University Of Southern Queensland

Faculty Of Engineering And Survey

ELECTRONICS AND THE ENVIRONMENT -- SINGAPORE PERSPECTIVE

A dissertation submitted by

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Abstract

This work presented in this dissertation gives a description of the impacts of electronic products during manufacture, during useful life and after their end of useful have had on the environment and human health when they are not well managed in Singapore and some countries in Asia.

Singapore is one of world largest manufacturer of electronics. In 2004 Singapore exported US$136.993 billions worth of electronic commodities, integrated circuits, color televisions, picture tubes, cathode ray tube, TV camera tubes, ink cartridges, printed wiring boards, personal computers, and etc.

The manufacture of electronics has the highest environmental impact as some hazardous chemicals used or by-products are being released into the environment. Also during the manufacture, lots of natural resources have been consumed such as virgin materials, water and fossil fuel that generates electricity.

The use of electronics also consume vast amount of electricity. The fossil fuel required to generate electricity for the use of electronics could severely deplete the sources of fossil fuel.

Disposing of end-of-life electronics could pose some severe impacts on human health and the environment when they are not well managed as many parts of electronics are made up hazardous materials such beryllium, brominated flame retardants, cadmium, chromium, lead and mercury. Exposure to some of these chemicals may increase the risk of developing cancer in people and even cause death.

The disposal of electronics industrial wastewater and solid wastes could also pose some severe impacts on human health and the environment since a variety of hazardous chemicals are used in the manufacture.

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Abbreviation

Name	Abbreviation
biochemical demand	BOD
brominated flame retardant	BFR
carbon dioxide	CO_2
cathode ray tube	CRT
chlorofluorocarbon	CFC
design-for-recyclability	DfR
design-for-disassembly	DfD
design-for-environment	DfE
electronic-waste	E-Waste
end-of-life	EOL
European Union	EU
extended producer responsibility	EPR
gross domestic production	GDP
hexavalent chromium	Chromium VI
information technology and communication	ICT
integrated circuit	IC
life cycle assessment	LCA
liquid crystal display	LCD
Microelectronics and Computer Technology Corporation	MCC
Organization For Economic Co-Operation And Development	OECD
original equipment manufacturer	OEM
personal computer	PC
polybrominated biphenyl	PBB
polybrominated diphenyl ether	PBDE
Pollution Control Department	PCD
pollutant standards index	PSI
printed wiring board	PWBs
Resource Conservation and Recovery Act	RCRA
Restriction Of The Use Of Certain Hazardous Substances In Electrical And Electronic Equipment	RoHs
Severe Acute Respiratory Syndrome	SARS
Singapore Ministry of The Environment	SMOE
Singapore National Environment Agency	SNEA
television	TV
total suspended solids	TSS
trade effluent regulations	TER
United States	U.S.
United States Environmental Protection Agency	U.S. EPA
Volatile organic compound	VOC

1 INTRODUCTION

This section paves a quick entrance to the issue of electronics and its environment – Singapore perspective.

1.1 Aim Of The Research Work

The project aims to find out the impacts of electronic products during manufacture, during useful life and after their end of useful have had on the environment and human health when they are not well managed in Singapore and some countries in Asia.

Singapore is one of world largest manufacturer of electronics. In 2004 Singapore exported US$136.993 billions worth of electronic commodities, integrated circuits (ICs), color televisions (TVs), picture tubes, cathode ray tube, TV camera tubes, ink cartridges, printed wiring boards (PWBs), personal computers (PCs) , and etc.

The manufacture of electronics has the highest environmental impact as some hazardous chemicals used or by-products are being released into the environment. Also during the manufacture, lots of natural resources have been consumed such as virgin materials, water and fossil fuel that generates electricity.

The use of electronics also consume vast amount of electricity. The fossil fuel required to generate electricity for the use of electronics could severely deplete the sources of fossil fuel.

Disposing of end-of-life (EOL) electronics could pose some severe impacts on human health and the environment when they are not well managed as many parts of electronics are made up hazardous materials such beryllium, brominated flame retardants (BFRs), cadmium, chromium, lead and mercury. Exposure to some of these chemicals may increase the risk of developing cancer in people and even cause death.

The disposal of electronics industrial wastewater and solid wastes could also pose some severe impacts on human health and the environment since a variety of hazardous chemicals are used in the manufacture.

1.2 Specific Objectives

Specifically, this study addresses six issues:

1. Evaluate the size and significance of the Singapore electronics industry;

2. Identify the environmental impact of various aspects of the Singapore electronics industry;

3. Document the relevant environmental regulations adopted in Singapore;

4. Document the current practices in other country regarding disposal of obsolete equipment;

5. Assess the possible ways in which better environmental management might be implemented in the electronics industry. And;

6. Review and critique the strategies being suggested by some of the world larger electronics original equipment manufacturers (OEMs) for better overall management of electronics industry environmental impact.

2 BACKGROUND AND LITERATURE

Over the last two decades, computing has become crucial to the infrastructure of advanced countries. Technological and innovation advances in both the Information Technology and Communication (ICT) and electronics industries revolution (especially, in semiconductor industry) have spurred economic growth and improved people lives dramatically in countless ways and electronic products have been part and parcel of our daily life. According to Moore's law , "in effect that at our rate of technological development and advances in the semiconductor industry, the complexity of ICs, with respect to minimum component cost will double every 18 months" (Wikipedia, The Free Encyclopedia 2005a). Such pace has seen many electronics and computers for office and home use made both affordable and widely used. That inherently means that current electronics and computers will be rendered obsolete in an earlier time. These EOL electronics which are literally known as electronic-waste (E-Waste).

Electronics pose some environmental impacts throughout their product life cycle, especially during the manufacture, use, and disposal stages. The impacts may range from natural resources depletion, endanger eco-system to threaten human health.

