E-Waste Curriculum Development Project

Phase 1: Literature Review

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What is E-waste? Is it a global issue?

Definitions

E-waste refers to discarded electrical and electronic equipment (EEE). The major discrepancies in the definitions of e-waste are related to 1) what it means for equipment to be 'discarded', and 2) what equipment the definition refers to. Although most definitions describe what it means for equipment to be discarded, they only give general or indicative descriptions of what equipment the definition refers to, in part because the descriptions are expected to change over time. Some definitions of e-waste are:

- "E-waste is a popular, informal name for electronic products nearing the end of their 'useful life'. Computers, televisions, VCRs, stereos, copiers, and fax machines are common electronic products... There is no clear definition for e-waste; for instance whether or not items like microwave ovens and other similar 'appliances' should be grouped into the category has not been established" (California Integrated Waste Management Board 2005).
- "Electronic waste or e-waste is any broken or unwanted electrical or electronic appliance... E-waste includes computers, entertainment electronics, mobile phones and other items that have been discarded by their original users. While there is no generally accepted definition of e-waste, in most cases e-waste consists of expensive and more or less durable products used for data processing, telecommunications or entertainment in private households and businesses" (Wikipedia 2006).
- "E-waste encompasses a broad and growing range of electronic devices ranging from large household appliances such as refrigerators, air conditioners, hand-held cellular phones, personal stereos, and consumer electronics to computers" (Puckett et al. 2002, p. 5).
- "Electronic equipment that is no longer useful as originally indented, but can be reused or recycled into a new product" (County of San Bernardino 2004).
- "E-waste is electronic waste. It includes a broad and growing range of electronic devices from large household appliances such as refrigerators, air conditioners, hand-held cellular phones, personal stereos, consumer electronics and computers. E-waste is hazardous, and it is generated rapidly due to the extreme rate of obsolescence. E-waste contains over 1,000 different substances, many of which are toxic, and creates serious pollution upon disposal. These toxic substances include lead, cadmium, mercury, plastics, etc." (Gaulon, Rozema & Klomp 2005).
- The European Union's two related directives – Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS) and Waste Electrical and Electronic Equipment (WEEE) – define EEE as "equipment which is dependent on electric currents or electromagnetic fields in order to work properly and equipment for the generation, transfer and measurement of such currents and fields... and designed for use with a voltage rating not exceeding 1 000 Volt for alternating current and 1 500 Volt for direct current" (European Union 2003a).

Currently, most e-waste in developed countries meets with one of the following fates (Puckett et al. 2002, pp 6-8):

- Put into storage and awaiting disposal
- Sent to landfill or incinerated
- Re-used, either second-hand or refurbished
- Recycled at recycling facilities in the country of consumption
- Recycled in prisons
- Exported to developing countries

The global significance of e-waste

Although most EEE is associated with developed countries' living standards, e-waste is a global issue for two main reasons. Firstly, developing countries own a substantial share of EEE. For example, of the estimated 20-50 million tonnes of e-waste discarded annually worldwide, Asian countries discard an estimated 12 million tonnes (Greenpeace n.d.a). This share will likely only increase with the rapidly developing economies of China and India, who will have 178 million and 80 million new computers, respectively, out of the global total of an estimated 716 million new computer users by 2010 (Greenpeace n.d.a). Increased consumption in developing countries has also been observed for other EEE, such as mobile phones. O'Meara Sheehan (2003) states that "in 1999, Uganda became the first African nation to have more mobile than fixed-line customers. Some 30 other African nations have since followed."

Secondly, e-waste is often sent for recycling and refurbishing in developing countries where labour is relatively cheap, and, once there, can simply be land filled. For example, 50-80 percent of the e-waste collected for recycling in the US is exported but "the E-waste recycling and disposal operations found in China, India, and Pakistan are extremely polluting and likely to be very damaging to human health. Examples include open burning of plastic waste, exposure to toxic solders, river dumping of acids, and widespread general dumping" (Puckett et al. 2002, p. 4). Brigden et al. (2005, p. 3) give examples of the hazardous conditions in developing countries: "For all dusts collected from the workshops in China, the concentrations of lead were hundreds of times higher than typical levels recorded for indoor dusts in other parts of the world". They continue with the case in India: "Dusts from general separation workshops contained the same metals at levels which, though somewhat lower than those recorded in China, were nevertheless still greatly elevated (5-20 times) over background levels" (Brigden et al. 2005, p. 3).

Effectively, developed countries are passing the responsibilities, risks and hazards of e-waste to developing countries. Furthermore, many e-waste exports are illegal. For example, "inspections of 18 European seaports in 2005 found as much as 47 percent of waste destined for export, including e-waste, was illegal" (Greenpeace n.d.b).

Why is E-waste becoming such a major issue?

Volume of e-waste

Despite the policies and programs that address the rise in waste, new landfills and incinerators are still required (OECD 2001, p. 10). According to the European Commission, "e-waste is the fastest growing component of municipal trash by a factor of three" (Schmidt 2002). According to a 2005 estimate by United Nations Environment Program, 20 to 50 million tonnes of e-waste is generated world wide (Brigden et al. 2005, p. 3). Short-life equipment such as computers and mobile phones are the most problematic (Greenpeace n.d.a). The number of personal computers worldwide, for example, "increased fivefold – from 105 million machines in 1988 to more than half a billion in 2002" (Worldwatch Institute 2005). By 2005, more than 1 billion computers were being sold each year while 100 million computers reached the end of their useful lives, 75 million of which were landfilled (Environment Australia 2005, p. 6). Puckett et al. (2002, p. 5) and Greenpeace (n.d.a) agree that the volume of e-waste is mainly due to planned obsolescence and the throw away ethic, which are partly driven by the potential for "... massive increase(s) in corporate profits, particularly when the electronics industry does not have to bear the financial burden of downstream costs" (Puckett et al. 2002, p. 5).

Some estimates of Australian e-waste volumes:

- Ipsos (2005) conducted a survey into household EEE that represented 62 percent of all Australian households. The survey found that households contain an average of 22 EEE each, totalling 92.5 million in the households represented by the survey. Among other measures, the survey details the types of EEE in Australian households; the amount of EEE disposed and the method of disposal; and the amount of EEE in storage.
- Department of Environment and Heritage (2005) offers a more conservative estimate: "There are approximately 45 million major appliances... 9 million computers, 5 million printers and 2 million scanners in households and businesses across Australia" of which 2.5 million are being discarded each year. Of these 2.5 million discarded units, 1.4 million are computers; of which more than half, equating to almost 20,000 tonnes, are sent are landfill (Environment Australia 2005, p. 6).
- For comparison, just a few years earlier Meinhardt (2001, Executive Summary, p. 25) reported that "approximately 240,000 computers are disposed of in this sector every year... approximately 15,000 units [scanners] would be disposed of each year... given the approximate product life of 5 years and its relatively recent market penetration, scanners are unlikely to have been disposed in large numbers to date, although this is likely to change in the future... disposal rates for printers are likely to be over 1.5 million per year... waste toner and printer cartridges are being generated in the order of 2.1 million to 8.7 million per year, depending on usage rates... [and] nearly 38,000 km of cabling of various types enters the waste stream each year" (Meinhardt 2001, Executive Summary, p. 25).
- "Australians have purchased over 40 million mobile phones in the past decade... including 7 million phones in 2004" (Bannerman 2004).

Some estimates of US e-waste volumes:

- More than 100 million computers, monitors and televisions become obsolete each year (Government Accountability Office 2005, p. 3). Furthermore, about 125-130 million mobile phones become unused every year, which is the equivalent of 65,000 tons of waste (Earth Tones 2006; US Environmental Protection Agency cited in Konrad 2005).
- Projections from the late 1990s accurately estimated the volume of computer e-waste, especially considering the overestimated recycle and reuse rates. The NSC's 1998 model estimated that by 2005, 60 million PCs annually would become obsolete (Biddle 2000, p. 4). Matthews' 1997 model, which was based on limited data, estimated that by 2005, with

a 45 percent recycle and reuse rate (Biddle 2000, p. 16), there would be 55 million PCs landfilled and 143 PCs recycled.

- Current projections estimate tremendous increases in e-waste volumes are still to come: "A recent report from the International Association of Electronics Recyclers projects that around 3 billion units will be scrapped during the rest of this decade in the US – or an average of about 400 million units a year, 200 million televisions and 1 billion units of computer equipment" (Pucket et al 2005, p. 7). Another projection on computer e-waste is: "According to industry experts, computer related sectors of the economy will continue to grow annually at rates well over 10% for at least the next decade" (Biddle 2000, p. 3).
- For comparison, the National Safety Council (NSC) estimated that, in 1998, over 20 million PCs became obsolete (Biddle 2000, p. 4), which is just 6 percent of the number of new PCs purchased. The NSC estimates that "... 16 million computer monitors and 11 million printers and scanners also became obsolete" (Biddle 2000, p. 4).
- "The U.S.-based research group INFORM released a report last year that estimated that by 2005, U.S. consumers will have stockpiled some 500 million used cell phones" (O'Meara Sheehan 2003).

In Europe, the average household "... uses 21 batteries a year, according to EU figures. In 2002, that added up to more than 158,000 metric tons of batteries, of which 28 percent were rechargeable. For industrial use, Europe went through 190,000 metric tons of lead acid batteries" (Associated Press 2006).

In many cases, the end-of-life disposal volumes only tell a fraction of the story. Williams (2004) found that the manufacture of a desktop computer and monitor requires fossil fuels of mass 11 fold greater than the products themselves. By comparison, the manufacture many other goods require 1-2 fold their mass in fossil fuel. William (2004) also found that "in contrast with many home appliances, life cycle energy use of a computer is dominated by production (81%) as opposed to operation (19%)". One of the most materials intensive components of a computer is the 2 gram microprocessor, which requires materials of mass 630 fold greater than its own (Worldwatch 2005). It's no surprise then, that "Santa Clara County in California, the birthplace of the semiconductor industry, contains more toxic waste sites than any other county in the United States" (Worldwatch 2005).

Emerging technologies, such as high definition television technologies, can also indirectly contribute to e-waste in the coming years. For example, Biddle (2000, p. 10) estimates that there are "more than 500 million televisions are in homes, businesses, and institutions" in the US. It is likely that most of these standard definition televisions will be replaced by their high definition counterparts.

The volume of e-waste will likely only increase in the near term, especially with the increasing number of people in developing countries coming 'online' with communication technologies. For example, between the years 2000 and 2004, the number of fixed line telephones in Nigeria doubled (Puckett et al. 2005, p. 11). However, in that same period, the number of mobile phones in use rose from 35,000 to almost 9.2 million – an increase by a factor of about 260; and the number of internet users rose from about 107,000 to almost 1.8 million (Puckett et al. 2005, p. 11).

Toxic substances in e-waste

In the US, "the Department of Toxic Substances Control has determined that most electronic devices are toxic" (Earth tones 2006). This conclusion is based on just a few of the 1000 different substances in e-waste, such as lead; tin: copper; antimony; cadmium: mercury; hexavalent chromium/chromium VI; plastics including PVC; brominated, chlorinated and phosphorous-based flame retardants; brominated organic compounds; phthalate esters and esters of long-chain organic acids; polybrominated diphenyl ethers (PBDEs); polychlorinated biphenyls (PCBs); barium: beryllium; toners; phosphor: arsenic; and additives, all of which can be poisonous to people and wildlife (Puckett et al. 2002, pp. 9-10; Meinhardt 2001., p. 30; Earth Tones 2006; Worldwatch Institute 2005; Brigden et al. 2005, p. 3; Environment Victoria 2005, pp. 8-9). There exists the potential to release these toxic substances to the industrial and natural environments at all stages of e-waste processing (Brigden et al. 2005, p. 3).

