evaluations. As will be discussed in Chapter 7, a focus was to have the Recyclability Index Score added as a metric on the same par as technical features and direct material costs.

A second key recommendation was "have competition and current standards to benchmark." Competition is a great motivator, so analyses were prepared for competitor products. The scores of several competitors' and HP's printers are charted in Figure 6-1.

The simple graph, with data labels detailing the brands, provided an instant visual motivator for the engineers.

Figure 6-1: Recyclability Index Scores Comparison



Finally, the third key recommendation was "Sell it as a barrier to entry," a Sales and Marketing concern. The way the WEEE Directive is written, if a company does not comply, that company cannot sell in Europe. That simple statement proved more powerful than any other argument in convincing engineers and designers to care about recyclability. Eventually, that became the opening line used in every meeting.

These internal recommendations were used during the implementation process. An external framework for implementing change is discussed in the following section.

6.3 Implementing Major Process Change

Creating a tool is the easy part when compared with getting people to actually use it because the tool itself is a technical problem, whereas use of it is a people problem. Understanding the human dimensions has the potential to improve the likelihood of success in influencing people to progress towards more sustainable production and consumption systems." [52]

According to a framework for overcoming resistance in managing change, several things are critical to successful transitions. [53] According to the authors, one needs critical mass and a commitment plan to make any organizational transition take place. For the Recyclability Index, the critical mass necessary was a significant number of engineers and some key project managers. In addition, informal leaders, those people who have great power that does not come from their job title, were specifically targeted. These people have the power to influence change simply by their actions.

The article lists several intervention strategies for overcoming resistance:

- "Problem finding
- Educational intervention
- Resistance management
- Role modeling
- Changing reward systems
- "Forced" collaboration" [53]

These strategies and their use in this project are discussed below. A variety of techniques are necessary for true organizational change.

6.3.1 Problem Finding

"Problem finding is one such neutral mechanism...It assumes that the very process of clarifying an issue or problem, as opposed to problem solving or action taking, will be unthreatening enough to encourage commitment." [53] In this project, the Recycling Strategy committee identified the problem before the internship began:

> *New legislation requires Extended Producer Responsibility and Design for Recycling. How can HP best meet these requirements and even turn it into a competitive advantage?*

6.3.2 Educational Intervention

Educating the engineers and designers was particularly important because the information was new to many of them. One technique used was to educate on basic information and then allow them to reach the same conclusion on their own. In the first meeting with one industrial design manager, whom we will call Joe, Joe was adamantly opposed to the idea of further limiting his designs. He has so many other restrictions placed on him that his initial reaction was immediately to resist and protect his right to control his job. Therefore, rather than trying to force the Design for Recyclability goals and ideas on him, a different approach was taken.

First, Joe went to visit HP's recycling center in Roseville, California with a team of Procurement staff and engineers (and no environmental staff). He watched the process himself and collected his own observations. Ironically, while he was at the facility, the workers were disassembling an older line of printers for which he had been the major designer. This particular printer was so difficult to disassemble that the workers were throwing the printers on the solid concrete floor to break the casings. Watching them throw his creation on the floor created an "Aha" moment for Joe.

When he returned from the trip, Joe held a debriefing for his whole design team. At this debriefing, he showed pictures and talked about the need for better Design for Recycling.

He talked about legislation, and made some design recommendations. The engineers' faces had looks of shock; they had never even heard of the WEEE Directive. One raised his hand and asked, "But how are we going to know how to do this? How will we even know if we're meeting the requirements?" Joe then pulled the Recyclability Index up on his computer and the projector and introduced it to the team. Basically, the engineers identified a need at this meeting, and then immediately received a solution. The buy-in created by this one event was incredible, and it came from Joe, the least likely of supporters.