2.1 Electronic-Waste

E-Waste, is a generic term used to describe the electronic products that are at the end of their useful life, enters our waste stream. It encompasses a broad range of brown goods that are intensively electronic in composition covering a wide range of consumer electronic products chiefly for entertainment, communication and information technology purposes, ranging from TVs, PCs, CRT monitors, liquid crystal display (LCD) monitors, laptops, ICT peripherals, and stereos to cellular phones.

2.2 Impacts Of Electronic Products

The electronics and computer industry is comprised of five major groups: semiconductor, industrial electronics, consumer electronics, computers and telecommunications. Its products include integrated circuits, electronic components and accessories, PWBs, consumer electronics, computer and peripherals, televisions, information communication technology products and other electronic equipment and supplies. The manufacture of electronics has the highest environmental impact as some hazardous chemicals used or by-products are being released into the environment. Also during the manufacture, lots of natural resources have been consumed such as virgin materials, water and fossil fuel that generates electricity. For example, Williams, Ayers & Hellers (2002) estimates that the total weight of secondary fossil fuel and chemical inputs to produce a single 2 grams 32 Megabytes Dynamic Random Access Memory package die was 1672 grams, or more than 630 times the weight of the final product. In 2002, there were about 65.9 millions 8 inches wafer equivalents processed worldwide (Semiconductor Industry Association. 2002). Based on Williams, Ayers & Hellers (2002), a fabricated wafer area of 1 centimeter square consumes 1.5 Kilowatts hour of electricity, and water use of 20 liters while producing 17 Kilograms of wastewater and 7.8 Kilogram of solid wastes. This can result in an estimated consumption of 3.10×10^{10} of electricity and 4.14×10^{11} liters of water and production 3.52×10^{11} Kilograms of wastewater and 1.61×10^{11} Kilograms of solid wastes. Beside that, air pollutants such carbon dioxide (CO_2) and chlorofluorocarbons (CFCs) are also emitted from the manufacture. These substantially large amount of resource consumptions, waste productions and air pollutants could severely damage our eco-system and health.

The use of electronics also consume vast amount of electricity. The fossil fuel required to generate electricity for the use of electronics could severely deplete the sources of fossil fuel. Very mild radiation (X-Rays) radiated from the CRT could pose serious chronic human health impact.

Disposing of EOL electronics could pose some severe impact on human health and the environment when they are not well managed as many parts of electronics are made up hazardous materials such beryllium, BFRs, cadmium, chromium, lead and mercury.

2.3 Why Is Electronic-Waste Hazardous?

According to Puckett et al. (2002) E-Waste is very hazardous because it is a crisis not of quantity but a crisis born from toxins and dioxins if incinerated. Smith and Raphael (2003) claim that manufacturing a single PC can generate 63 kilogram of waste and involves a witch's brew of chemicals linked to high rates of cancer and birth defects among workers and communities. Electronic products are made up of a multitude of components ranging from precious metal such as gold and silver and toxin substances such as BFRS and mercury to carcinogenic substances such as arsenic, beryllium, cadmium, chromium, dioxins and lead. Most of these toxic substances in E-Waste could have posed severe threat to eco-system or scavengers' health in dismantling the discarded electronic products. For greater detail regarding the human health impact associated with the above mention toxic chemicals and where they are found for example, in a typical PC, refer to Chapter 2.4.

2.4 Materials Found Inside A Desktop Personal Computer

The problem with obsolete PC is that many of its parts have very little recyclable potential. The PC may have a steel frame, aluminum chassis, thin gauge insulated wire, cables, PWBs with obsolete transistor, capacitors and resistor, and disk drives. Pure gold and silver can be found in electronic contacts in some very old model computers, but there is hardly any pure gold and silver in the newer computer. The treasure in computer can be in ICs and their parts that are reusable.

Microelectronics and Computer Technology Corporation (MCC) (1996) states the composition of a desktop personal computer based on a typical desktop personal computer, weighing approximately 32 kilograms, has the following materials listed in the Table 2-1 below.

Table 2-1: Composition Of A Desktop Personal Computer Based On A Typical Desktop Computer, Weighing ~ 32 kilograms

Name	Content (%)	Value (US $/T.O.)	Intrinsic Value (US $)	Recycle Efficient (%)	Value Of Recycled (US $)	Value Of Non-Recycled	Use/Location
Plastics	22.9907	0.05	11.73	20	2.35	9.39	Includes organics, oxides other than silica
Lead	6.2988	0.03	1.93	5	0.10	1.83	Metal joining, radiation shield/CRT, PWB
Aluminum	14.1723	0.06	9.11	80	7.29	1.82	Structural, conductivity/housing, CRT, PWB, connectors
Germanium	0.0016	93.00	1.49	0	0.00	1.49	Semiconductor/PWB
Gallium	0.0013	90.00	1.15	0	0.00	1.16	Semiconductor/PWB
Iron	20.4712	0.02	4.18	80	3.34	0.84	Structural, magnetivity/(steel) housing, CRT, PWB
Tin	1.0078	0.20	2.06	70	1.44	0.62	Metal joining/PWB, CRT
Copper	6.9287	0.09	6.01	90	5.41	0.60	Conductivity/CRT, PWB, connectors
Barium	0.0315	1.35	0.43	0	0.00	0.43	Getter in vacuum tube/CRT
Nickel	0.8503	0.25	2.17	80	1.74	0.43	Structural, magnetivity/(steel) housing, CRT, PWB
Zinc	2.2046	0.04	0.81	60	0.49	0.32	Battery, phosphor