With the exception of some plastics, the recycling rate for almost all of these substances is nil (Environment Australia 2005, pp. 8-9). About 70 percent, of heavy metals in US landfills comes from e-waste (Earth Tones 2006; Silicon Valley Toxics Coalition cited in Schmidt 2002). Currently, one of the most threatening substances is lead, of which only 5 percent is recycled in Australia (Environment Australia (2005, p. 8). Specific examples include:

- "... glass cathode ray tubes... contain an average of 4 pounds of lead. Multiply that by the 315 million computers expected to become obsolete in the United States by 2004, and there is 1.2 billion pounds of lead to worry about. The color monitors of most computers contain a CRT that fails federal toxicity criteria for lead and is classified as hazardous waste by the U.S. Environmental Protection Agency" (Schmidt 2002).
- An expected 312,000 pounds of lead will come from the more than 500 million stockpiled mobile phones in the US (O'Meara Sheehan 2003).

Printed circuit boards are usually the main source of precious metals in EEE. "A ton of circuit boards yields approximately 10 ounces of gold" (Broughton 1996 cited in Biddle 2000, p. 22). Specifically, an average, mid-1990s computer contains 0.25-1 grams of gold, as well as platinum and silver (Biddle 2000, p. 22). In 1996, about 55 percent of a PC could be recovered, with the recovered components valued at $34 (Microelectronics and Computer Technology Corporation 1996 cited in Biddle 2000, p. 26). However, to reduce materials costs, computer manufacturers are now relying more heavily on plastics, which carry their own set of toxicity and recyclability issues. As of 2000, computers contained about 90 percent fewer precious metals than they did in 1996 (Biddle 2000, p. 22).

Brigden et al. (2005) and Environment Victoria (2005, pp. 8-9) discuss the physiological and health impacts of these toxic substances at sufficient concentrations on humans and animals. In particular, they highlight:

- disruption to endocrine systems including the oestrogen, androgen, thyroid hormone, retinoid and corticosteroid systems; inhibition of human androgen hormone reception; and ability to mimic natural oestrogen hormones, leading to altered sexual development in some organisms.
- damage to both male and female reproductive systems, including interfering with development of the testes; reduction in semen production and quality; abnormal morphology of sperm; low egg hatchability; and reduced fertility rates.
- DNA damage in lymphocytes, fetal and developmental toxicity; growth retardation; abnormal brain development, which can result in intellectual impairment; and possible long-term impacts on memory, learning and behaviour.
- damage to the central nervous system (CNS) and blood system, including CNS depression and neurotoxicity; immune system suppression, including inhibition of a key blood cell enzyme.
- damage to the brain, including swelling; liver, including liver necrosis; kidney, including renal toxicity; thyroid; pancreas; lymph nodes; spleen; and bone, including bone toxicity.
- hypertension (high blood pressure); cardiovascular and heart disease; respiratory tract irritation, including irritation of the nose, mouth and eyes.
- vomiting, headaches, dizziness and nausea.
- contact dermatitis; skin lesions; carcinogenic, including tumour promotion and lung cancer; anaemia; CBD (a currently-incurable, debilitating disease that can sometimes be fatal); and mortality.

EEE also introduces pollution indirectly, particularly as greenhouse gas emissions. Department of Environment and Heritage (2005) estimates that over 42 million tonnes of greenhouse gases result each year from the manufacture, use and disposal of electrical and electronic equipment purchased by Australians. Even more indirect are the transport emissions from 'telesprawl', a term coined by Mokhtarian and Handy at the Institute of Transportation Studies at UC Davis and discussed by O'Meara Sheehan (2003): "Apparently, there is some concern that telesprawl – people living farther away because they reply on machines for communication – has become a reality in parts of California... the Internet now allows a person in Europe, for instance, to easily order a book to be air-shipped from the United States before it is available locally. And history suggests that transportation and communication tend to increase in tandem."

Poor recycling rates

Department of Environment and Heritage (2005) summaries recycling practices in Australia: "Some metals are recovered from major appliances, but the remaining hazardous and other materials (including lead, mercury and phosphors) are landfilled as intact product or 'shredder flock'". Some estimates and examples of EEE recycling rates in Australia include:

- Meinhardt (2001, p. 26) estimates personal computer recycling, landfilling and storage rates will increase sharply between 2001 and 2006, and slow between 2006 and 2011. They also give estimates of annual figures and a cumulative total.
- "A limited survey of 100 South Australian households by Göl et al. (EPA 2000) indicated that 46% had yet to replace their first computer and, out of those that had replaced their first computer, approximately 40% had done so within five years after their original purchase. The majority of replaced household computers identified in the study were either placed into storage (34%) or had been passed on for reuse (26%), generally within the family... The percentages will also differ to, but are generally consistent with, those identified overseas, as illustrated by estimates from studies in Florida (Price 1999), which indicate that of the total obsolete computers in the State, approximately 8% are landfilled, 21% recycled and over 71% are in storage awaiting disposal" (Meinhardt 2001, pp. 25-26).
- Of the estimated 2,625,000 to 10,500,000 cartridges being sold each year, about 17 percent are recovered (Meinhardt 2001, p. 28).
- In 2004, 7 million mobile phones were purchased and according to Randall Markey from the Australian Mobile Telecommunications Association, 1.5 million were returned for recycling (Bannerman 2004). However, further investigation revealed that only about 100,000 phones had been returned and that the plastic in the phones may not have been recycled at all (Bannerman 2004).

Government Accountability Office (2005, p. 28) conclude that poor recycling rates in the US prevail because, for consumers, throwing away products is the cheapest and most convenient option. Some estimates and examples of EEE recycling rates in the US include:

- "According to the National Safety Council's (NSC) May 1999 Electronic Product Recovery and Recycling Baseline Report: Recycling of Selected Electronic Products in the United States... only 11% of the 20 million computers that became obsolete in the United States in 1998 were recycled" (Schmidt 2002).
- "More than half the old personal computers replaced by consumers last year were put to productive use instead of being dumped or stored away, according to a nationwide survey by MetaFacts, a San Diego research firm... The survey, conducted last year, included 7,527 households and 2,500 workplaces around the country. It found that 30.1 percent of household respondents keep their old computers and use them, 22 percent pass them on to friends and 17.1 percent keep them in storage. An additional 8.9 percent donate the old machines to charity and 8.6 percent junk them. Only 3.6 percent said they recycle their old PCs" (Schoenberger 2005).
- "Government researchers estimate that three quarters of all computers ever sold in the U.S. are lying in basements and office closets, awaiting disposal. An estimated 63 million personal computers are expected to be retired... that's one computer becoming obsolete for every new one put on the U.S. market" (Worldwatch 2005).

- "Less than 2 percent [of mobile phones] are recycled – usually refurbished and resold to consumers in Latin America and Asia, or disassembled for gold and other parts, according to EARTHWORKS" (Konrad 2005).

Due to the lack of definitive standards regarding recyclers, it is likely that many recycling rate estimates are overstated (Schmidt 2002). Most of the time, 'recycled' means 'exported for recycling', and often, most of the exported wastes are landfilled. In fact, Puckett et al. (2005, p. 8) reports that the UK exported about 160,000 tons of e-waste in 2003 and that about 22% of all export wastes in some European countries are illegal.

Transfer of end-of-life problems to developing countries

Puckett et al. (2002) details the current situation involving the export of e-waste from developed countries to developing countries for processing:

- "Rather than having to face the problem squarely, the United States and other rich economies that use most of the world's electronic products and generate most of the E-Waste, have made use of a convenient, and until now, hidden escape valve – exporting the E-waste crisis to the developing countries of Asia... Indeed, informed recycling industry sources estimate that between 50 to 80 percent of the E-waste collected for recycling in the western U.S. are not recycled domestically, but is very quickly placed on container ships bound for destinations like China. Even the best-intentioned recyclers have been forced, due to market realities, to participate in this failed system" (p. 1). Government Accountability Office (2005, p. 29) confirm that is, in fact, the case in the US.
- "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. And it was clear that many did not want to know" (p. 2).
- "The open burning, acid baths and toxic dumping pour pollution into the land, air, and water and exposes the men, women, and children of Asia's poorer peoples to poison (p. 1)... Vast amounts of E-waste material, both hazardous and simply trash, is burned or dumped in the rice fields, irrigation canals and along waterways" (p. 2).

Puckett et al. (2005) add:

- In Nigeria, only about 25-75 percent of imported computer equipment can be cost effectively repaired and sold, with a lot of the remainder being dumped or burned (p. 6).
- "... it appears that far too many governments are looking the other way and are failing in dramatic fashion to properly enforce and implement the [Basel] Convention for post-consumer electronic waste..." (p. 3). (See later section, 'What regulation and/or market mechanisms are in place?', for a description of the Basel Convention)
- If the Basel convention was enforced and/or near-future EEE was non-hazardous, then Countries like Nigeria have the skills, capacity and low-wage economy for successful and profitable EEE repair operations (p. 4). Nigeria does not yet, however, have the capacity for materials recovery operations (p. 13).

The impact of e-waste in developing countries is not limited to the end-of-life. Many metals used in EEE are imported from developing countries. For example, gold is mined in Peru, Turkey, Tanzania and other countries (Konrad 2005). "The Environmental Protection Agency ranks hard-rock mining as the nation's leading toxic polluter" (Konrad 2005).

What are the current challenges faced by engineers and industry to eliminate e-waste?

Overcoming the issues associated with e-waste faces several barriers as outlined in this section. However, an underlying factor of many issues presented in the previous section, 'Why is e-waste becoming a major issue?', is the wasteful nature of the design philosophy currently evident throughout all industries. That is, the linear 'cradle-to-grave' model, sometimes know as 'take, make and waste'. In the cradle-to-grave model, products are designed under the assumption that their materials and energy will be disposed of at end-of-life, with virtually no account for resource reuse or recycling. This practice gives rise to not only a tremendous volume of waste, but also a tremendous amount of toxic dispersal. Some alternatives to the 'cradle-to-grave' model are considered in the later section, 'What are the general approaches taken to overcome the issues associated with e-waste?'.

The value of foreign e-waste reduction trial programs to Australian industry is diminished. Meinhardt (2001, p. 91) notes that "Australia has unique issues (such as distance to recycling markets, small population and markets) which could not be extrapolated from international collections". Nonetheless, many of the technical, financial, commercial, strategic and information challenges to eliminating e-waste are common.

Technical

RMIT & Product Ecology (2004, pp. i-ii) offer six key technical challenges to recycling e-waste:

- Potential environmental and health hazards associated with brominated flame retardants in plastics
- Difficulties associated with identification of plastics
- Lack of high grade end use markets to make use of recyclate i.e. without sufficient end use markets it can lead to significant down cycling
- Uncertainties associated with processing leaded glass in smelters, although this appears to be the only viable market for the material in Australia
- Lack of alternative markets for leaded glass in Australia beyond lead smelters
- There is a limit to the reuse of circuit boards. While the components of the circuit board can be reused (i.e. the micro-chips, relays, capacitors etc) the board themselves can only be reused if they are transferred into another unit of the same type of product.

The most challenging component of EEE to recycle is plastic. Bannerman (2004) and Schmidt (2002) highlight issues with recycled plastic purity, suggesting that it is difficult to make recycled plastic pure enough to be useful. Schmidt (2002) and RMIT & Product Ecology (2004, p. 45) suggest that the most significant challenge is separating the plastics in EEE. EEE components are not usually labelled properly or easily identifiable, which makes it likely that even a small amount of incompatible plastic will enter and contaminate a batch of material.

Financial and commercial

RMIT & Product Ecology (2004, pp. ii-iii) offer six key financial and commercial challenges to recycling e-waste:

- High costs of collection and disassembly relative to the value of recovered materials and components.