A few weeks later, Joe voluntarily attended a Design for Environment session given by Ab Stevels of Philips Corporation. By studying the problem himself and not being forced into anything, he had reached similar conclusions and even became an advocate for the Recyclability Index. In a feedback memo after the internship concluded, he wrote:

> "With WEEE recently passing it is imperative that HP take seriously the implications associated with DfE/DfR. The cost impact to HP will be significant. If we properly design, implement, and market various DfE/DfR programs it will most likely place us at a competitive advantage. The biggest challenge with the Recyclability Index tool will be to get management buy off (i.e. measurable metric added to the program objectives.) I think it [the Recyclability Index] could be useful. I think that is should be useful….I also felt that [intern's] desire to get input from future users should only help to make the document more successful in meeting the intended goals."

A second activity undertaken for educational purposes was the PDT Poster Fair. The PDT hosts an annual poster fair in which people from throughout the division can exhibit new technology and management ideas. The Recyclability Index was featured on a poster at this event, and thus was introduced to people throughout the division. In one day, hundreds of people were introduced to the WEEE Directive and Design for Recycling. The exposure provided also forged connections with engineers who were personally interested in these issues.

6.3.3 Resistance Management

"Resistance to change in organizations takes many forms; change managers need to analyze types of resistance in order to work with it, reduce it, and secure the needed commitment from the resistant party." [53] The key to understanding resistance is understanding the true reasons behind the resistance. In the case of the Recyclability Index, no one is opposed to helping the environment; no one said, "I want to pollute. I want to produce products which cannot be recycled." Rather, they are concerned about additional demands on their jobs and additional requirements, which may result in higher costs or not meeting other requirements. The resistance is almost instinctual to yet another constraint on design. The culture at HP is resistant to change in some ways.

The response taken to this was to design the Recyclability Index in such a way that engineers saw it as adding little or no work for them. It was very important that responsibility for actually using the Recyclability Index remained with the Product Steward; therefore the engineers were not given additional responsibility.

6.3.4 Role Modeling

This particular technique focuses on the demonstration of commitment by upper management or leaders. At the executive level of HP, there is definitely interest and vision for environmentally responsible product design. CEO Carly Fiorina has identified sustainable development as a key component of HP's strategy. HP was a major sponsor and the information technology provider for the United Nations Summit on Sustainable Development in 2002. Through various statements made to the press, it is clear that HP sees sustainability and environmental issues as something to be concerned about.

At a divisional level, there is some support from management as well. The PDT Manager and his senior management team authorized the Recycling Strategy committee and have provided funding for various initiatives. In addition, the Recycling Strategy committee gives presentations on project status and future directions on a regular basis to this senior management team. By giving both time and money, the management at PTD is showing support for initiatives like the Recyclability Index.

6.3.5 Changing Reward Systems

Early in the project, it became clear that engineers had to be evaluated on a given metric for that metric to even be considered. Every engineer said, "If I'm not evaluated on it, it goes to the bottom of my list." For this reason, getting the Recyclability Index score as an institutionalized metric was a goal of the internship. That was the only way to ensure the change would be institutionalized.

The score was added as one of the thirteen metrics on an Overall Metric Sheet for PDT. This metric sheet was introduced in 2002 and first used on one particular product. It will slowly be institutionalized across all the PDT products. Inclusion in the metric sheet institutionalized the Recyclability Index. Now that the engineers are measured on it, they are concerned about improving the Design for Recyclability.

6.3.6 "Forced" Collaboration

"Forced" collaboration is when the people have no choice but to comply with the change. Here, if a company does not comply with the WEEE and RoHS Directives, the company cannot sell products in Europe starting in 2005. HP has such a significant business in Europe that the threat of losing that critical market makes everyone pay attention and care. Thus, the design teams are forced to design to at least the minimum recyclability.

6.4 The Environmental Business Case and Change

The motivations for implementing a Design for Environment / Design for Recycling program may not at first be obvious. The Environmental departments in American corporations have long occupied the place of "those annoying people who place restrictions, cost money, and never help the business." Instead of business creation or cutting costs, the activities have often been limited to legal compliance. However, that seems to be changing.