							emitter/PWB, CRT
Tantalum	0.0157	1.71	0.27	0	0.00	0.27	Capacitors/PWB, power supply
Indium	0.0016	30.00	0.48	60	0.29	0.19	Transistor, rectifiers/PWB
Vanadium	0.0002	100.00	0.16	0	0.00	0.16	Red phosphor emitter/CRT
Terbium	0.0000	933.00	0.15	0	0.00	0.15	Green phosphor activator, dopant/CRT, PWB
Beryllium	0.0157	0.40	0.06	0	0.00	0.06	Thermal conductivity/PWB, connectors
Gold	0.0016	390.00	6.27	99	6.21	0.06	Connectivity, conductivity/PWB, connectors
Europium	0.0002	35.00	0.06	0	0.00	0.06	Phosphor activator/CRT
Titanium	0.0157	0.30	0.05	0	0.00	0.05	Pigment, alloying agent/(aluminum) housing
Ruthenium	0.0016	15.00	0.24	80	0.19	0.05	Resistive circuit/PWB
Cobalt	0.0157	1.75	0.28	85	0.24	0.04	Structural, magnetivity/(steel) housing, CRT, PWB
Palladium	0.0003	173.00	0.56	95	0.53	0.03	Connectivity, conductivity/PWB, connectors
Manganese	0.0315	0.07	0.02	0	0.00	0.02	Structural, magnetivity/(steel) housing, CRT, PWB
Silver	0.0189	5.33	1.03	98	1.01	0.02	Conductivity/PWB, connectors
Antimony	0.0094	0.19	0.02	0	0.00	0.02	Diodes/housing, PWB, CRT
Bismuth	0.0063	0.26	0.02	0	0.00	0.02	Wetting agent in thick film/PWB
Chromium	0.0063	0.25	0.02	0	0.00	0.02	Decorative, hardener/(steel) housing
Cadmium	0.0094	0.14	0.01	0	0.00	0.01	battery, blue-green phosphor emitter/housing, PWB, CRT
Selenium	0.0016	2.00	0.03	70	0.02	0.01	Rectifiers/PWB
Niobium	0.0002	5.14	0.01	0	0.00	0.01	welding allow/housing
Yttrium	0.0002	5.00	0.01	0	0.00	0.01	Red phosphor emitter/CRT
Rhodium	0.0000	650.00	0.01	50	0.01	0.01	Thick film conductor/PWB
Platinum	0.0000	448.00	0.09	97	0.07	0.00	Thick film conductor/PWB
Mercury	0.0022	0.09	0.00	0	0.00	0.00	Batteries, switches/housing, PWB
Arsenic	0.0013	0.00	0.00	0	0.00	0.00	Doping agent in transistors/PWB
Silica	24.8803	0.00	0.00	0	0.00	0.00	Glass, solid state devices/CRT, PWB

One Troy Ounce (T.O.) = 1.097 Ounces = 31.1 grams

(Source: MCC 1996)

A PC may make up multitude components but many of them are very toxic such as arsenic, barium, beryllium cadmium, chromium, lead, mercury and BFRs (in some plastics, PWB and wire/cable insulation), and can cause serious damage to both the eco-system and human health upon improperly disposal. It contains valuable metals too such as 0.51 grams of gold and 6 grams of silver.

Some of the possible toxins in PCs are:

- **Beryllium.** Beryllium is primarily used as a hardening agent in alloy such beryllium copper as beryllium copper has one the highest melting points of light metals and will not spark against other metals. There are about 5 grams of beryllium in a typical PC (MCC 1996). It can be found in the PWBs and connectors in a computer. The United States Environmental Protection Agency (U.S. EPA) Office of Air Quality, Planning and Standards (2000) claims beryllium and its alloys are considered very poisonous by inhalation. Chronic beryllium disease may cause death and increase the risk of developing lung cancer in people. Acute beryllium disease may include rashes and ulcers.

- **Brominated flame retardants.** Flame retardants such as polybrominated biphenyl (PBB) and polybrominated diphenyl ether (PBDE) used to incorporate into PWBs, computer casings and cables for fire safety requirements. Incinerating BFRs can produce polybrominated dibenzo-p-dioxins, which have similar toxicological effects to chlorinated dioxins. The European Union (EU) Directive on "*The Restriction Of The Use Of Certain Hazardous Substances In Electrical And Electronic Equipment*" (RoHs) requires OEMs to stop using PBBs and PBDEs in their electronic products from 1st July 2006.

McPherson, Thorpe and Blake (2004) reveal that in the first national wide analysis of BFRs, the Clean Production Action and the Computer Take Back Campaign, found these neurotoxins in the dust samples swiped from computers. Researchers claimed that PBDEs threats are constantly found in human tissues and breast milk.

The health effects of BFRs' have not been studied extensively in humans. However, (Kemmlein, Hahn &, Jann 2003) finds that controlled studies in laboratory animals show that some BFRs disrupt thyroid function, causing hyperactivity and problems with learning and memory Thyroid hormone is critical for brain development early in life. These studies observed problems with learning, memory and behavior. They also show that exposure to PBDEs during development can decrease thyroid hormone levels, affect reproduction, and reduce immune system performance.

- **Cadmium.** Cadmium bromide is used in engraving, lithography, and photography in semiconductor industry owing to its characteristics such as low electrical resistance and corrosion resistance. The largest source of cadmium is nickel-cadmium rechargeable batteries but they have been replaced by lithium ion and nickel metal hydride. Cadmium is also added as a plastic stabilizer and flame-retardant in to polyvinyl chloride plastic insulation of wires and cables.

  Inhalation of cadmium oxide fumes is acutely toxic to the respiratory epithelium, and high exposures result in severe bronchial and pulmonary irritation. Repeated low exposures can cause permanent kidney damage, which can go unnoticed without testing until the condition is severe. The U.S. EPA Office of Air Quality, Planning and Standards (2000) classifies cadmium as a probable human carcinogen of medium carcinogenic hazard. The EU directive on RoHs requires OEMs to stop using cadmium in their electronic products except cadmium plating from 1st July 2006.