- The negative value of some components and materials, including CRT glass, wooden cases and some plastics.
- The high cost of the recovery of lead from leaded glass at lead smelters
- The low cost of landfill disposal.
- Poor markets for leaded glass (technical issues make the separation of lead from the glass difficult). Either material could be utilised in a variety of high-grade end-markets but together they are a problem.
- A co-ordinated industry effort is difficult as almost half the Australian computer sales are by many SMEs outside the industry association. The large computer companies that are part of the Australian Information Industry Association have only about a 40 percent share of the Australian computer market, where as the SMEs have combined market share of 50 percent (AIIA & Planet Ark Consulting 2005, p. 8). The situation for televisions is better, with about 60 percent of televisions sold are brands from companies who are part of the Consumer Electronics Suppliers' Association or the Australian Electrical and Electronic Manufacturers' Association (Consumer Electronics Suppliers Association 2004, p. 23).
- The need to ensure that companies are not competitively disadvantaged by companies unwilling to meet the same environmental responsibility standards.
- The large number of 'orphan products' without brand owner to take responsibility for recovery. Orphan products have 50 percent share of the Australian computer market (AIIA & Planet Ark Consulting 2005, p. 8).

Government Accountability Office (2005, pp. 10-13) discuss how, in the US, the costs to consumers of recycling e-waste, mainly fees and inconvenient drop-off locations, usually outweigh any incentives. Many e-waste recyclers charge fees to cover costs such as labour, expensive shredding machinery, and their own fees for toxic material disposal (Government Accountability Office 2005, pp. 12-13). Puckett et al. (2002, p. 12) highlights an example of financial challenges in action: "A pilot program conducted by the U.S. EPA that collected electronic scrap in San Jose, CA estimated that it was 10 times cheaper to ship CRT monitors to China than it was to recycle them in the U.S."

Schmidt (2002) adds another challenge to the commercialisation of e-waste recycling: "… the recycling industry is composed of a veritable jungle of overlapping specialists: primary recyclers that refurbish products for resale; secondary recyclers that 'demanufacture' equipment to extract raw materials such as metals, plastic, and glass; smelters that use CRT glass as inputs to produce raw metals; and so-called 'third party' resellers – typically nonprofit organizations – that sort and repair obsolete products for resale or donation." The lack of structure in the industry leads to confusion and hence very little action.

The Santa Clara County Department of Environment Health (2004, p. 20) found that a consumer-level barrier is sometimes government-imposed recycling fees, with a positive correlation evident between recycling fees and illegal disposal. Illegal disposal is a larger problem in rural areas, which are at a disadvantage due to longer transport distances to processing centres (Santa Clara County Department of Environment Health 2004, p. 4).

Strategic

Planned obsolescence to the extent and in the manner that it is currently practiced in industry is generally counterproductive to minimising e-waste. For example, "the wireless industry compounds the e-waste problem through planned obsolescence of cell phone handsets and by locking phones to proprietary networks practically ensuring that consumers need to buy a new handset when switching between wireless carriers" (Karan cited in Earth Tones 2006). However, there is also a solid argument for planned obsolescence: "Rapid technological advances and lower product prices for more powerful machines are contributing to shorter product life spans and frequent replacement" (Santa Clara County Department of Environment Health 2004, p. 3). A solution to this dilemma, as recommended by Environment Victoria (2005, p. 3), is to design EEE that are only durable and reliable but also upgradeable.

Fortunately, some EEE is useful even after it has been outmoded. Schoenberger (2005) notes that "more than half the old personal computers replaced by consumers last year were put to productive use instead of being dumped or stored away, according to a nationwide survey by MetaFacts, a San Diego research firm". Surveys such as MetaFacts' send signals to industry that may influence a shift away from planned obsolescence. Schoenberger (2005) continues: "this may be bad news for PC makers who want older machines to be regarded as technologically obsolete, prompting consumers to buy the latest models. But it's good for the environment, as recycling programs come on line that can capture discarded PCs before they pose hazards, said Dan Ness".

Information failure

Meinhardt (2001) discusses the lack of awareness of Australian users, industry and government regarding end-of-life computer issues:

- "The average computer user in Australia is unaware of the scope of the problem of disposal of waste computer equipment. While consumers may be aware of their individual difficulty in locating an appropriate recycling or disposal pathway for their equipment, many do not understand the nature of hazardous materials used in computer manufacture and the requirement for special disposal" (p. 87).
- "Users also lack awareness of the range of reuse and recycling options available to them. A number of international manufacturers of computers and printers provide information online on extending the life of purchased computers..., reducing environmental impacts during product use... and purchasing at lower environmental cost... However this information is mostly targeted to the US market and generally does not incorporate Australian contacts" (p. 88).
- "Consultation with some Australian manufacturers showed that there may be a lack of awareness of the achievements being made by international parent companies in the environmental arena" (p. 88).
- "The lack of recognition of the size of the waste computer problem has provided few economic incentives to invest in collection systems or infrastructure. ICT manufacturers have been the only stakeholders with an understanding of the waste equipment volumes; however their focus has not traditionally been on disposal, and dissemination of information to players in the waste and/or recycling industry has not been undertaken. Conversely, recyclers and waste companies have considered infrastructure investment to be too risky without a greater certainty of equipment flows. Because of this lack of data, there has been little analysis undertaken in determining the most suitable methods of collection needed" (p. 91).

A survey by the Santa Clara County Department of Environment Health (2004, p. 19) identified education of the public as a major need. The survey summary states that "currently, e-waste recycling programs are promoted by local governments through a variety of methods, such as newsletters, brochures, and websites... Other targets for an educational message included regulators, local businesses, schools, and waste haulers. Additionally, elected and appointed decision-makers must understand the issues and costs of CRT management" (Santa Clara County Department of Environment Health 2004, p. 19).

Puckett et al (2005, p. 6) state that African nations (and other developing countries), the primary destination of e-waste, do not understand the hazards associated with e-waste. They continue: "Consequently... almost all of the discarded imported electronic waste is thrown into formal or informal dumpsites, all of which are unlined, unmonitored, close to the groundwater and routinely set afire" (Pucket et al. 2005, p. 6).

Another type of information failure is the lack of data on e-waste trade. The only type of e-waste with codes under the Harmonized Tariff Schedule (HTS) is batteries (Puckett 2005, p. 5). Data on e-waste volumes may encourage 'resource mining' for valuable resources. For example, Government Accountability Office (2005, p. 9) state that "... computers typically contain precious metals, such as gold, silver, palladium, and platinum, as well as other useful metals like aluminum and copper. The U.S. Geological Survey reports that one metric ton of computer circuit boards contains between 40 and 800 times the concentration of gold contained in gold ore and 30 to 40 times the concentration of copper, while containing much lower levels of harmful elements common to ores, such as arsenic, mercury, and sulfur. The research we reviewed also suggests that the energy saved by recycling and reusing used electronics is significant. The author of one report by the United Nations University states that perhaps as much as 80 percent of the energy used in the life cycle of a computer, which includes manufacturing, can be saved through refurbishment and reuse instead of producing a new unit from raw materials".

What regulation and/or market mechanisms are in place?

Many developed countries now have some form of regulation in place to combat the issues associated with e-waste. Many of these regulations were introduced to satisfy the Basel Convention, to varying effect. The strictest regulations regarding the Basel Convention are the European Union's 'Waste Electrical and Electronic Equipment' directive and Australia's 'Hazardous Waste (Regulation of Exports and Imports) Act 1989'. The strictest regulation influencing product design is the European Union's 'Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment' directive. The European Union's laws have influenced Governments of developing countries, particularly Asian countries where a lot of EEE is manufactured, to introduce matching laws so that their products can meet the standards for import into the counties of the European Union. Japanese regulations stipulate recycling targets for manufacturers for many types of EEE.

OECD

The OECD's 'Environmentally Sound Management of Used and Scrap Personal Computers (PCs)' guidelines "... focus on reuse and recovery of used PCs and their constituent materials, but do not address other environmental issues such as product design, choice of materials and energy efficiency. The guidelines highlight areas such as substances of concern in reuse/recovery and disposal activities, facility requirements (including energy recovery) and transport" (Meinhardt 2001, p. 54).

Basel Convention

In 1994, the Basel convention was created to help "counter the unsustainable and unjust effects of free trade in toxic wastes" (Puckett et al. 2002, p. 2). The treaty calls for the adoption of a "total ban on the export of hazardous materials from rich [OECD] to poor [non-OECD] countries for any reason, including for recycling... [, for] all countries to reduce their exports of hazardous wastes to a minimum and, to the extent possible, deal with their waste problems within national borders" (Puckett et al. 2002, p. 2).

There are 165 nations that have ratified the Basel Convention and three countries – US, Afghanistan and Haiti – that have signed but not ratified it (Puckett et al. 2005, p. 3, Annex IV). Puckett et al. (2002, p. 3) describes: "... U.S. officials have actively worked to defeat, and then to weaken, the Basel waste export ban."

Other International

RMIT & Product Ecology (2004, p. 45) identifies other international level protocols and standards for e-waste:

- "A new international protocol (PROMISE) is being developed to facilitate the embedding of information in products using microchip technology. Information on the chip would include materials and potential secondary markets, as well as instructions for disassembly".
- The International Standards Organisation's ISO 11469 standard is the international standard for polymer identification. ISO 11469 provides a labelling convention for polymer constituents and additives.

Australia (Federal)

Australia is yet to enforce product-take back of EEE as already introduced in other developed nations. Consequently, many Australian arms of EEE companies do not implement the same recycling standards as they do in countries where take-back and recycling is enforced (Environment Victoria 2005, p. 17), Regulatory activity in Australia includes:

- Australia's regulations are one of very few worldwide that impose pre-export testing. Australia's effort to implement the Basel convention is 'The Hazardous Waste (Regulation of Exports and Imports) Act 1989'. The Act encompasses EEE for disassembly, re-use, recycling, recovery or disposal (Meinhardt 2001, p. 47). Australia's 'Criteria for the Export and Import of Used Electronic Equipment' is used to determine whether a particular e-waste is hazardous. Most computer waste is assumed to be hazardous unless proved otherwise by the exporter (Environment Australia 2005, p. 19) .
- RMIT & Product Ecology (2004, Appendix B) summarise Australian legislation and policy relevant to electronic waste
- "The National Environment Protection Measure - Movement of Controlled Waste Between States and Territories (Movement of Controlled Waste NEPM) establishes a nationwide tracking system for the interstate transport of controlled wastes... similar to how the Basel Convention defines hazardous wastes" (Meinhardt 2001, p. 48).
- Australian Electrical and Electronic Manufacturers Association (AEEMA), Consumer Electronic Suppliers Association (CESA), and Australian Information Industry Association (AIIA), the peak electrical and electronic industry associations, are developing voluntary product stewardship initiatives (Department of Environment and Heritage 2005).
- "Extended producer responsibility for waste computer and peripheral equipment has not yet been incorporated into the ethos of Australian computer manufacturers. While the international parent companies of many Australian manufacturers have implemented a number of environmental initiatives, product stewardship in the Australian computer industry is currently in its infancy" (Meinhardt 2001, p. 37).

Australia (State)

Environment Victoria (2005, p. 17) state that "the ACT is the only jurisdiction that bans computer waste to municipal landfill". In a thorough overview, Meinhardt (2001, pp. 49-51) summarises the Australian regulations at the state level:

- Australian Capital Territory: "The ACT's Environmental Standards: Assessment and Classification of Liquid and Non-Liquid Wastes provides directives for the generation, storage and disposal of waste materials created through the processing of computer components. All materials must be classified as either inert, solid, industrial or hazardous waste, however the tables provided to assist with classification cannot be applied to electronic scrap..."
- New South Wales: "The New South Wales EPA Environmental Guidelines: Assessment, Classification and Management of Liquid and Non-Liquid Wastes form the basis of the State's waste classification standard, and is similar to that adopted by the ACT Government..."
- Northern Territory: "The Northern Territory currently does not have any licensed landfill site in operation, requiring all Listed Wastes to be disposed in neighbouring States under the Movement of Controlled Waste NEPM. Works are currently being undertaken by the Department of Lands, Planning and Environment, documenting licensing requirements for handlers, transporters and disposers of Listed Wastes."
- Queensland: "The transportation of waste computer equipment or scrap within Queensland may require a permit under the Environmental Protection (Waste Management) Regulation 2000, as it is likely to contain materials that are considered Trackable Wastes..."