More and more companies are working on creating "The Business Case for Sustainable Development." Companies are attempting and actually finding ways for their environmental decisions to be economically beneficial for the company. The generally accepted definition of sustainable development, offered by the World Commission on Environment and Development, is: "Sustainable development seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future. Far from requiring the cessation of economic growth, it recognizes that the problems of poverty and underdevelopment cannot be solved unless we have a new era of growth in which developing countries play a large role and reap large benefits." [54]

Responsible corporate citizenship has been a tenant of HP's philosophy for years, and environmental responsibility is a crucial piece of that. In addition, innovation is core to the company's philosophy and image. HP's logo that appears on products, advertising, and correspondence, states, "HP invent." "Innovation is also a sustainability issue. First, sustainability requires new products and services that are less greedy of natural resources, create less pollution and waste, and are more affordable to poor people." [54] HP's long history of responsible corporate citizenship and culture of innovation make it more responsive to a project such as this one. The PDT is inventing ways to make products more recyclable and less damaging to the environment. The Recyclability Index is part of a larger project focused on minimizing energy consumption, emissions during use, material use, end-of-life impacts, and hazardous components throughout the Imaging and Printing Division.

Although the topic of integrating sustainable development principles into business decisions is not new, many companies have found it much more difficult in practice than it at first seems. This process requires a radical shift in thinking along the lines of:

- "Moving from seeing only costs and difficulties in the concept of sustainable development to seeing savings and opportunities

- Evolving from using end-of-the-pipe approaches to pollution to using cleaner, more efficient technologies throughout entire production systems and, further, seeking to make sustainable development integral to business development
- Changing from linear, 'throughput' approaches to systems and closed-loop approaches
- Moving from seeing environmental and social issues as the responsibility of technical departments or experts to seeing these issues as company-wide responsibilities
- Changing premises of confidentiality to ones of openness and transparency
- Changing from narrow lobbying to more open discussion with stakeholders." [54]

Every one of these shifts was part of the process of this internship. Developing the Recyclability Index is of no value if it is not used by anyone in the organization and not incorporated into the design process. Each of the shifts is discussed in detail below, including how it was addressed during the course of the internship.

Traditionally, environmental aspects of business have been seen as a cost—meeting regulations, installing pollution-controlling equipment, adding more expensive energy-saving components. However, for the Printer Development Team, the shift to thinking of sustainability as an opportunity has already begun. The Recyclability Index is one project under the umbrella of a larger team, the Recycling Strategy committee.

Changing from end-of-the-pipe strategies to changes further upstream is core to this project. The whole concept of the Recyclability Index is to create ways to make decisions at the design stage to make recycling easier at the end-of-life. By designing easy-to-remove components in the printers, the entire end-of-life situation is addressed proactively, rather than tacking on something at the end of the pipe. In addition, by starting from the design phase, HP looks at much more of the product's lifecycle and resulting environmental impacts.

By working as a project team incorporating procurement, marketing, recycling, and finance, all aspects of the product's lifecycle are considered. The cross-functional team is able to contribute opinions and ideas on each project to keep the view broad and systems-level, rather than just on one stage in the product lifecycle. The team's research is now playing a key role in a larger HP supply chain and end-of-life modeling process.

Environmental issues at the HP divisions are primarily the responsibility of the Product Steward. However, although accountability rests with that position, the objective of the Recyclability Index is to educate the design community about the effects of their decisions, and to enable them to make tradeoffs based on these decisions. The Index was not designed in a vacuum with just the Product Steward—engineers, designers, and even financial analysts gave input into its design. The situation is similar to Quality Management, which once was the responsibility of a specific individual full-time, but eventually became part of everyone's job. Environmental management should eventually become part of every designer's responsibilities. In the near future, however, responsibility must remain with the Product Steward to ensure things are being completed and nothing is overlooked.

As laws like the WEEE Directive come into effect, environmental responsibilities will no longer be able to be compartmentalized. Companies who see the larger picture and understand the value of cross-functional teams and concurrent engineering will incorporate environmental concerns with other areas to find the best overall solution. Companies who choose to only meet the minimum compliance may see greater costs in the long run. HP views long-term strategy as a company strength, and thus will attempt to meet these requirements at a broader level.