- **Lead.** Lead has been widely used in electronic components such as metal joining, radiation shield, CRT, PWB, some old batteries and fluorescent tubes. Most of the lead can be found in CRT display and monitors, follow by, tin-lead solder (usually in the ratio of 60/40 tin-lead). There are about 2 kilograms of lead in typical desktop weighing 32 kilograms and with a recycled value of merely US $0.10 in the United States (U.S.) (MCC 1996). Byster (2001) concludes that consumer electronics constitute 40 percent of lead found in landfills in the U.S. The EU's Directive on RoHs requires OEMs to stop using lead in their electronic product from 1st July 2006 except lead in glass of CRTs, electronic components and fluorescent tubes, and lead as an alloying element in steel containing up to 0.35 percent lead by weight, aluminum containing up to 0.4 percent lead by weight and as a copper alloy containing up to 4 percent lead by weight.

  Lead could be passed from the pregnant woman to the fetus if she had excessive lead exposure during pregnancy. Lead and its compounds may cause chronic anemia and damage to the kidneys and nervous system. Children particularly are susceptible to lead poisoning because it can accumulate in their nervous system as their bodies grow and develop.

- **Hexavalent Chromium** (Chromium VI)**.** It is used as harder for steel housing, stabilizer for plastic housing, and colorant in pigment for decorative purpose. Chromium VI may asthmatic bronchitis even in small concentrations, and in high dosages it will cause of digestive tract cancers, coetaneous and nasal mucous membrane ulcers and dermatitis.

  It is well documented that contaminated wastes can leach from landfills. Incineration results in the generation of fly ash, and there is widespread agreement among scientists that wastes containing chromium should not be incinerated. The EU directive on RoHs requires OEMs to stop using chromium VI in their electronic product from 1st July 2006.

- **Mercury.** It is used as a backlighting system that illuminate laptop and other flat panel display screens. The amount of mercury used in a typical desktop PC weighing approximately 32 kilograms is about 0.7 grams and it has no recovered value (MCC 1996). Should everybody dispose of their used PCs at once through landfill or incineration, of course, a significant amount of mercury would be released to the environment. The EU directive on RoHs requires OEMs to stop using mercury in their electronic product from 1st July 2006 except for mercury in compact fluorescent lamps not exceeding 5 mg per lamp.

  Definite symptoms of chronic mercurialism may not appear until after six months of exposure, or longer. The symptoms are primarily of the nervous (includes headaches, drowsiness or insomnia) and digestive (includes loss of appetite, altered sense of taste , nausea, vomiting, abdominal pain, diarrhea) systems.

However, the hazardous materials found in electronic products have some valuable properties which are beneficial to human health. The leaded glass in CRT helps to block dangerous X-rays generated by the impact of the high energy electron beam, for example (Wikipedia, The Free Encyclopedia 2005b).

Replacing the hazardous material is not an easy task. For example, designers have not come up with materials that can replace the hazardous materials yet. To obtain the same beneficial effect, such material might be more expensive. Therefore many OEMs are hesitating in replacing the hazardous materials in their products, as they believe that the dosage of the hazardous material found in their products would not cause any harms to its user so long as they are used as instructed.

Nevertheless, disposing of E-Waste still poses some impact to human and the environment as they are disposed of in bulk at a time. Assuming there are 1000 units of PC needed to disposed of. Based on MCC (1996), there are 0.7 grams of mercury, 7.36 kilograms of plastics, 2.02 kilograms of lead, 5 grams of beryllium, 2 grams of chromium and 3 grams of cadmium. This can result an estimated 0.7 kilograms of mercury, 7.36 x 10^3 kilograms of plastics, 2.02 x 10^3 kilograms of lead, 5 kilograms of beryllium, 2 kilograms of chromium and 3 kilograms of cadmium. The hazardous material found in these 1000 units of PC is clearly substantial.

In a nutshell, EOL electronics intrinsically are difficult to recycle.

2.5 Why Is Electronics -Waste A Growing Environmental And Social Problem?

Discarded EOL electronics are a fast-growing percentage of the municipal waste stream. According to an article “Electronics: A New Opportunity for Waste Prevention, Reuse, and Recycling”, published by the U.S. EPA (2001), over 20 million personal computers became obsolete in 1998. Only 13 percent were reused or recycled in U.S.. A technical study conducted by Carnegie Mellon University projected that in 1997, estimated approximately 143 million computers in the U.S. will be recycled by the year 2005 and the number of obsolete computers will soon be as high as 315 to 680 million units. That recycled figure is expected to grow over the next one to two decades due to several crucial factors:

1. The triumph of digital over analogue system in the computer and electronic industries leads to replacement of analogue TVs and CRT monitors by high definition TVs and LCD monitors respectively. This will produce tens of millions of obsolete TV and monitors that are likely to end up in our waste stream;

2. Based on information from "Computer Display Industry and Technology Profile", and figures presented in "Electronic Product Recovery and Recycling Baseline Report", the useful life of a desktop computer purchased in 1997 was expected to be 6 to 7 years, and by 2005, the average life span of a new desktop computer is expected to be 2 years in the U.S.. We are facing the problem in Singapore too, the worst of all, it even spreads to other consumer electronics, especially mobile phones. Nokia (1997) mentions that as technology developments in the cellular market accelerate, consumer need have also become varied, these two simultaneous trends lead to constantly shortening product life cycles and differing lifestyles boost

growth in its annual report. This is probably due to the trend of keeping up the latest technology has motivated to purchase new products at shorter intervals.