- South Australia: "South Australian legislation, viz. the Environment Protection Act 1993 and Environment Protection (General) Regulations 1994, is similar to Queensland in that it indicates activities which require a licence rather than classifying any particular material as listed or controlled waste by quantity or concentration..."
- Tasmania: "The Environmental Management and Pollution Control (Waste Management) Regulations 2000 uses several acts and regulations, including the Movement of Controlled Waste NEPM, to define controlled substances. Any manufacturing, installation, servicing or decommissioning involving a controlled substance is a controlled activity under the regulations unless it is shown that the state of the waste does not possess the hazardous characteristics described by the Movement of Controlled Waste NEPM. It has been indicated that computer components would not demonstrate these characteristics when in their solid form, and only those stages of waste processing where materials are separated (e.g.recovery of precious metals) may be classified as a controlled activity..."
- Victoria: "The overarching principles of the Environment Protection Act 1970 include both product stewardship and the waste management hierarchy. As computer equipment contains a mixture of the wastes listed in Schedule 1 of the Environment Protection (Prescribed Waste) Regulations 1998 it is likely to be classified as 'prescribed industrial waste..."
- Western Australia: "Controlled wastes within Western Australia are listed by the Environmental Protection (Controlled Waste) Regulations 2001. Controlled wastes must be transported and disposed of only by licensed companies..."

EU: Waste Electrical and Electronic Equipment

European Union (2003a) describes the objectives of its Waste Electrical and Electronic Equipment (WEEE) directive: "The purpose of this Directive is, as a first priority, the prevention of waste electrical and electronic equipment (WEEE), and in addition, the reuse, recycling and other forms of recovery of such wastes so as to reduce the disposal of waste. It also seeks to improve the environmental performance of all operators involved in the life cycle of electrical and electronic equipment, e.g. producers, distributors and consumers and in particular those operators directly involved in the treatment of waste electrical and electronic equipment."

European Union (2003a) is rigorous in its stipulations, detailing the families of products that fall under the directive. The next major target is an average waste collection rate of four kilograms per capita annually by 31 December 2006 (Environmental News Service 2004).

The directive has been criticised for being unfair to countries outside the European Union (EU) and even for being illegal. The American Electronics Association (AEA), which has 300 member companies, claimed that the directive would violate international trade law obligations with the World Trade Organisation (WTO) by imposing requirements on foreign manufacturers (Hunter & Lopez 1999; Knight 2000). However, after investigation, the AEA's claim was deemed unfounded (Silicon Valley Toxics Coalition 1999).

EU: Restriction of Certain Hazardous Substances

European Union (2003b) describes the objectives of its Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment (ROHS) directive: "The purpose of this Directive is to approximate the laws of the Member States on the restrictions of the use of hazardous substances in electrical and electronic equipment and to contribute to the protection of human health and the environmentally sound recovery and disposal of waste electrical and electronic equipment".

The directive stipulates that manufacturers cannot use lead, mercury, cadmium or hexavalent chromium, or the brominated flame retardants PBDE and PBB in products from July 1, 2006 (Environmental News Service 2004). The EU will review and update the directive every four years (Environmental News Service 2004).

EU: Registration, Evaluation and Authorisation of Chemicals

Council of the European Commission (2006, p. 39) describes the purpose of its proposed Registration, Evaluation and Authorisation of Chemicals (REACH) regulatory framework: "The purpose of this Regulation is to ensure a high level of protection of human health and the environment as well as the free circulation of substances on the internal market while enhancing competitiveness and innovation."

Under REACH, chemical producers and importers whose volume is at least 1 tonne per year must register those chemical with a Chemicals Agency (European Commission 2006, p. 3). Producers and importers must also disclose safety information so that their chemicals can be used with minimal hazard (European Commission 2006, p. 3). Each registered chemical and proposal for animal testing is evaluated (European Commission 2006, p. 3), For chemicals that cause cancer, mutation or problems with reproduction, or chemicals that bioaccumulate, use-specific authorisation must be sought (European Commission 2006, pp. 3-4). This restriction on highly hazardous chemicals is expected to encourage substitution with safer chemicals (European Commission 2006, p. 4).

The regulation was first proposed in 2003. The proposal has since been through revisions and the Council has produced a Common Position. The final agreement and adoption of the proposal is expected by the end of 2006 (Europa 2006).

Europe

European legislation focuses on EEE such as white goods, brown goods and lighting, rather than computing equipment (Meinhardt 2001, p. 55). Meinhardt (2001, p. 55) surveys some of the legislation in Europe that incorporates computers:

- 1997 Italian waste management decree setting out take back and recovery obligations for certain ICT equipment.
- 1998 regulation in the Flemish Region of Belgium, requiring manufacturers, importers, distributors and retailers to take back all ICT equipment free of charge.
- 1998 ordinance in Switzerland on the take back and disposal of WEEE.
- 1998 regulation in Norway on the acceptance, collection, recycling and disposal of WEEE.
- 1999 order in Denmark making local authorities responsible for collection and recovery of ICT equipment (funded by local taxes or collection fees).
- producer responsibility obligations in Sweden which allow customers buying a new product to return an old product of the same type free of charge. Producers are also obliged to provide information on the content of the equipment when requested by pre-treatment operators.

Tojo (1999) adds:

- "The objectives of the Dutch Decree are to 1) reuse as many products and materials as possible and 2) dispose of the wastes in such a way that the associated risks to the environment are minimised" (Ministry of Housing, Spatial Planning and the Environment 1998 cited in Tojo 1999, p. 61).
- "The objective of the Danish waste policy in general is to reduce waste and recycle as much as possible" (Danish Environmental Protection Agency 1999 cited in Tojo 1999, p. 62).

AIIA & Planet Ark Consulting (2005, p. 36) add that is often Municipal Governments that bear collection cost, while manufacturers only bear recycling and processing costs:

- "In Denmark, for example, small electronic devices must be collected with household waste and larger items are taken to municipally-run drop-off sites.

- German law will require municipalities to organise and finance end-user collection while manufacturers are responsible for recycling the collected material.
- In Sweden, consumers can take back an old product when a new product is purchased but can take obsolete equipment to a municipally-run recycling centre if not buying a new replacement."

The EU now has rules for battery collection. Associated Press (2006) reports: "The European Union was expected to agree on new rules for collecting and recycling batteries to limit pollution caused when they are incinerated or buried in leaky landfill sites, a program estimated to cost industry at least euro200 million (US$253 million)... The new rules impose targets for collecting used batteries ranging from regular AA batteries to those used in mobile phones and laptops. By 2012, a quarter of all batteries sold must be collected once they run out. By 2016, the target will rise to 45 percent. The rules also determine how they must be recycled once collected... If companies are to take cell phones and computers back cost-effectively, the products' design will have to change to make them easier to recycle. This could actually save companies money because they'd favor simpler designs with fewer parts".

UK

A recent incident with UK waste highlights the difficulty with implementing industry wide regulations, such as the Basel Convention, but also shows the effectiveness of the regulations in preventing breaches. Vidal (2005) reports: "More than 1,000 tonnes of contaminated household refuse disguised as waste paper on its way to be recycled in China is to be sent back to Britain after being intercepted in the Netherlands... English household rubbish due to be recycled escaped over the border to Germany and that waste has now turned up in Indonesia... According to Dutch officials... "They used two companies and switched between three different UK ports. It was clearly an attempt to deceive the authorities"... a study by Impel, a group of waste inspectors from six European countries, suggested that up to 20% of the tens of thousands of containers full of waste plastic and paper sent annually from Europe for recycling to China and south-east Asia may be illegal... That is now considered an underestimate. New evidence from the Netherlands suggests that 70% of the European waste shipped via there to developing countries is illegal".

Asia

The EU's WEEE and RoHS directives are set to impact the Asian economies, whose industries supply a large amount of the worlds EEE. A survey of 359 electronics manufacturers in Greater China and South Korea that export to Europe found that 51 percent are RoHS-compliant (Global Sources 2005, p. 3). By June 2006, this figure is expected to be 93.3 percent (Global Sources 2005, p. 3). However, some expect the directives to increase the manufacturing costs, at least during the transition period.

China

China is expected to feel the impacts of the EU's WEEE and RoHS directives. The China Chamber of Commerce for Import and Export of Machinery and Electronic Products suggests that the directives will affect $5.6 billion worth of Chinese exports to the EU (Global Sources 2005, p. 3). By comparison, China's total exports of electromechanical products were about $400 billion in 2005 (Global Sources 2005, p. 3). Li (2006) suggest that the directives may ultimately cause a loss in foreign trade of about $37 billion. However, China View (2005) presents more conservative findings: "China's export to the EU market reached US$150 million last year. The export volume of these products is expected to fall by 30 to 50 per cent as a result of these two new directives." Li (2006) also states that "industry insiders estimate that the directive will lead to a 10 percent rise in production costs in China's electronics industry."

In response to the two EU directives, "the Chinese government is developing its own China RoHS law, which is likely to be broader in scope and even more comprehensive than the EU directive. The new legislation will apply to every participant in the electronics supply chain, from manufacturers and distributors to importers and retailers. And unlike the EU's 'self-certification' approach, the new law will require every product to be tested before it is allowed entry into China. All products sold in China or imported to the country will be required to comply with the law as of January 2007" (Li 2006). The new laws, if implemented in a timely fashion, will help offset the impacts of the EU directives (China View 2005).

Taiwan

In a world-first legislation of its kind in 1998, the Taiwanese Government introduced the 'Environmental Protection Administration Recycling Management Fund' to support and facilitate the collection, tranportation and disposal of computers, printers, household appliances, televisions and air conditioners (Environment Victoria 2005, p. 30). Financially, the fund is maintained by recycling fees for computer manufacturers (Environment Victoria 2005, p. 30).

Like China, Taiwan is also expected to feel the impact of the EU's WEEE and RoHS directives. Taiwan's export to of EEE to the EU is worth an average of $10 billion (Global Sources 2005, p. 3). "According to the semi-official Industrial Technology Research Institute, the WEEE and RoHS directives could increase costs between 3 percent and 5 percent for branded electrical and electronics product vendors and raise producers' manufacturing costs from 5 percent to 10 percent" (Ho 2005). Preparations to accommodate the directives are underway. "According to a survey conducted by the bureau, 63 percent of domestic manufacturers have started to prepare for WEEE regulation, while 87 percent of them said they have begun to comply with RoHS" (Ho 2005).

Japan

Japan is countering e-waste by mandating upstream design criteria and requiring the take-back of selected EEE (Puckett et al. 2002, p. 4; OECD 2001, p. 105). In 2000, the approval of a 'Basic Law for Establishing a Recycling-based Society' saw the start of several specific recycling laws (Environment Victoria 2005, p. 29). For example, since 2001, Japanese Businesses have been required to recycle PCs; and since 2003, manufacturers have been required collect and recycle used computers, with costs subsidised by a 3000-4000 yen (AU$34-45) per unit fee absorbed into the purchase cost (Environment Victoria 2005, p. 29).

Another law to emerge from the Basic Law is discussed by Meinhardt (2001, pp. 57-58): "The Law for Recycling of Specified Kinds of Home Appliances [SHAR] (effective as of April 2001) obligates Japanese manufacturers, retailers and consumers to share the cost of disposing of televisions, refrigerators, washing machines and air conditioners. Manufacturers are required to meet designated recycling rates for each product, and to safely dispose of any hazardous materials. Larger manufacturers have set consistent prices for take-back of goods, and established recycling plants to handle both materials covered by the Act and other electronic goods. Retailers are obliged to pick up discarded appliances and return them to manufacturers, with consumers contributing towards the cost of transportation and recycling."

Japan's Ministerial Order sets reuse and recycling rate targets for various products at 50-60% by weight (Article 4, Ministerial Order cited in Tojo 2005, p. 78). Article 2.1 of the SHAR law stipulates that targets "... should be fulfilled by product reuse, component reuse, and material recycling with a positive monetary value..." (Tojo 2005, p. 78).

The articles of the SHAR law that are relevant to EEE are (Tojo 2005, p. 80):

1. Waste reduction through promotion of less material use and greater longevity of products (Article 18) Target: products that create large volumes of waste stream at the end of their life.