To change from confidentiality to openness is an ambitious and multi-layered goal. Within PDT, this is accomplished by "scoring" HP's current designs as well as competitor products using the Recyclability Index, and then making that information available throughout the division. By using a quantitative metric and openly showing the methodology, the team hopes to eliminate accusations of bias. The data can be used to chart progress much like other metrics. On a company-wide scale, this means sharing results across divisions, and being open about design decisions and their reasoning. Outside of HP, the decision to share information about recyclability is for the company to make. At this point in time, no other companies are sharing their models or results, so HP will keep the Recyclability Index proprietary for the time being.

Finally, stakeholders are a major consideration at every step of the process. This project at first glance seemed to fall under the Product Steward's interests; however, the actual stakeholder community reached across functional and divisional lines. Obviously the Recycling Strategy committee and the PDT Product Steward are stakeholders because they identified the need and sponsored the project. The other Product Stewards are stakeholders because they were involved in the creation process, validated the models, and will adapt the tool for their own divisions. They have great interest in a result that is useful to them.

A corporate-level organization exists that is tasked with creating company-wide environmental policy. However, the communication between that group and the Product Stewards is poor. Corporate Environmental was informed about the project and asked for input early in the creation of the Recyclability Index, but otherwise provided no support. The European team was very involved in the project; they have a direct interest since they are responsible for the actual takeback and recycling in Europe. Previously, their contact with the design teams had been quite limited. This project provided a way for their learnings to be communicated back to the design teams. The people in the European Team were consulted throughout the project, and the team leader approved the WEEE Compliance calculation used in the Recyclability Index.

Of course the designers and engineers in PDT are stakeholders as well. Their daily jobs will be impacted by the project. Finally, the Product Recycling Solutions (PRS) group, which runs HP's own recycling center, was extremely involved in the project. The people at PRS have significant knowledge and experience that was leveraged throughout the project. The Recyclability Index will be used to make their jobs easier and hopefully decrease costs. Another group of stakeholders are the consumers who buy HP's products.

Although these shifts in thinking are radical if done in one step, they can be implemented slowly to allow people to acclimate and reduce resistance. Overall, the Printer Development Team was very open to many of these changes, and most of the shifts had begun before the conclusion of the internship. Although if blatantly asked about taking one of the above steps, the engineers' response would be tentative and wary, overall the entire division accepted the Recyclability Index. Most of the feedback was constructive, and people were very open to the ideas presented because they felt the Index was fair and objective. This is not to say every engineer on every project is using it without question, but the Index is slowly being integrated into the design process for the PDT.

One of the most important lessons an environmental manager can learn from this experience is that changes to more environmental ways are rarely successful when done "for green's sake." Rather, they must be shown to correlate to some business reason, whether it is regulatory compliance, revenue generation, cost avoidance, or creation of competitive advantage. Approached from these angles, and fully supported by financial evidence, the environmental idea can be "sold".

Chapter 7: Results and Analysis

The Recyclability Index can be run either with design data, such as CAD drawings and Bills of Material, or determined from disassembling an actual product. This allows Hewlett-Packard to analyze competitor products by disassembling the printers, since HP does not have access to competitor design data. Scores were produced for several printers by tearing down the products and filling out the Recyclability Index.

7.1 Results of the Model

This section will first discuss the results of percent recyclable then the Recyclability Index Score and category scores.

The recyclability percentage was determined using the calculation methodology described in Chapter 5. The following table shows the recyclable and recoverable percentages that were calculated. For some printers, the data was insufficient to do this calculation because the printers were borrowed and had to be reassembled. Therefore, it was not possible to disassemble to a point in which a reliable calculation could be made for percent recyclable.

Table 7-1: Printer Recyclability and Recoverability

Printer	Recyclable %	Recoverable %
Brand A- Printer 2	87%	87%
Brand A- Printer 3	88%	89%
Brand B- Printer 2	45%	79%
Brand B- Printer 3	77%	93%
Brand C- Printer 1	73%	90%
Brand C- Printer 2	66%	85%
Brand D- Printer 2	70%	80%
Brand D- Printer 3	71%	81%

The WEEE Directive requirements are that all products must be at least 65% Recyclable and 75% Recoverable. Again, recoverable is defined here as recyclable plus that material which can be burned for waste-to-energy. As the table above shows, most of the printers above should easily meet the WEEE Directive requirements. In addition, the calculation was done using the method developed for the Recyclability Index; the European Union may introduce a different methodology at some point in the future.