3. Lacking of electronic recycling infrastructures and high cost associated in disposing of E-Waste in safely in U.S. (Smith and Raphael 2003). Monitor (2004) estimates the cost of recycling computers in U.S. ranges from US$10 to $60 per unit. For example, Hewlett-Packard (HP) charge consumers a fee of US$13 to 34 to have their used computers (any brand) picked up in the U.S. (Waste News 2001).

   Sodhi & Knight (2000) discuss the economic problems of recycling electronic products in the U.S. and suggest that generally, the profit from component recovery is low because of high labor cost despite the recovery of gold and silver in the recycling, and the recycler would make a loss in cases of wastes containing hazardous materials such cadmium and lead. They also show that the ratio of profit to cost of a materials recovery process varies throughout the normal process and is negative for several stages in the process.

   As for the case in Singapore, refer to Chapter 2.9.

4. The rapid pace of innovation and evolution of computer and electronic technologies have enable the manufacturers to offer greater functionality to users at a reduced price. The trend of keeping up the latest technology has motivated to purchase new products at shorter intervals. With the help of improvised global logistic, online purchasing and purchasing power, make it even more easier for consumers to purchase these products;

5. Growing global consumption and dependence as computing is a crucial to the

infrastructure of advanced countries in this digital era. And;

6. Landfills are banned in most countries as they either have reached their limits or are used contained either incinerated municipal waste or biodegrade waste. Townsend et al. (2003) find out heavy metal such as lead, and organic compound such BFRs found in most E-Waste can be leached into landfill leachate.

   Incineration of hazardous waste with energy recovery would be the preferred option for sustainable disposal of hazardous waste. However, the flue gas emitted chimney flue requires extensive clean-up using a variety of systems such as electrostatic precipitators, scrubbers and bag filters to remove the potentially highly toxic pollutants. The flue gas treatment systems are expensive, and consequently disposal cost via incineration are high and can represent many times the equivalent cost of landfill depending on the degree of hazard associate with the waste.

   Environmentalists point out that incineration fails to destroy all the toxic materials completely and that the residues escape into the environment through flue gases. They also point out that burning certain kinds of wastes will unavoidably create dioxins as by-product. We should take considerable effort to keep being release as dioxins are extremely carcinogens.

2.6 Exporting Of Electronic-Waste

The recycling and disposal of the E-Waste, while being lucrative business prospective for some, have posed very serious human health and environmental problems when it is improperly disposed of in. All parties - the exporters, importers, traders and recyclers, utilize loopholes in laws and enforcements. Compounding the problem is increasing and mostly illegal E-Waste imports from industrialized countries. Puckett et al. (2002) claim that 50-80 percent of E-Waste collected for recycling in the U.S. is actually exported to developing nations such as China, India and Pakistan, and 90 percent of that has been destined for China, as these countries are equipped with cheap labor forces and there no laws and regulations enacted to tackle the E-Waste. Even if they were, they were not well enforced.

But to date, government, industry and consumer have only taken small measure to deal with this looming issue even they are well aware of its effects and consequences. China's top legislature is deliberating the draft amendment to the Law on Solid Waste Pollution Prevention to avoid becoming the "World's Largest Dumping Ground" by tightening control over the mounting trafficking of foreign garbage (People's Daily Online 2004).
If it were to enact, such regulations would impede the dumping of e-waste by foreigners in China. Therefore, the foreign dumpers will choose to dump their E-Waste in India since India legislations has no specific guidelines or laws for E-Waste or its handling, recycling or trading (Wankhade 2004). This could mean that the more than 90 percent of the exported E-Waste will be dumped into India in the near future.

2.7 Basel Convention And Associated Legislations

The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes And Their Disposal, adopted by the diplomatic conference on 22nd March 1989 in Basel, was developed under the auspices of the United Nations Environment Programme and entered into force in May 1992. The Convention regulates the transboundary movements of hazardous wastes and provides obligations on its parties to ensure that such wastes are managed and disposed of in an environmentally sound and effective manner as closely as possible to the source of generation. It is also a global treaty that grew out of the need to stop the dumping by the developed countries of hazardous waste in developing countries who were ill-prepared to deal with its impacts through providing access to information and technical assistance on best practice guidelines and procedures for waste handling, storage and destruction. The main objectives of the Convention are found in Table 2-2. However, the Convention does not cover radioactive waste or waste discharged from ships.

Table 2-2: Objectives Of The Basel Convention

1.	Transboundary movements of hazardous wastes should be reduced to a minimum consistent with their environmentally sound management;
2.	Hazardous wastes should be treated and disposed of as close as possible to their source of generation.
3.	Minimize the generation of hazardous wastes in terms of quantity and hazardousness;
4.	Ensure strict control over the movements of hazardous wastes across borders as well as the prevention of illegal traffic;
5.	Prohibit shipments of hazardous wastes to countries lacking the legal, administrative and technical capacity to manage and dispose of them in an environmentally sound manner. And;
6.	Assist developing countries and countries with economies in transition in environmentally sound management of the hazardous wastes they generate.

(Source: Secretariat Of the Basel Convention 1992)

After the initial adoption of the Convention, some nations and environmental organizations argued that it did not go far enough in prohibiting international hazardous waste dumping. Therefore, in 1995, the Ban Amendment was introduced to strengthen the Basel Convention by prohibiting the export of hazardous waste, for any reason, from a member state of the Organization For Economic Co-Operation And Development (OECD) to non-OECD countries for final disposal recovery and it was proposed that the Ban Amendment be formally incorporated in the Basel Convention as an amendment (Decision III/1) (Secretariat Of The Basel Convention, United Nations Environment Programme n.d).

In 1999, the Basel Protocol On Liability And Compensation For Damage Resulting From Transboundary Movements Of Hazardous Wastes And Their Disposal was adopted. The objective of the Protocol is to provide for a comprehensive regime for liability and for adequate and prompt compensation for damage resulting from the transboundary movement of hazardous wastes and other wastes and their disposal including illegal traffic in those wastes (United Nations 1999).