2. Reuse of components and material recycling (Article 16, 21) Target: a) products whose parts and material can be reused or recycled; b) industries whose products contain components that can be reused in a new product.
3. Collection and recovery of end-of-life products by industries (Article 26) Target: products whose producers could collect and recover (reuse or recycle) their products when they come to the end-of-life phase.

United States of America

Government Accountability Office (2005, p. 14) summarise the inadequacies of US Federal law: "... current federal laws and regulations (1) allow hazardous used electronics in municipal landfills, (2) do not provide for a financing system to support recycling, and (3) do not preclude electronic products generated in the United States from being exported and subsequently threatening human health and the environment overseas".

Since 2005, the United States Environmental Protection Agency (US EPA) has spent about US$2 million on several programs aimed at recycling and minimising the environmental risks of computing equipment waste, which are discussed by Meinhardt (2001, pp. 58-59), Government Accountability Office (2005, pp. 25-27) and Environment Victoria (2005, pp. 30-31). By comparison, federal agencies spent about $10 billion on EEE and related services in the 2004-2005 financial year alone. This large margin reflects the results obtained by the US EPA's programs. The programs were successful to the extent that they were implemented – only 61 federal facilities out of thousands participated (Government Accountability Office 2005, p. 27). Lack of mandatory participation has been identified as a key downfall in these programs (Government Accountability Office 2005, p. 28).

There is also some activity regarding e-waste at the state level. Pucket et al (2005, p. 9) reports that in 2003, 26 states had introduced 56 e-waste bills, however none of the bills prevent the export of e-waste to developing countries. In 2004, 22 states had 36 e-waste bills awaiting ratification (Environment Victoria 2005, p. 30). Some state laws already in place are:

- "Minnesota has drafted purchasing language that requires proper, environmentally-sound end-of-life disposal... All waste materials, components and residuals managed under this Contact will be restricted in international markets as follows: All waste materials including processing residuals shall be processed, used, reused, reclaimed or disposed of only in Canada, Mexico or the United States" (The Federal Network For Sustainability n.d.).
- California's "Department of Toxic Substances Control has determined that most electronic devices are toxic, and as of February of this year were banned from landfills under the state's Universal Waste Regulation. Unfortunately, since that ban became effective, California is nowhere close to 100 percent compliance of that law, and consumers are still disposing toxic e-waste into landfills" (Earth Tones 2006). Contributing to the poor compliance rate is the complication that under Californian law "... only hazardous waste facilities should legally accept CRTs, and that disposal by existing collection and recycling facilities is illegal" (Environment Victoria 2005, p. 31).
- "The states of Connecticut, Florida, Minnesota, and Wisconsin also have considered bills prohibiting the disposal of CRT equipment as MSW. North Carolina and California are considering bills to require industry to take back outmoded electric appliances. California also requires that CRTs be handled as hazardous waste, making the development of recycling programs exceedingly difficult. New Jersey's program goes so far as to define electronics as universal waste. This is an important program to watch because, in essence, universal waste rules are intended to allow for the classification of materials that are potentially hazardous, but can be source separated, processed, and recycled or reused. New Jersey officials are considering the establishment of universal waste consolidation centers throughout the state that will not only handle electronics, but also handle more traditional consumer universal wastes such as thermostats and other mercury switches, batteries, and fluorescent lamps" (Biddle 2000, p. 17).

Despite these programs, the US still attracts criticism about its efforts in combating e-waste. For example, Puckett et al. (2002, p. 3) states: "The U.S. government policies appear to be designed to promote sweeping the E-waste problem out the Asian back door... the United States government has intentionally exempted E-wastes, within the Resource Conservation and Recovery Act, from the minimal laws that do exist (requiring prior notification of hazardous waste shipments) to protect importing countries. When questioned, officials at the United States Environmental Protection Agency (EPA) admit that export is very much a part of the U.S. E-waste disposal strategy and the only issue of concern for the U.S. might be how to ensure minimal environmental standards abroad."

The Resource Conservation and Recovery Act, which was introduced in 1976, bans companies from throwing away many waste EEE (Schmidt 2002).

Canada

Environment Victoria (2005, p. 31) summarise the e-waste regulations in Canada:

- All waste issues are the responsibility of Provincial and Municipal Governments.
- In 2002, Electronics Product Stewardship Canada was formed to work with Provincial Governments to develop programs for the collection and recycling of e-waste.
- In 2004, guidelines suggested that the cost of managing e-waste should be borne primarily by manufacturers.
- In 2005, the province of Alberta began charging a $30 levy on every new desktop computer sold.
- In province of Ontatio, the 'Waste Diversion Act' requires manufacturers and retailers to waste from packaged products, including EEE.

Other National

RMIT & Product Ecology (2004) present a review of national level legislation, protocols and standards:

- They offer an analysis of key components of national legislation policy (p. 33). The analysis includes 8 European countries, Japan and Taiwan and indicates whether there are in place mandatory and/or voluntary legislations; landfill and or/materials bans; recycling and/or collection programs; and also note who takes responsibility for collection at end-of-life. The key results are that Netherlands, Sweden, Switzerland and Denmark have either a landfill ban of material bans in their take-back legislation; and that Norway, Denmark, Belgium, Italy and Japan have either collection and/or recycling targets in legislation (p. 32).
- They also offer a description and comparison of several national and global policies on e-waste (Appendix E). The analysis indicates whether there are in place mandatory and/or voluntary legislations; landfill and or/materials bans; and recycle and or collection targets. The analysis also indicates who funds the system and who is responsible for collection or take-back.

Extended Producer Responsibility

There are legislations in force that place the responsibility of end-of-life processing explicitly on the producer. This strategy is referred to as 'extended producer responsibility'. Currently, the European Union, Japan, South Korea, Taiwan and several states of the US, but not Australia, have these types of legislation (Brigden 2005, p. 3).

These are several definitions of Extended Producer Responsibility (EPR). One example is:

"Extended Producer Responsibility is an environmental protection strategy to reach an environmental objective of a decreased total environmental impact from a product, by making the manufacturer of the product responsible for the entire life-cycle of the product and especially for the take-back, recycling and final disposal of the product. The Extended Producer Responsibility is implemented through administrative, economic and informative instruments. The composition of these instruments determines the precise form of the Extended Producer Responsibility" (Lindhqvist 1992 cited in Tojo 2005, p. 5).

Tojo's (2005, p. 8) definition is based on another offered by Lindhqvist (2000):

"... a policy principle to promote total life cycle environmental improvements of product systems by extending the responsibilities of the manufacturer of the product to various parts of the product's life cycle, and especially to the take-back, recovery and final disposal of the product."

The OECD (2001, p. 10) sees EPR as an "... extension of traditional environmental responsibilities [of] producers and importers", and thus focuses on the producer's responsibility at the post-consumer stage:

"OECD defines EPR as an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle" (OECD 2001, p. 9).

An effective EPR-based policy would:

- Be non-prescriptive (Tojo 2005, p. i).
- Engage the whole product chain, not just point sources (Tojo 2005, p. i; OECD 2001, p. 9).
- Consider the entire life cycle of the product (Tojo 2005, p. i).
- Prioritise prevention of environmental problems at the source over end-of-pipe solutions (Tojo 2005, p. i; OECD 2001, p. 29).
- Provide incentives for the manufacturer to attend to its responsibilities. (Tojo 2005, p. i; OECD 2001, p. 9).
- Prevent waste (OECD 2001, p. 29).
- Close materials loops (OECD 2001, p. 29).
- Result in more environmentally compatible products (OECD 2001, p. 29).

OECD (2001, pp. 27-29) presents 15 'guiding principles' that could well fit into this list, and 20 examples of more-specific, possible objectives for EPR policies.

Tojo (2005) discusses 2 studies. The first study investigates the environmental effectiveness of mandatory EPR programmes on 21 manufacturers of EEE and cars in Sweden and Japan (Tojo 2005, p. iv). The second study examines how 5 EPR programs in Japan (EEE), The Netherlands (EEE, batteries), Switzerland (EEE, batteries) were implemented (Tojo 2005, pp. v-vi). The results of the first study suggest that:

- "the more control the manufacturers have over the downstream infrastructure, the more likely it is that measures belonging to the higher ladder of resource efficiency will be taken" (Tojo 2005, p. iv).
- there is a clear link between EPR legislation and the associated action. In fact, all participating manufacturers "acknowledged influence from EPR legislation on their efforts to reduce product environmental impacts" (Tojo 2005, p. vii).
- manufacturers take anticipatory action in the face of upcoming legislation (Tojo 2005, p. vii)

Since the 1990s, EPR has been implemented by several governments, especially those of OECD countries (Tojo 2005, p. i). O'Meara Sheehan (2003) discusses some cases:

- "Perhaps the best model so far of 'extended producer responsibility' is Germany's packaging law, which went into effect in 1991 and has required manufacturers and distributors to recover their packaging and reuse or recycle it."

- "Some countries in Asia, too, have made progress in this area. Since 1998, Japan has mandated producer take-back of electrical appliances; this is now being extended to computers and other electronics. As the Japanese government requires companies to take back products containing lead, companies such as Sony, Panasonic, Hitachi, Sharp, NEC, and Toshiba are investing in lead-free technologies."
- "Also in 1998, Taiwan started a take-back system for computers, televisions, and large home appliances that requires retailers to accept used electronics, regardless of where they were sold."

Tojo (1999, pp. 106-112) and OECD (2001, pp. 127-133) describe the characteristics of EPR program for EEE in Japan, the Netherlands, Sweden and EU, and EEE regulation in Denmark. OECD (2001, pp. 135-136) also discusses the allocation of responsibility for those programs and regulations.

EPR is perhaps most valuable for countries such as Australia, who design and manufacture very little of the EEE in their own market and hence have limited capacity for influencing the environmental soundness of products at the design level. For these countries, EPR is one of a limited number of strategies to encourage more ecologically sustainable EEE (Environment Victoria 2005, p. 4)

Product stewardship

The concept of 'Product stewardship' helps to define how responsibility for a product is shared among its stakeholders. There are several definitions of Product Stewardship, including:

- "Product stewardship is a principle that directs all participants involved in the life cycle of a product to take shared responsibility for the impacts to human health and the natural environment that result from the production, use, and end-of-life management of the product" (Product Stewardship Institute 2004).
- "Product Stewardship is an approach that recognises that manufacturers, importers, governments and consumers have a shared responsibility for the environmental impacts of a product throughout its full life cycle" (Environment Protection and Heritage Council 2004, p. 2).

Product stewardship aims to:

- "encourage manufacturers to redesign products with fewer toxics, and to make them more durable, reusable, and recyclable, and with recycled materials" (Product Stewardship Institute 2004).
- "reduce adverse impacts and internalise unavoidable costs within the product price, through action at the point(s) in the supply chain where this can be most effectively and efficiently achieved" (Environment Protection and Heritage Council 2004, p. 18).
- "move beyond disposal to facilitate a paradigm shift toward 'zero waste' and 'sustainable production'" (Product Stewardship Institute 2004).

Product Stewardship Institute (2004) suggests a 'duty-of-care' approach to assigning responsibility to stakeholders (manufacturers, retailers, consumers and government). "The greater the ability of a party to influence the life cycle impacts of a product, the greater the degree of that party's responsibility" (Product Stewardship Institute 2004).

There are 5 models for product stewardship. In increasing order of government involvement, they are (Environment Protection and Heritage Council 2004, p. 4):

1. non-intervention (business as usual)
2. voluntary industry initiatives
3. voluntary industry-government agreements
4. co-regulatory approaches

5. fully regulatory schemes

Environment Protection and Heritage Council (2004) discusses the potential and impacts of a co-regulatory model in Australia. They suggest 22 guiding principles for a Product Stewardship Agreement (Environment Protection and Heritage Council 2004, pp. 11-12).

What are the general approaches taken to overcome the issues associated with e-waste?