The Recyclability Index outputs much more than percentage recyclable, however. The results of the teardowns and analyses are summarized in the Table 7-2:

Table 7-2: Printer Scores by Model

Printer Model	**Overall**	**Material Selection**	**Dis-assembly**	**Haz. Materials**	**Value Recovery**
maximum score	***100***	*%*	*%*	*%*	*%*
Brand A- Printer 1	**36**	43%	30%	0%	0%
Brand A- Printer 2	**24**	29%	30%	-33%	0%
Brand A- Printer 3	**24**	36%	10%	0%	0%
Brand A- Printer 4	**24**	29%	-10%	100%	0%
Brand B- Printer 1	**12**	43%	-40%	33%	0%
Brand B- Printer 2	**-17**	0%	-80%	33%	0%
Brand B- Printer 3	**40**	50%	30%	0%	0%
Brand C- Printer 1	**28**	36%	10%	33%	0%
Brand C- Printer 2	**-15**	-14%	-60%	67%	0%
Brand D- Printer 1	**36**	57%	30%	-67%	0%
Brand D- Printer 2	**44**	64%	20%	0%	0%
Brand D- Printer 3	**40**	50%	40%	-33%	0%

As the chart shows, all the scores were positive except two. Overall, Brand D scored the highest, though Brand A scored respectably.

7.2 Analysis of the Results

The Brand C- Printer 2 and the Brand B- Printer 2 received the lowest scores overall. This was primarily because both printers are painted almost entirely silver, and painted plastic is extremely difficult to recycle. In addition, the Brand C printer has five separate Printed Circuit Boards, which require time and effort to remove in manual disassembly. The Brand B- Printer 2 was extremely difficult to disassemble, with an excessive number of screws holding the cover in place. There were also a few Printed Circuit Boards, all of which were difficult to remove. For both printers, the two categories furthest from ideal were Printed Circuit Boards and Coatings (painting).

In comparison, the highest scoring printers were not painted and had limited the number of Printed Circuit Boards. The Brand D- Printer 2, the highest scoring printer of this group, was very easy to disassemble, used molded-in labels, and had only one Printed Circuit Board.

While a significant number of the printers scored similarly (24 to 40), they earned the points from different categories. There was significant variation in the four categories across the printer brands. Brand A printers are very simple and easy to disassemble, as shown by the scores in that area. Scores for Brand A printers in Material Selection are lower than average because Brand A does not label the plastic parts and uses plastic labels instead of molded-in or paper labels.

Brand B's Printers 2 and 3 score well in the Materials category. However, all the Brand B products scored poorly in the Disassembly category. Brand B printers are by far the most time-consuming and labor-intensive to disassemble. In addition, the Brand B-Printer 1 has three Printed Circuit Board greater than ten square centimeters in area. This results in additional manual disassembly in end-of-life treatment.

Brand C's two printers evaluated had very different scores. Printer 1 scored well overall, but Printer 2 scored negatively because of painting and multiple circuit boards. In Hazardous Waste, both printers scored above 0. However, because the two printers were so different, it is difficult to make many generalizations about the brand.

As discussed above, the Brand D products overall score quite well on the Recyclability Index. Brand D scores particularly well in Materials and Disassembly. However, the overall scores are hurt by poor results in the Hazardous Materials category. This is generally a result of ink contamination and poor ink containment inside the printers. If the ink waste is not properly contained in the printer housing, it can contaminate plastics, metals, and other components. This makes recycling difficult and potentially dangerous, as some inks become combustible in the shredder.

The most interesting observation is that each company seems to have different strengths. One example is the excellent snap-fit system used by Brand A for the printer cover. The snap fits are well labeled and easy to release. A second example was an interesting metal decorative feature used by Brand D. Only a few tabs held the lightweight piece of metal to the printer top; this eliminated the need to paint the plastic, as the same shiny silver look was achieved.