The Basel Convention is the broadest and most significant international treaty on hazardous wastes presently in effect. The impact of hazardous wastes on the environment has large repercussions; particularly on the quality of waters and land. Effective regulation of the management and disposal of hazardous wastes requires cooperation at the global level. The Basel Convention is the first and foremost global legal instrument regulating the transboundary movement of hazardous wastes and their disposal.

According to Basel Action Network (2005) as of May 2005, the Basel Convention has 163 parties, 55 of them have been ratified. Singapore has signed through the deposit of acceptance – yet to ratify. Three Signatories are ratification, acceptance, or approval. The Secretary-General of the United Nations acts as the depositary of the Convention and its Protocol.

2.8 Singapore Electronics Industry

The electronics industry has played an important role in the industrial development Singapore that in turn spurs the economic development of Singapore. Manufacturing in ICT and electronic product is one of the fasting growing and most important sector in Singapore and the global economy even thought its share in Gross Domestic Production (GDP) has been declining during the period between 2000 and 2003. The electronics industry was badly affected by the global economic slowdown, the war in Iraq, and the outbreak of Severe Acute Respiratory Syndrome (SARS) in 2003. Growth in Singapore's economy was sluggish in 2002 and 2003 (TradeWatch 2004). It only started to have picked up during the four quarter 2003 as new investments in higher production PWB assemblies, passive components, displays (including LCDs) electrical devices and photonics components in Singapore, which in turn spurred the demands (Wetzel 2003). Singapore manufacturing industry as a whole accounted for a GDP of 2.7percent in 2003 (Ministry Of Trade And Industry, Republic of Singapore 2005).

Singapore relies on an extended concept of entrepot trade by purchasing raw goods and refining them for re-export especially in wafer fabrication industry. She would buy of ICs, semiconductors, color TV, picture tubes, CRT, TV camera tubes, ink cartridges, printed circuit board assemblies (e.g. motherboards, sound cards, interface cards), plastics casings, computers, disk drives, tape drives, printers, keyboards and peripheral units and accessories, pagers, cellular/hand phones, TV cameras, video cameras and recorders, batteries and blank printed circuit boards. These commodities normally come from the U.S., Malaysia, China, Taiwan. After refining them, she would re-export them to U.S., Malaysia, China, Taiwan, EU, China, Japan Hong Kong, Taiwan, South Korea, Thailand, Australia.

2.9 Management Of Electronic-Waste In Singapore

In Singapore, obsolete electronics namely come from three major sources:

1. **Individual consumers.** Individual consumers replace their electronics such mobile phone whenever there are new models with additional functions in the market. As for computer, most users would upgrade their computer by replacing certain interface cards or mother boards rather than the whole unit. They usually either sell their used electronics such TVs and PCs (usually faulty) to garbage collector, or functional ones to secondhand dealers such as Cash Converter. Electronics, especially, used functional mobile phone, are usually treated as trade-in commodity while buying a new model. The dealers may either resell them in local or export them to overseas for resale after refurbishment. But the secondhand market for mobile phone is very small. The garbage collector may then resell their electronics to some local licensed recyclers.

2. **Large number users.** This group of users may come institution, business organization and government sector. They may change their used electronics especially computer every two to three years. They will trade-in their used computers while buying new ones from certain OEMs. The disposed computers may range hundreds to thousands in each replacement.

3. **OEMs.** Almost all the OEMs that generate E-Waste not simply due to used electronics but because of faulty and rejected electronic products. Some may dispose their themselves but many would contract electronics recyclers to handle their wastes.

Some individual consumers may dump their used (may be usable) electronics trash bin and let municipal waste collectors handle them. These collectors may either dispose of them themselves or let the electronics recycler (see Table 5-7 for a list of electronics recycler found in Singapore) to handle them. Only a small portion of them are disposed of in incineration plant or treated to certain extent prior to landfill as Singapore is a highly industrialized and urbanized city-state with three and half million people staying on an island of 647 kilometer square. According to Radio Singapore International (2004), landfills on the mainland have reached their limits and Pulau Semakau, an offshore landfill site is used mainly for landfill the incinerated municipal solid waste.

Singapore Ministry of The Environment (SMOE) (2000) stated that the E-Waste is defined as a hazardous waste under the hazardous (control of export, import and transit) Act and its regulation were enacted and came into operation on 16th March 1998 and continued to take effect - this act has enable Singapore to fulfill its obligations under the Basel Convention, which it acceded to on a 2nd January 1996.

In Singapore, hazardous wastes are treated prior to dispose of in locally, except for some special wastes of which they do not have the facilities in Singapore to treat them. The Hazardous Waste (Control of Export, Import and Transit) Bill was passed by Parliament in November 1997 to ensure sound and effective management, transportation and disposal of hazardous wastes in Singapore. Under the Act and its regulations, any companies or individuals who export, import or transit any hazardous waste listed under the Basel Convention will have to apply a permit from Pollution Control Department (PCD). Those who export, import or transit any hazardous waste in contravention of the Act may be liable for prosecution.

3 SINGAPORE ELECTRONICS INDUSTRY

3.1 Introduction

With her abundant computing resources, unparalleled access to the region with its excellent logistics connectivity transparent, pro-business government, strike-free and highly-skilled labor, and world-class superb computing and telecommunication infrastructures, Singapore continues to be a favorite location for investors despite the economic slowdown, the war in Iraq, and the outbreak of SARS in 2003. This reflects the strength of international confidence in Singapore as an investment location.