Design for Environment and Life Cycle Assessment

Design for Environment (DfE) and Life Cycle Assessment (LCA) are two concepts that support low materials intensity, low toxicity and high recyclability. The use of these concepts in the EEE manufacturing, information technology and communications industries continues to grow significantly (RMIT & Product Ecology 2004, p. 34), which leads to progress in Design for Recyclability, as RMIT & Product Ecology (2004, p. 19) summarises:

“Manufacturers are placing greater emphasis on the recyclability of materials used in PCs and the impact the physical design has on the recyclability of products.

Manufacturers are now reducing the amount of different plastics in their units making it easier to sort for recycling. They are increasingly looking at the type of plastic used to ensure that there is a market for the recycled resin. Plastic components over a certain size are being labelled to aid the recovery of the plastic.

Manufacturers are ensuring that their units are easier to dismantle, thereby aiding the recycling process. There is a reduction in the number of screws used and preferences now made towards parts that clip together”.

O’Meara Sheehan (2003) also highlights the benefits of DfE: “If manufacturers were to design computers, cell phones, etc. for easy disassembly and recycling, it would make the task easier wherever it takes place.”

Environment Victoria (2005, pp. 34-35) offer examples of ways to improve the environmental performance of EEE and the industry itself:

- Reducing the overall number of parts and materials used.
- Labelling materials, or coding them using electronic tags, to facilitate recycling and provide information on toxicity.
- Use of metals in preference to plastics, as they are easier to recycle.
- Standardisation of components to make disassembly easier.
- Avoiding glues that contaminate the recycled materials, making sorting difficult.
- Reducing the number of screws and using parts that snap together (and if screws are used, using the same type of screws, all oriented in the same direction, so they can be removed in rapid succession, using one tool).
- Eliminating paint and dyes that contaminate and weaken plastics when recycled.
- Switching to water-based paints which can be easily dissolved.
- Creating computer components and peripherals of biodegradable materials.
- Re-evaluate use of ‘cheap’ products which downgrade the product cycle and reduce the viability of disassembly and recycling.
- Technology and knowledge sharing between manufacturers and demanufacturers.
- Encouragement and promotion of green procurement for corporate buyers.
- Transform current sales model of providing ‘products’ to one of providing ‘services’.

The next section, ‘Who is taking these approaches in industry?’, gives example of DfE in industry.

See Appendix A for more information on Design for Environment and Appendix B for more information on Life Cycle Assessment.

Recycling and collection

Effective recycling and collection initiatives can increase the life of raw materials and prevent the release of toxic substances to the environment. Recycling is labour intensive and relatively costly because the currently obsolete EEE was not designed with disassembly in mind. A 1997 report estimates that the processing of 1000 tons of computers can create an average of 30 jobs (Platt & Hyde 1997 cited in Biddle 2000, p. 30).

Santa Clara County Department of Environment Health (2004, pp. 34-36) highlight the benefits and barriers of five collection models:

- Drop-off event (one-day or multiple days).
- Permanent collection facility.
- Curbside collection.
- Retail collection.
- Nonprofit/thrift retail collection.

RMIT & Product Ecology (2004) adds some general barriers with the take-back and recycling approach:

- "Retail drop-off is not considered practical for most consumers (size/weight and the fact that old products are not necessarily disposed of at the same time as the new purchase)" (p. 16).
- Older products, which are entering the waste stream now, are not designed to accommodate easy disassembly and recyclability (p. 41).
- "According to reprocessors, recycling of older computers, burnt out CRTs, printers and photocopiers needs to be subsidised, as the value of the recovered materials is less than total costs. Other computer products pay for themselves through resale of systems, components or materials. A monitor is estimated to have a value of around $40-$60/unit if it is not burnt or broken. Otherwise they have a negative value of around $12-$25/unit excluding collection. Newer CPUs have a value of around $500/tonne. Printers and scanners have almost no value because they do not contain a large volume of metals or components" (p. 54).

Biddle (2000) further adds barriers pertaining specifically to recycling and remanufacturing organisations:

- "Although these organizations are able to procure a fairly large number of computers, they must still contend with an inventory of roughly 50 percent that do not function properly. As such, there is a cost associated with transporting scrap to a demanufacturing facility. There is also a cost for ensuring that non-functional CRTs are recycled ($200-$300 per ton)" (p. 19).
- As is the case with facilities in the United States, capital and operating costs can be high: "Detailed engineering and design work is required, and capital costs can range from $250,000 to $500,000 or more, with operating costs in the neighborhood of $10,000 to $15,000 a month – or more, depending upon facility throughput" (Platt & Hyde 1997 cited in p. 30).

Limited legislation in most countries means that local governments pay for EEE recycling and collection most often. However, governments, especially local governments, cannot afford to run these initiatives alone. Although there is still debate as to who should take financial responsibility for recycling and collection, a survey of US local governments by the Santa Clara County Department of Environment Health (2004, p. 17) showed that the popular suggestion is that it should be manufacturers, distributors and retailers that should carry most of the costs. Santa Clara County Department of Environment Health (2004, Appendix C) also provides a 'how-to' guide on managing e-waste targeted at local governments.

The next section, 'Who is taking these approaches in industry?', gives example of industry-led recycling and collection initiatives. Meinhardt (2001, pp. 72-74) summarises some government-led EEE recycling and collection initiatives:

- Netherlands: "Stichting Computerbemiddeling Onderwijs (SCBO or Computers for Classrooms) receives donated computer equipment that is commercially redundant and supplies it to primary and secondary schools and tertiary institutes for vocational education and adult training."
- Spain: "A take-back collection trial for corporate computers and office equipment and domestic brown goods (televisions, video recorders, etc.) was conducted in Bilbao between October 1994 and December 1996."
- United Kingdom: "At the request of the United Kingdom Government, a collection and recycling scheme for all electrical equipment was trialled by the Industry Council on Electrical and Electronic Equipment Recycling (ICER) The trial ran for approximately 2 years between October 1995 and April 1997."
- United States of America: "One study undertaken in San Jose, California under the US EPA's Common Sense Initiative modelled a corporate take-back program for collection of electronics through three retail outlets... total 62,000 pounds of material recovered... The net cost came to $US18,000 or $US584 per ton. Of the revenue returned, 38% was from resale of functioning equipment and the remaining 62% from sale of materials for scrap... A comparative analysis was also undertaken to determine the difference in costs from recycling monitors locally in the United States ($US15,000) or shipping them overseas for processing ($US1,500). The overseas options were significantly less at $US142 per ton."
- United States of America: "Another US trial, which was unique in its development approach, was conducted by the Minnesota Office of Environmental Assistance (MOEA). The MOEA established a partnership with the American Plastics Council, Panasonic-Matsushita, Sony Electronics Inc and a waste management company, each of which provided funding for the trial. The MOEA called for and received participation by a range of organisations, including Local Government, electronics retailers and waste management contractors... The MOEA and its partners managed the transportation and disposal of the collected material from the 65 collection sites involved in the 3 month program... The trial provided drop-off facilities for electrical equipment to approximately 1.3 million people and collected around 700 tonnes of material."

The San Jose initiative is taken by Meinhardt (2001) from Biddle (2000, p.19, Appendix A). Biddle (2000, Appendix A) summarises this initiative and another seven municipal council collection initiatives in the United States, including:

- "US Union County, New Jersey's electronic collection program found that the dismantling of TVs and recovery of TV circuit boards could yield up to $25 a unit by selling boards to local repair shops... With the standard charge for CRT processing at $5.00 to $10.00 a unit, recycling costs can be offset for TVs through circuit board recovery" (p. 11).

Product Leasing

Meinhardt (2001, p. 25) reviews the status and effectiveness of EEE leasing in Australia: "Leasing of equipment is well established in Australia, particularly in the institutional and corporate sector. Industry participants estimate that approximately 600,000 computers are currently leased in Australia. Approximately 240,000 computers are disposed of in this sector every year. Leasing of scanners and printers is also established, although at a much lower rate. Approximately 15,000 units would be disposed of each year."

Eco-Labelling

Eco-labelling helps consumers make informed purchases by publicly endorsing environmentally responsible products. In Europe, PCs have been endorsed using eco-labels under the following schemes (Meinhardt 2001, pp. 55-56):

- "The Swedish Confederation of Professional Employees' TCO '95 and TCO '99 Certification for personal computers (including the CPU/case, monitor and keyboard), which covers ergonomic qualities and environmental impact in addition to emissions (electric and magnetic fields, noise and heat), energy efficiency and ecology."
- "The Nordic Environmental Label (or Swan label), which is a multinational environmental labelling scheme operating in Sweden, Finland, Denmark, Iceland and Norway. The label criteria apply to the CPU/case, monitors and keyboard, and the main requirements are ergonomics, energy efficiency, low electric- and magnetic emissions, ecological requirements concerning choice of materials and construction, and electrical safety and fire risk."
- "The German Blue Angel Eco-mark (or Umweltzeichen). A non-profit company created by German manufacturers as part of a product stewardship strategy developed this mark. It licences use of the Blue Angel logo to companies meeting specific environmental criteria. Of all European environmental labels, Blue Angel has greatest recognition and penetration within the computer industry... The Blue Angel mark is cited by a number of international computer manufacturers on their web-sites as an environmental benchmark that a number of their products meet."

In 2000, the Japanese Government began an eco-labelling program for computers (Environment Victoria 2005, p. 30). The eco-label's criteria considers design for recycling, take-back and recycling provision, elimination of hazardous substances, and energy conservation (Environment Victoria 2005, p. 30).

Alternatively, warning labels are also valuable. For example, almost all current EEE would qualify a 'future hazardous waste' warning label (Santa Clara County Department of Environment Health 2004, p. 20).

Who is taking these approaches in industry?

International

Meinhardt (2001, pp. 60-71) discusses the progress of the following EEE manufacturers with regard to design for environment and take-back recycling programs: Apple, Canon, Compaq, Dell, Fujitsu, Hewlett Packard, IBM, Lexmark, NEC Packard Bell, Toshiba and Xerox. All of the manufacturers have both design for environment and take-back recycling programs in place. RMIT & Product Ecology (2004, pp. 35-36) adds Phillips, Ericsson, Nokia, AT&T and Sony to the list of manufacturers using design for environment. Consumer Electronics Suppliers Association (2004, pp. 36-42) further adds Sharp, Samsung, LG, Mitsubishi, Hitachi, Sanyo and Matsushita to the list of manufacturers using design for environment. RMIT & Product Ecology (2004, Appendix C) and Environment Victoria (2005, pp. 12-13) summarise a variety of e-waste minimisation programs, including industry associated programs; company programs; collaborative R&D programs; office consumables programs; and related industry programs.

Biddle (2000, p. 19) reports: "In 1996 Envirocycle processed 23 million pounds of CRT glass (11,500 tons). It charges $5-$15 to recycle monitors – depending on quantity and quality, and most of its business still comes from equipment manufacturers. Company officials note that maintaining a quality feedstock is the key to success... In addition, at least one of the three manufacturers of CRT glass in the US has made a commitment to use cullet from Envirocycle's recovery operations."

Biddle (2000, Appendix C) also lists 15 collection, recycling and remanufacturing organisations in the United States.

Some companies are taking the initiative to develop recycling expertise for newer technologies ahead of demand, as RMIT & Product Ecology (2004, p. 54) reports: "While few flat screen products are currently entering the waste stream, the number will increase over the next few years. A company in Berlin, Vicor GmbH, has undertaken a pilot recycling project in which LCDs were manually separated. Liquid crystals were removed and destroyed catalytically and 70% of the glass was recovered."

Australia

The optimal e-waste minimisation strategy for Australian industry may differ from that of Europe and other parts of the world, as Consumer Electronics Suppliers Association (2003, p. 19) discusses: "The highly regulated approach taken in Europe may not be necessary or appropriate here. We have already seen how much can be achieved through voluntary initiatives, albeit with the support of government. What we do need is a much more clearly informed direction from government in developing a framework for managing product life cycles, and a commitment from industry to develop product stewardship programs that are real and sustainable. In particular, we need to engage with those sectors that have so far stayed out of the product stewardship debate, for example automotive suppliers."