There are several benefits of this competitive analysis. First, on a broad scale, it enables benchmarking with the competition and establishes baselines for future designs. Second, it identifies strengths and learnings from other designs, which may enable HP to make more recycling-conscious decisions. Third, it validates the model and was used midstream to refine the data entry questions and answers.

7.3 Measures of Success for the Project

The success of the Recyclability Index can be measured by several different metrics. First, success can be measured by Hewlett-Packard's satisfaction with the Index, and more importantly, implementation of the Recyclability Index into the design process. In addition, the spread of the Recyclability Index to other divisions of Hewlett-Packard can also show institutional acceptance.

From a long-term perspective, Hewlett-Packard can measure the success of the Recyclability Index by cost savings. The true impact of using the Index will be seen several years in the future when the products being designed today come back. The institutionalization of the Index will show success; that is, if it is used in every division across the company. If designers and engineers are evaluated on their design, and the end-of-life treatment costs are included in Profit & Loss statements, then the value of the Recyclability Index will be more apparent.

In broader terms, success can be measured by the environmental impact. Reduced environmental impact, less waste, and more efficient use of resources are all ways to evaluate this project. In addition, if HP can lead other companies to design more recyclable products, then there will be a large cumulative impact.

7.3.1 Hewlett-Packard Response to Project- Printer Development Team

The response from the PDT Product Steward to the Index was very positive. Because she was intimately involved in the development of the Index, she was able to ensure the final product was one that would be useful and value-add to her job. The PDT team that first conceived this project was pleased with the Recyclability Index and its potential to unify with other tools, such as cost models. Finally, the design community in the Printer Design Team has responded with positive yet tentative response.

The Recyclability Index score has been added to the Overall Metric Sheet used for each new design. This metric sheet measures various factors and compares with competitors and goal values. The significance of this is that now Recyclability Index is one of the eleven metrics which printers are evaluated on. These are shown in visual displays, appear on performance reviews, and are generally regarded as target values. This also gives great validity to the Recyclability Index and acceptance by senior management at the division. In fact, the recyclability metric was added at the request of the Division Comptroller.

Finally, Hewlett-Packard feels the Recyclability Index is unique and valuable enough to apply for intellectual property protection. Hewlett-Packard is applying for patents in both the United States and Europe for the Recyclability Index tool. This shows a belief in the value of the tool, and the potential for its use to develop competitive advantage.

7.3.2 Hewlett-Packard Response to Project- Imaging & Printing Group

There was a positive response from most of the stakeholders overall. The Environmental Product Stewardship Program Manager for the Imaging and Printing Group stated:

> "At a time when the concept of extended producer responsibility for the return and recycling of products is taking hold in various regional legislative/regulatory mandates, the Recyclability Index provides an extremely valuable and effective tool for our Product Stewards and Design Engineers to assess their products' capability to meet these requirements and to identify opportunities for improvement. These opportunities can be in areas such as ease of disassembly, standardization and marking of materials, elimination of hazardous and/or difficult-to-recycle materials, etc. This will be a great contribution to our overall Design for Environment (DfE) program effectiveness."

Although the Recyclability Index was originally developed for the ink jet personal printer division, HP is a very large company that makes a multitude of products. HP plans to leverage the Recyclability Index across multiple divisions and utilize the knowledge gained. Product Stewards across the Imaging & Printing Group and Enterprise Systems Group will use modified versions of the Recyclability Index. Relationships have developed with product stewards in all of those divisions, and they are each modifying the original version of the tool for use on their respective products. A User's Manual was written to assist them in adapting the Index. Although the questions may vary among products, the Index provides a common methodology. The scores will not be directly comparable across divisions, but the percentage recyclable values. By using the same tool system, the overall Design for Recycling situation can be better understood. It enables continuity and uniformity across the company. This reduces unnecessary complexity and duplicate work.