3.2 Singapore Manufacturing Sector

The manufacturing sector of Singapore has played an important role in the development of Singapore. However, the downturn leveled off in the 2003 after a brief recovery in 2002 probably owing to the heightened uncertainty surrounding the impending the United States-Iraq war. The manufacturing sector was further hit by the SARS and a confluence of others such as weaker than expected recovery in global ICT demand in 2003.

In the second-half of 2003, there had been significant improvement in manufacturing industry namely due to several factors. First, Singapore was removed from World Health Organization list of SARS-hit countries at the end of May. Second, the external environment has had improved, with the US economy and global ICT market showing more sustained signs of recovery. In line with these improvements, there was some recovery in manufacturing industry. Nevertheless, for that year, as a whole, the manufacturing industry experienced a sharp decline in the GDP. Table 3-1 gives some data regarding the GDP of various industries in Singapore.

Table 3-1: Gross Domestic Product by Industry

Year **Industry**	**2001**	**2002**	**2003**	**2004**
Construction	-2.6	-12.1	-9.5	-6.5
Manufacturing	**-11.6**	**7.8**	**2.7**	**13.9**
Services Production Industries	2.4	3.1	1.3	7.5
Wholesale & Retailer Trade	-3.3	2.6	6.7	14.6
Hotels & Restaurants	-0.6	-1.8	-9.9	12.4
Transport & Communications	4.0	6.2	-1.8	9.1
Financial Services	3.7	-4.1	4.3	6.0
Business Services	2.0	4.7	-1.5	2.2

GDP at 1995 market prices

Percentage change over corresponding period of previous year

(Source: Ministry Of Trade And Industry Republic of Singapore 2005)

The manufacturing industry is divided into Electronics, Chemicals, Biomedical Engineering, Precision Engineering, Transport Engineering and General Manufacturing industry clusters. Table 3-2 gives the amount of the net investment committed by the different clusters of Singapore manufacturing industry. The U.S. remained the main source of investment followed by EU. In 2004, the manufacturing sector attracted US$5004.9 millions worth of fixed asset investments. One can also notice from the table that the electronics industry cluster has the highest net investment commitment in the Singapore manufacturing sector, and it is worth of US$ 2993.6 millions or about 59.8 percent of the total manufacturing industry.

Table 3-2: Net Investment Commitments In Manufacturing Investment Commitments By Industry Cluster

Year / Cluster	2001	2002	2003	2004
	US$ Millions			
Electronics	**2795.6**	**2819.5**	**2560.1**	**2770.4**
Chemicals	1148.9	1228.5	952.4	988.5
Biomedical manufacturing	505.9	517.3	516.7	514.7
Precision Engineering	**630.0**	**582.2**	**256.6**	**223.2**
Transport Engineering	247.6	183.1	124.8	293.6
General Manufacturing industries	225.2	129.2	142.2	214.5
Total	**5553.2**	**5459.8**	**4552.8**	**5004.9**

(Source: Ministry Of Trade And Industry Republic of Singapore 2005)

3.3 Singapore Electronics Industry

Singapore electronics industry, comprises of the electronics cluster and precision engineering cluster, is the largest industry in the manufacturing sector of Singapore. It is of strategic importance to the economy in terms of export, value added, technology innovation and a spillover benefit to the economy. In 2004, the electronics industry generated an output worth US$136933 millions of domestic export and export commodity, representing 48.1 percent of the total manufacturing commitment of US$284835 millions.

Government liberal policies have played an important role in the growth of Singapore electronics industry by attracting foreign investment into the industry. She removed foreign investment restrictions and introduced steps to strengthen the supervisory and corporate governance frameworks. Hence, large foreign firms dominate the electronics industry as most of these firms are subsidized by the government. In fact, the foreign firms invested sixes greater than local firms as the return to investment is substantial greater among them than the locals. In 2003, the industry has 220 firms and employed a total of 87,508 workers.

The Singapore electronics industry is further subdivided into five sub-industries:

- **Semiconductors.** In 2004, Singapore hosted to 12 wafer fabrication plants, 18 IC assembly and test facilities, and over 30 IC design firms. Hobday (1994) observes the main operations are that of testing and assembly. Once the semiconductors are assembled in Singapore, they are shipped back to the U.S. and Europe, where they are sold to brand-name OEMs and assembled into final products.

  In 2004, MediaTek (Taiwan) is the world's sixth largest fabrication IC design firm had invested US$30.3 million to set up an Recreation & Development center here which would hire up to 300 IC design engineers over five years. MediaTek specializes in optical storage, high-end consumer electronics and IC design;

- **Electronic Manufacturing Services, Storage and Peripherals.** This burgeoning sub-industry is primarily concerned with the manufacturing of end user electronic products, such as mobile handsets, flat panel televisions, computing equipment and data networking equipment. Singapore used to be the world's leading exporter of hard disk drive for a number of years. However, in 2000, Chua (2002) observes that Singapore had been squeezed out of its position as one of the top three exporters of PCs and disk drives by Taiwan and the UK.

In 2003, Hewlett-Packard announced plans to invest US$1 billion in Singapore, manufacturing of its top-of-the-line Superdome servers for the global market.

In 2004, Seagate (USA), one of the world largest manufacturers of hard disk drives, leveraged on technology and its existing competencies in Singapore to conceptualize and manufacture a 1" USB pocket drive here. They invested about US$120 million setting up a new media plant here;

- **Electronics Modules and Components.** This sub-industry covers the manufacturing of printed wiring boards and assemblies, passive components, electrical devices and displays such as LCDs.

  With the increasingly demand for LCD monitors, a new industrial park with a size of 35 hectare has been established in Singapore called the "Advanced Display Park". It has dedicated and sophisticated facilities to meet the stringent requirements for making LCD.

  Singapore aims to grow its advanced display industry by attracting not just LCD makers but also manufacturers of plasma display panel and organic light emitting devices.