AIIA & Planet Ark Consulting (2005, p. 9) confirm that this voluntary approach could work: "Computers are getting smaller and lighter and increasingly homogenous in materials and technologies. They are also easier to disassemble and the use of toxic substances is declining with further improvements predicted due to the commencement of substance regulations... and other product design legislation being introduced across the globe. These directives [regulations and legislations], while of significant importance, reinforce what many AIIA members have already been demonstrating in their own company 'design for the environment' initiatives. For example, in 1995, some of our members started labelling plastics in their products to facilitate the end-of-life recycling process." They continue on to state that "AIIA and its members have an ultimate goal of zero waste to landfill" (AIIA & Planet Ark Consulting (2005, p. 10).

However, current rate of e-waste generation in Australia suggests that not enough is being done. In contrast to the extensive programs abroad, activity in take-back, refurbishment, recycling and remanufacture of computer and peripheral equipment by manufacturers in Australia is limited. To improve activity in Australia, AIIA & Planet Ark Consulting (2005) and Consumer Electronics Suppliers Association (2004) suggest a co-regulatory approach and support the creation of a Producer Responsibility Organisation to aid the co-regulatory process. Consumer Electronics Suppliers Association (2004) discuss a recently established Producer Responsibility Organisations, Product Stewardship Australia Limited, whose purpose is "... to develop, coordinate and promote a phased national collection and processing scheme for EoL [end-of-life] electronic and electrical products..." (Consumer Electronics Suppliers Association 2004, p. 10).

Some of the few take-back programs include (Meinhardt 2001, p. 37):

- Computers: "The only collection scheme for obsolete computers currently in place is that established by Compaq Computer Australia with funding assistance from the NSW Environment Protection Authority. This scheme (known as the Computer Asset Recovery Service) commenced in January 2000 and focused on large corporations. It does not accept obsolete computers from domestic sources, and has limited geographical coverage of Australia. The NSW EPA advised that over a period of 15 months the service collected approximately 200 tonnes of computers, monitors and related equipment, including items such as fax machines which are outside the scope of this project."
- Printers: "Hewlett Packard also currently has a trade-in program in Australia, whereby old printers are taken back by the manufacturer when customers purchase a new laser printer. The old printers are either recycled or refurbished and resold. However the program is limited to certain models of printers, including limitations on the model of old printer accepted and new model purchased. The extent of participation in this program is not known." An update from Hewlett Packard (2004) informs of another program that recycles printer cartridges. This program is in partnership with Planet Ark and Close the Loop, a recycling service provider (Hewlett Packard 2004). Up until 2004, the program "has recycled 60,000 ink and toner cartridges, and helped to divert 269,000m3 of materials from landfill" (Hewlett Packard 2004).
- Printer/toner cartridges: "Fuji Xerox Australia has a program for return of printer cartridges. Customers are provided with a recovery box which is collected by arrangement with Fuji Xerox when full. Ricoh Australia has also recently introduced a service for take-back and recycling of toner cartridges. While recovery of cartridges in Australia is more widespread than these two programs, these services are offered by recycling companies rather than the manufacturers."

AIIA & Planet Ark Consulting (2005, p. 8) add "... IBM has a range of product recycling and end-of-life disposal programs in place via Global Asset Recovery Services. In 2004, more than 83,000 monitors, PCs, printers and servers were resold through this program, extending their usefulness. Of the 155 tonnes of old equipment IBM scrapped in 2004, almost 84% by weight was recycled".

RMIT & Product Ecology (2004) report on a variety of Australian programs that target e-waste:

- "The Mobile Phone Industry Recycling Program (MPIRP) is an industry funded recovery and recycling scheme specifically for mobile phone handsets, batteries and accessories. Developed and co-ordinated by the Australian Mobile Telecommunications Association (AMTA), the MPIRP is a national program with joint industry membership covering mobile phone producers and distributors, carriers and retailers... The cost of administering the recovery and recycling scheme is covered by a AU$0.40/handset levy on the sale of new phones... Since 1999, approximately 30 tonnes of mobile phones, batteries and accessories have been collected for recycling in Australia... [with] over 100,000 batteries were collected in the program's first six months... Products recovered from the phone recycling process include: nickel, cadmium, gold, silver, plastics – all used in new products" (Appendix D).
- Some charities, such as Computer Bank and Technical Aid for the Disabled in New South Wales, and Com IT and InfoXchange in Victoria, are directly involved with computer refurbishing and reuse (p. 12). Other charities such as St Vincent de Paul, Brotherhood of

St Laurence and Diabetes Foundation, are involved in take-back, testing and resale (p. 13). Both The Salvation Army and Red Cross used to be involved in take-back, testing and resale but, for various reasons, no longer accept appliances (p. 13).

- "Many councils own and/or operate transfer stations located in their municipality. These are open to the public for drop off of any goods too large for rubbish collection" (p. 13), which includes waste EEE.
- "... EcoRecycle Victoria funds Household Chemical Collections (HCC) each month somewhere in Victoria, in conjunction with Councils. In addition to chemicals they accept miscellaneous products including Nickel Cadmium (NiCad) batteries, automotive and mobile phone batteries, fluorescent tubes and fire alarms" (p. 14).
- "The Australian Mobile Telecommunications Association (AMTA) runs a program to collect mobile phone batteries and handsets through bins in retail outlets (see Appendix B). A new program has also been established by Close the Loop and Planet Ark to collect toner and ink cartridges through bins in Australia Post and Harvey Norman stores" (p. 14).
- Resource NSW and AIIA, with reprocessor HMR, undertook Recycle IT!, a pilot collection and recycling project for computer and peripheral parts between November 2002 and March 2003 in Western Sydney (p. 20). Both permanent and temporary drop-off points were established and two one-day drop-off events were run, based on HCC collection days (p. 20). The project resulted in the collection of 6383 pieces totalling a mass of 57 tonnes (p. 21). EcoRecycle Victoria plans to build on Recycle IT! with a trial take-back program in Melbourne (Environment Victoria 2005, pp. 19-20).
- Fuji Xerox partnered with Visy in a recycling trial for plastics from copier housings (p. 49). About 1 tonne of material was processed (p. 49). The trial was not particularly successful, mainly because the plastics were not sorted well enough (p. 49). The plastics were later exported for reprocessing (p. 49). Now, Visy usually recycles post-consumer PET plastic only and Fuji Xerox is considering exporting its sorted plastics to Japan for recycling (p. 49).
- Close The Loop recycle printer consumables, such as toner and inkjet cartridges, with zero waste to landfill (p. 48). Their new process sorts up to 12 polymers types and produces pure streams of ABS and HIPS plastics (p. 48). Close The Loop is considering including printer and photocopier housings in their recycling operations (p. 48). Their partners include Hewlett Packard, Canon, Epson, Brother and Panasonic (p. 48).

Environment Victoria (2005, p. 32) lists 11 computer rerurbishers and recyclers in Victoria, Australia, while there are only two major EEE disassembly and reprocessing organisations in Australia (RMIT & Product Ecology 2004, pp. 40-41):

- "HMR has plants in the US, Phillippines, Malaysia, Vietnam and Melbourne, Sydney, Adelaide and Brisbane in Australia... While their core business is computers, they also take back other obsolete electronic equipment from industry, and after testing will either resell or reprocess it... Equipment that cannot be repaired and resold is disassembled for recovery of components and materials."
- "MRI has facilities in Melbourne and Sydney... Computers are either repaired for sale or disassembled for recovery of electronic components and materials."

The aim of the 6-partner Melbourne TV Recycling Pilot was to gather data and insight into the recovery and processing of consumer electronics (RMIT & Product Ecology 2004, p. 25). The project officially ran from November 2001 to March 2002, but MRI, the designated reprocessing partner, accepted products as early as September 2001 as late as September 2002 (Consumer Electronics Suppliers Association 2003, p. 39). RMIT & Product Ecology (2004, p. 28) report that "the total cost of collection and reprocessing... [was] approximately $22 per unit". Consumer Electronics Suppliers Association (2003, p. 8) summarise the key outcomes and conclusion of the project:

- Diversion of 3,500 TVs, computer monitors and VCRs in the period funded by the pilot.

- Report documenting and evaluating a diverse range of information, data and knowledge acquired during the course of the pilot project, including recommendations on future expansion of the scheme.
- Development of a product handling an processing system for collection, disassembly, processing and recycling.
- Foundations for the development of an industry-agreed collection and recycling scheme for consumer electronics.
- Capacity handling development for up to 100,000 units per annum.

Environment Victoria (2005, pp. 22-25) have performed a review and scoring of the top six computer companies in Australia, which together have 58 percent computer market share in Australia. The companies were compared against best practice and received scores out of 100. The results were (Environment Victoria 2005, p. 24):

- Dell Australia and New Zealand, 78.5
- Hewlett-Packard Australia, 78.0
- IBM Australia/NZ, 64.0
- Acer Computer Australia, 39.0
- Apple, 31.5
- Toshiba, 22.0

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Appendix A: Design for Environment

The information in Appendix A is taken from draft versions of two documents developed by The Natural Edge project:

- Engineering Sustainable Solutions Program, Critical Literacies Portfolio, Whole Systems Portfolio, Module 1: Achieving energy and materials efficiency, Unit 1: Setting the context: radical resource productivity.
- Engineering Sustainable Solutions Program, Critical Literacies Portfolio, Module 2.3: Whole Systems Engineering Design, Unit 1: Profitable Greenhouse Solutions.

Background Information

As Hawken *et al* wrote in *Natural Capitalism*,

> *By the time the design for most human artefacts is completed but before they have actually been built, about 80–90 percent of their life-cycle economic and ecological costs have already been made inevitable. In a typical building, efficiency expert Joseph Romm explains, 'although up-front building and design costs may represent only a fraction of the building's life-cycle costs, when just 1 percent of a project's up-front costs are spent, up to 70 percent of its life-cycle costs may already be committed. When 7 percent of project costs are spent, up to 85 percent of life-cycle costs have been committed'. That first one percent is critical because, as the design adage has it, 'all the really important mistakes are made on the first day'.*

Designs for infrastructure, buildings, cars and appliances now have long design lives. The size and duration of infrastructure and building developments, for instance, demand that they should now be much more critically evaluated for efficiency and function than ever before.

Former Minister for Environment, Senator Robert Hill, when talking about the new Parliament House, sums up the loss of opportunities from a lack of a design for environmental approach,

> *Across Lake Burley Griffin is one of Australia's most famous houses - Parliament House. Built at considerable cost to the Australian taxpayer, it was officially opened in 1988. Since 1989, efforts have been made to reduce energy consumption in Parliament House, resulting in a 41 per cent reduction in energy use with the flow-on effect of reducing greenhouse gas emissions by more than 20,000 tonnes annually. This has also brought about a saving of more than $2 million a year in running costs. But the new wave of environmental thinking would have us question why these measures weren't incorporated in the design of the building in the first place and what other opportunities for energy saving design features were missed? It's a simple example of how the environment is still considered an add-on option as opposed to being central to the way we do business.*[1]

Currently considerable opportunities are being missed at the design phase of projects to significantly reduce negative environmental impacts. There are a great deal of opportunities here for business and government to reduce process costs, and achieve greater competitive advantage through greener product design. As Senator Robert Hill also stated,

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[1] An address to *The International Society of Ecological Economists* by the Federal Minister for the Environment and Heritage Senator the Hon Robert Hill Australian National University Canberra July 6, 2000 (www.deh.gov.au/minister/env/2000/sp6jul00.html).