As part of this initiative, the Recyclability Index has been integrated into the Imaging and Printing Group Design for Environment Guidelines. These guidelines will be used to evaluate all new imaging and printing products, and although somewhat product-specific, provide a uniform approach to evaluate product designs. The Imaging and Printing

Group produces the largest volume of products at HP, so the potential value in savings for HP by using this tool is quite high.

7.3.3 Measures of Success for the Project- Corporate-Level Integration

The long-term goal is to use the Recyclability Index for HP products. This will enable HP to accurately measure recyclability company-wide and back up any claims with exact quantitative data. The Recyclability Index can ensure compliance with the WEEE and RoHS Directives as well as consolidate environmental data.

In the 2002 Corporate Sustainability Report, it was stated: "Our corporate vision is clear and unyielding: to be the recognized worldwide leader in delivering environmentally sustainable solutions for the common good." As Hewlett-Packard seeks industry leadership on environmental issues, the Recyclability Index can play a pivotal role in proving that Hewlett-Packard is not just offering rhetoric, but taking action.

7.4 Environmental Benefits

There are great potential environmental benefits from better Design for Recycling. These include reduced toxics, reduced waste in landfills, less pollution from incineration and treatment, and more efficient recycling processes that use fewer natural resources.

7.4.1 Reduced Toxics

There are other environmental benefits from using the Recyclability Index. First, the Index penalizes for hazardous substances. Not only is reducing hazardous substances more healthy for the consumer and less risky at the end-of-life stage, but there are environmental benefits of not producing those hazardous substances in the first place. Mining and recovery of mercury, lead, and cadmium uses energy, water, and other resources. Limiting the use of these substances and replacing them with materials that are less intensive to produce decreases the overall environmental impact.

7.4.2 Landfill Wastes

A simple calculation illustrates the potential for reducing landfilling by better Design for Recycling.

Assume Printer A is 73% recyclable; Printer B is only 65% recyclable. If Printer B could reach the recyclability of Printer A,

Printer B sales forecast for Europe	300,000	units per year
Total mass of Printer B	11	lbs
If improved from 65% to 73% = 8% * 11 lbs =	0.88	lbs
Total landfill/incineration savings per year =	264,000	lbs per year
	132	tons per year

This is theoretical example, but the potential is impressive, considering the number of products HP sells in Europe. By increasing the recyclability of the printer even slightly, a significant amount of material can be recycled instead of landfilled or incinerated. Landfills require space and have the potential for leakage into groundwater.

7.4.3 Incineration Wastes

Incineration presents its own environmental issues, particularly in pollution released during the burning. "It is estimated that emissions from waste incineration account for 36 tonnes per year of mercury and 16 tonnes per year of cadmium in the [EU] Community." [55] Dioxin and furans are also released during incineration. PVC is a common component in electrical waste; it has been shown to release hazardous gases when incinerated. Therefore, any reduction in the amount of material incinerated is beneficial for both the environment and human health.

7.5 Conclusions

Overall, the project succeeded in meeting its objectives. By seeing how design decisions affect recyclability and to what magnitude, engineers can make conscientious decisions about DfE and DfR. The feedback from Hewlett-Packard was very positive. The financial benefits of using the Recyclability Index will probably not be calculable until the WEEE Directive takes effect in 2005. However, the potential financial benefit is several million dollars.

The fairly new and developing field of Design for Recyclability presents great opportunity and challenge. There are significant barriers for legislation and voluntary programs to succeed:

> "While recycling surely provides both social and economic benefits, increasing the current recovery rates will require overcoming significant structural barriers; developing new institutional infrastructures; and redesigning products, processes, and materials. Indeed it is a daunting task to restructure large sectors of the materials economy that are primarily linear and open and convert them into contained economic systems based on closed-loop recycling." [56]

By choosing a proactive approach, companies like Hewlett-Packard can use takeback legislation to help both their business position and the environment. The Recyclability Index enables HP to design products that are more recyclable and to integrate environmental design into the regular product design process. The analysis of results shows that Hewlett-Packard is in a position of legal compliance already; however, there is much room for improvement. The Recyclability Index, used with other design tools and processes, will be used to make that improvement happen.