> *Building construction and motor vehicles are two high profile industry sectors where producers are utilising Design for Environment (DfE) principles in their product development processes, thereby strategically reducing the environmental impact of a product or service over its entire life cycle, from manufacture to disposal. Companies that are incorporating DfE are at the forefront of innovative business management in Australia. As the link between business success and environmental protection becomes clearer, visionary companies have the opportunity to improve business practices, to be more competitive in a global economy, and increase their longevity*.[2]

The Department of Environment and Heritage has published *Product Innovation: The Green Advantage: An Introduction to Design For Environment for Australian Businesses*[3] which highlights the benefits of pursuing a 'Design for Environment' approach. This is backed up by numerous studies. 'Design for Environment' provides a new way for business to cost effectively achieve greater efficiencies and competitiveness from product re-design. Harvard business school Professor Michael Porter *et al*, highlights the ways that 'Design for Environment' at the early stages of development of a project can both reduce costs and help the environment. Some of businesses' most significant costs are capital and inputs, such as construction, raw materials, energy, water and transportation. It is therefore in businesses' best interest to minimise these costs, and hence the amount of raw materials and other inputs they need to create their product or provide their service. Business produces either useful products and services or unsaleable waste. How does it assist a business to have plant equipment and labour tied up in generating waste? Table 1 below lists the numerous ways companies can profitably reduce waste. Addressing such opportunities therefore gives businesses numerous options to reduce costs and create new product differentiation.

Table 1 *Design for Environment can assist a firm's competitive advantage* both by reducing process costs and through helping the firm to create product differentiation. *(Source:* Adapted from Porter, M. and van der Linde, C. (1995))

Design for Environment can Improve Processes and Reduce Costs Through:	**Design for Environment Provides Benefits to Reduce Costs and Create Product Differentiation**
• Material savings from better design. • Increases in process yields and less downtime through designing-out waste and designing the plant and process to minimise maintenance and parts. • Better design to ensure that by-products and waste can be converted into valuable products. • Greater resource productivity of inputs, energy, water and raw materials to reduce costs. • Reduced material storage and handling costs through 'just in time' management.	• Higher quality, more consistent products. • Lower product costs (e.g. from material substitution, new improved plant efficiencies etc.). • Lower packaging costs. • More efficient resource use by products. • Safer products. • Lower net costs to customers of product disposal. • Higher product resale and scrap value.

[2] The Department of Environment and Heritage (2001) *Product Innovation: The Green Advantage: An Introduction to Design for Environment for Australian Business* (www.deh.gov.au/industry/finance/publications/producer.html).
[3] Ibid.

• Improved OH&S. • Improvements in the quality of product or service.	• Products that meet new consumer demands for environmental benefits.

A 'Design for Environment' approach to reducing environmental impacts is one of the best approaches business and government can take to find win-win opportunities to both reduce costs and help the environment. The Design for Environment approach is reminiscent of the 'total quality movement' in business in the 1980s where many were sceptical at the beginning that re-examining current business and engineering practices would make a difference. Many doubted that win-win opportunities could be found. Today it is assumed that such win-win opportunities exist if business takes a total quality approach. The DEH publication *Product Innovation: The Green Advantage* showed that many companies are finding win-win ways to reduce costs and improve product differentiation through a Design for Environment approach.

Case Study: DfE Applied – RLX computer server[4]

The evolving economy of the world is highly dependent on fast, reliable computers. Server appliances for internet hosting provide the computing power for companies to have a large footprint on-line. Server appliances are large groups of computers (servers), typically mounted together in racks. Often large numbers of these racks are used to meet required hosting needs.

Computing power is the design focus, with other issues (i.e., ease of use, affordability, efficiency, size, etc.) considered to be secondary, if addressed at all. The specifications for conventional server racks depend on the manufacturer, but the leading brand incorporates 42 servers into a rack, with two processors per server. The processors used are similar to those for home computers, requiring dedicated fans to blow over large heat sinks. Electrical connections within a single server are accomplished with wiring, which is a source of failure. The large number of Ethernet cables required by such a rack is difficult to manage. A company requiring 336 servers to meet their hosting needs will need 8 server racks, each containing 42 servers. Each server costs roughly $4000 and weighs 29 lbs, so the complete system will cost $1,350,000 and weigh nearly 10,000 lbs. This setup will require 264 amps to function.

RLX, a relative newcomer to server development, decided to take a new approach to server design. Through market research, they recognized the importance of both compact design and energy efficiency to server customers, in addition to computing speed. RLX used whole-systems analysis to determine how best to meet these new design parameters. Analysis was performed at the processor level, the server level, the rack level, and the system level, resulting in a product which better meets customer needs.

The RLX blade server is centred about an efficient processor built by Transmeta. This processor requires 20% of the electrical power of an equivalent Pentium III processor. As a result, no heat sinks or dedicated fans are required for cooling, reducing the size of each server. RLX servers require 1/8 as much space as traditional designs, so 336 servers fit in a single rack, versus 8 racks of competitors. Each server costs $1500 and weights 3 lbs. The initial cost of a 336 server system ($504,000) is 63% less and weighs 80% less than the leading competitor's equivalent system. Due to a smaller footprint and reduced electricity consumption (43 amps), the operating costs are less too, saving an additional $133,000/y. To further improve on the competition, RLX made the overall system more reliable with solid-state electrical connections and redundant power supplies. No tools are required to install additional servers, so expansion of computing abilities is straightforward. In addition, 1/12 as many Ethernet cables are required per rack, making their management significantly easier.

[4] Background information was summarised from material supplied by Amory Lovins, and further material can be sources from the RMI website (http://www.rmi.org/sitepages/pid984.php), and the Data Center Charrette Report (www.rmi.org/sitepages/pid626.php).

Appendix B: Life Cycle Assesment

The information in Appendix B is taken from draft versions of two documents developed by The Natural Edge project:

- Engineering Sustainable Solutions Program, Critical Literacies Portfolio, Module 1.1: The role of engineers in sustainability, Unit 1: Redefining the role of the engineer and built environment professional.
- Engineering Sustainable Solutions Program, Critical Literacies Portfolio, Module 2.1: Resource productivity improvement, Unit 2: Greening of industry – improving industrial process efficiency

Summary

- Life Cycle Assessment (LCA) is a methodology to assess the environmental impacts of a product, process or service[5].
- The International Organisation for Standardisation's (ISO) defines Life Cycle Assessment as[6]:
    - o "A systematic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the functioning of a product or service throughout its life cycle".
- According to the ISO 14040 series, LCA is conducted by 1) developing an inventory of all inputs (materials, energy) and outputs (waste, emissions, other environmental impacts); 2) evaluating potential impacts based on inputs and outputs compiled in inventory; and 3) interpreting results.
- Businesses manufacture products using processes, or provide services – taking a life cycle approach to their daily activities, they take into consideration not only the finished product or service by the inputs and outputs at each state of the process (or production or service delivery), but also how it will impact the environment and community.
- The life cycle of making a t-shirt[7]:
    - o Raw Materials – fertiliser, energy, water
    - o Processing – energy, cleaners, dyes
    - o Manufacturing – energy, waste
    - o Packaging – paper, plastics, waste
    - o Transport – energy
    - o Use – bleach, detergents, water, energy
    - o Either one of 1) Disposal, 2) Reuse (go back to f.), or 3) recycle (go back to a.)
- A lifecycle approach helps us to engage in whole systems thinking – both understanding the complex interactions between energy and material throughout the life of a product, and thinking in the long term about the impacts these interactions will have on the environment and society. LCA ultimately helps industry, government and the consumer make informed decisions about product purchasing.

[5] US EPA's Life Cycle Assessment page, <http://www.epa.gov/ORD/NRMRL/lcaccess>.
[6] ISO 14040.2 Draft: Life Cycle Assessment – Principles and Guidelines.
[7] UNEP/SETAC (2004) *Why take a Life Cycle Approach?* (UNEP, Paris). Freely downloadable at <http://www.fivewinds.com/uploadedfiles_shared/UNEPBooklet.print.pdf>.

- LCA example – avoid shifting problems from one part of the environment to the other[8]:
    - Methyl Tertiary Butyl Ether (MTBE) is added to gasoline to increase combustion levels, reducing emissions.
    - MTBE may be toxic if it is not combusted fully, and is now present in our major waterways and in the atmosphere
    - LCA lesson – focusing on one part of the emissions cycle (i.e. reducing pollution from automobile combustion) has created problems in other parts of the cycle ie. MTBE exceeding allowable levels in major water sources.

Case Study: LCA Applied – the IVL/Volvo EPS System[9]

The Swedish Environmental Institute (IVL) and the Volvo Car Corporation developed the Environment Priority Strategies for Product Design (EPS), an analytical design tool that aids design decision making with respect to environmental impact. EPS includes an environmental index called an environmental load unit (ELU) – a single value that reflects the environmental impact of a material throughout its lifecycle. ELU for a particular material is the sum of three values that describe the entire life cycle impact, divided into manufacturing (including raw materials), use and disposal. By considering the impact of a material in three stages, a more representative overall estimate can be determined. The three values are quantified using an established environmental index. Of more practical use are values of ELU/kg or ELU/m^2, which can then be multiplied by the mass or area of the material to give the overall environmental impact.

Calculations at Volvo show a wide spectrum of environmental impacts among the materials used in their cars. For example, platinum toped the raw materials list with 7,430,000 ELU/kg followed by rhodium at 4,950,000 ELU/kg. Iron was bottom of the list with 0.96 ELU/kg. Volvo also analysed its air emissions, where CFC-11 topped the list with 541 ELU/kg and carbon dioxide was bottom with 0.108 ELU/kg. Water emissions were also analysed.

At Volvo, "these factors are calculated by a team of environmental scientists, ecologists, and materials specialists so as to obtain environmental indices for every applicable raw material and energy source, together with their associated pollutant emissions… [Of interest are] the very high values for platinum and rhodium in the raw materials listings, a result of the high extraction energy required for these two metals. The use of CFC-11 is given a high environmental index as well because of its effects on stratospheric ozone and global warming. Finally, the assumption is made that the metals are emitted in a mobilizable form. To the extent that an inert form is emitted, the environmental index may need to be revised."

Graedel and Allenby (2003) demonstrate the use of ELU by comparing the environmental impact of a galvanised steel automotive front end component with its polymer composite counterpart. Compared to the steel component, the composite component has a 40 per cent lower mass and generates ten times less scrap.

The results show "…that the steel product has a larger materials impact during manufacturing, but is so conveniently reusable that its end of life ELU is lower than that of the composite. However, the steel front end is heavier than the composite unit, and that factor results in much higher environmental loads during product use. The overall result is one that was not intuitively obvious: that the polymer composite front end is the better choice in terms of environmental impacts during manufacture, the steel unit the better choice in terms of recyclability, and the polymer composite unit the better overall choice because of lower impacts during product use. Attempting to make the decision by analyzing only part of the product life cycle would result in an incompletely guided and potentially incorrect decision."

[8] ibid.
[9] Case Study is taken from Graedel, T.E. Allenby, B.R. (2003) *Industrial Ecology* (Pearson Education Inc., New Jersey), 2nd Edn. Chapter 16: The LCA Impact and Interpretation Stages, pp 198-202.

Case Study: LCA of Washing Machines[10]

This example uses LCA to compare three medium-sized washing machines (4.5-5kg capacity), with the basis of the comparison being the average number of washes during the typical lifetime of the washer i.e. 3500 washes.

The washing machines comprise the following life cycle stages:

- extraction of raw materials
- transport of raw materials for initial processing
- packaging, transport of materials and components to washing machine manufacturer
- manufacture of washing machine
- packaging, transport and distribution of washing machine
- operation of washing machine – including detergent and its packaging, water and wastewater treatment
- transport and disposal of washing machine.

In an LCA the potential and likely environmental impacts of each stage noted above must be considered. For example during the operation and disposal of the washer, impacts such as air pollutants, water pollutants and consumption, greenhouse emissions and solid waste, and the use and production of toxic/hazardous substances can be clearly identified:

- Washing machine operation - waterborne emissions, wastewater treatment and manufacture of treatment chemicals; energy used for water heating, motor functioning, water pumping.
- Detergent and its packaging – detergent manufacture i.e. energy, chemicals, box and carton materials, waste.
- Washing machine disposal – transport to disposal, energy used in shredding and compacting, materials recycling, solid waste produced.

[10] ISO 14040.2 Draft: Life Cycle Assessment – Principles and Guidelines.