Endnotes

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[3] WEEE Directive, Commission Version, 60.
[4] WEEE Directive, Commission Version, 29.
[5] WEEE Directive, Commission Version, 63.
[6] www.svtc.org/cleancc/weee/euweee/directive/weee_article_ens.htm
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[11] http://eerc.ra.utk.edu/clean/nepsi/
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[28] Geiser, Materials Matter, 228.
[29] Geiser, Materials Matter, 219.
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[31] Exporting Harm, 1, www.svtc.org/cleancc/pubs.harm.htm
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[35] Auer, R, et al. "An Assessment and Prioritization of 'Design for Recycling' Guidelines for Plastic Components", 6.

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[37] Vezzoli, "An Overview of Life Cycle Design and Information Technology Tools", 27.
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[41] Das, Sanchoy, et al. "Strategies and Economics in the Disassembly of Personal Computers- A Case Study", 259.
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[52] Stone, "When case studies are not enough- the influence of corporate culture and employee attitudes on the successes of cleaner production initiatives", 353.
[53] "Commitment Planning Strategies", Organizational Transitions: Managing Complex Change, 95-100.
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Appendix A: Definitions

recycling	the reprocessing in a production process of the waste materials for the original purpose or other purposes
recyclable	able to be recycled under current recycling technology and infrastructure
nonrecyclable	material or component that is technically not able to be recycled using standard techniques on a commercial scale. Current infrastructure does not support recycling the material.
technically recyclable	the material has been proven to be recyclable on a small lab scale, but is not necessarily able to be recycled large-scale, and may not be recycled in practice.
recoverable	assumed definition based on European legislation is that "recoverable" includes all materials that are either recyclable or can be incinerated for energy recovery
energy recovery	the use of combustible waste as a means of generating energy through direct incineration with or without other waste but with recovery of the heat
waste-to-energy	using energy recovery techniques to treat waste
treatment	any activity after the WEEE has been handed over to a facility for depollution, disassembly, shredding, recovery or preparation for disposal and any other operation carried out for the recovery and/or the disposal of the WEEE
end-of-life	The stage of a product reached when a consumer no longer has use for product and it must be disposed or remanufactured or recycled. Per the WEEE Directive, the expense at this point becomes the manufacturers responsibility.
EOL cost	The cost for reverse logistics, treatment, and disposal of a product to the manufacturer after the product has reached the end of its useful consumer life.
recyclability	The amount of a product which is able to be recycled, generally given in percent.
recyclate	Material that has been recycled and is now ready for a use in a new product
hazardous material	Material or chemical that has been found to have properties which are harmful to human health or ecosystems. The list of hazardous materials varies depending on country, material use, and physical properties.
WEEE Directive	Directive of the European Union on Waste Electrical and Electronic Equipment that mandates takeback and extended producer responsibility. It also requires recyclable content in new product designs and set standards for recycling.

RoHS Directive	Directive of the European Union on Restriction of Hazardous Substances that prohibits certain chemicals and mandates treatment for other chemicals in electronic equipment.
EEE	Electrical and Electronic Equipment: equipment which is dependent on electronic currents or electromagnetic fields in order to work properly and equipment for the generation, transfer and measurement of such currents and fields falling under the categories set out in Annex 1A and designed for use with a voltage rating not exceeding 1000 Volt for alternating current and 1500 Volt for direct current.
eco-label	Product certification, typically provided by independent NGO or government agency, to verify that a product or service meets specified environmental, and in some cases, consumer protection, performance standards.
Blue Angel	German eco-label, the first national and one of the most recognized ecolabeling programs.
Recyclability Index	Same as Recyclability Index Tool. This is the Excel-based tool that evaluates design for recycling, estimates recyclability, and identifies areas of concern. It is to be used to quantitatively measure designs and help make more environmentally-conscious design decisions.
Recyclability Index Score	An output of the Recyclability Index, this score is a number between -100 and 100 which represents how well the product is designed for recycling, including disassembly, materials, hazardous substances, and potential value recovery. The better the Design for Recycling, the higher the score.
DfR	Design for Recycling: making choices in the design processes in order to make the product easier and better to recycle