- **Machinery and System sub-industry.** This sub-industry, together with the Precision Modules and Components sub-industry, is categorized under the Precision Engineering cluster. These two sub-industries embody multi-disciplinary capabilities in manufacturing process design, control engineering, engineering software, semiconductor equipment and materials, precision production system and precision components. There is a dense concentration of firms in Singapore that sell precision machined metal parts (e.g. disk drive frames, IC lead frames, IC bonding wire, etc). These firms largely grew up, with the support of government policy, to supply the foreign electronics firms that established production facilities. And;

- Precision Modules and Components sub-industry. This is an integral part of the electronics industry in Singapore, which embodies a strong base of capabilities, including tooling, production engineering and rapid prototyping, all developed over the past 30 years. This sub-industry is pervasive across many industries and has a strong foundation. To further develop this sub-industry, emphasis will be placed on helping Singapore-based companies diversify into new high growth markets, target new geographical regions and move into higher value-added activities.

Table 3-3 shows the employment, remuneration, total output and value added of the different clusters of EPE industry. It created about 180 thousand jobs in 2004. Other statistical values in remuneration and value added have increased slightly as compared with that in 2003.

Table 3-3: Principal Statistic Of Manufacturing by Cluster, 2004

Statistic Item **Cluster**	**Employment (No.)**	**Remuneration ($ Millions)**	**Value Added ($ Millions)**
Semiconductor	33752	970.0	4424.2
Electronic Manufacturing Services, Storage & Peripherals	45724	970.0	3818.2
Electronics modules & Components	10618	242.4	787.9
Electronics (Total)	**90094**	**2182.4**	**9030.3**
Machinery & Systems	28630	666.7	1272.7
Precision Modules & Components	61229	1212.1	2363.6
Precision Engineering (Total)	**89859**	**1878.8**	**3636.3**
Grand Total (2004)	**179953**	**4061.2**	**12666.6**

(Source: Ministry Of Trade And Industry Republic of Singapore.2005, Economic Survey Of Singapore 2004.)

3.4 Singapore’s Export, Import, Re-Export and Domestic Export In Electronics And Precision Engineering Industry

Singapore relies on an extended concept of entrepot trade by purchasing raw goods and refining them for re-export especially in wafer fabrication industry. Table 3-4 presents Singapore’s trade in electronics and shows how it is distributed among imports, exports, and domestic exports. The trade commodities consist of ICs, semiconductors, color TV picture tubes, CRT, TV camera tubes, ink cartridges, PWB assemblies (e.g. motherboards, sound cards, interface cards), plastics casings, computers, disk drives, tape drives, printers, keyboards and peripheral units and accessories, pagers, cellular/hand phones, TV cameras, video cameras and recorders, batteries and blank PWBs. These commodities normally come from the U.S., Malaysia, China, Taiwan. After refining them, she would re-export them to the U.S., Malaysia, China, Taiwan, EU, China, Japan Hong Kong, Taiwan, South Korea, Thailand, Australia.

Singapore used to depend on the U.S. and EU markets for her imports, exports, domestic exports, and entrepot exports. However, during the last few year, the total trade with East Asian countries, particularly the Japan and Malaysia, has been growing.

Table 3-4: Import, Export And Domestic Export By Commodity Section

Year	2004		
	US $ Millions		
Commodity	Import	Export	Domestic Export
Electronic Valves[1]	37396.4	48445.5	16180.6
Data Processing Machines[2]	5061.8	16324.8	11744.2
Parts For Office & DP Machines[3]	10772.1	12063.0	7893.3
Communication Equipment[4]	9689.1	9984.2	4084.2
Electrical Circuit Apparatus[5]	3405.5	3867.3	1870.3
Electrical Machinery[6]	3740.0	3170.3	1305.5

Includes ICs, semiconductors, color TV picture tubes, CRT for computer monitor, TV camera tubes, microwave tubes and parts for these products;

Includes ink cartridges, printed circuit board assemblies (e.g. motherboards, sound cards, interface cards) plastics casings and other parts and accessories for computers;

Includes computers, disk drives, tape drives, printers, computer monitors, computer keyboards and peripheral units and accessories;

Includes pagers, cellular/hand phones, TV cameras, video cameras and recorders, radar and navigational equipment, radio remote controls, satellite discs and parts for these products;

Includes signal generators, ion particle accelerator for semiconductor industry, electroplating or electrolysis machines, batteries, capacitors sparks plug, light bulbs & tubes and parts for these products. And;

Includes blank printed circuit boards, circuit breakers, fuses, connectors, switchboards and control panels and parts for these products.

(Source: Department Of Statistics, Ministry Of Trade & Industry, Republic Of Singapore 2005.)

Other raw material such metal, chemicals and water are also imported. Gold, copper and steel are imported from the U.S. and China. Plastic. Semiconductor ingot is imported from the U.S., Taiwan and Malaysia rather growing from imported silica. Chemicals are imported from Malaysia, the U.S. and Taiwan. Part of water needed to manufacture electronics is also imported from Malaysia.

The electricity needed to power up the electronics industry is generated either from imported natural gas from Malaysia, Indonesia and Australia, or crude petroleum from the U.S. and China. Part of the water needed to rinse the wafer is imported from Malaysia. Solder is imported from Malaysia, Taiwan or EU. Basically, other than manpower (about 90 to 95 percent is Singaporeans), everything needed to manufacture electronics is imported.

3.5 Strategic Decisions

Local companies make their strategic decisions for themselves, and overseas firms make their strategic decisions under influence of their headquarters stationed abroad. The development strategy is based on synchronizing skill formation with the progression of companies along the production capability spectrum rather than on leapfrogging technologies.

Should there be any desirable national directions for companies to follow, then incentives are provided and disciplines imposed when companies seek some form of government assistance.

3.6 Conclusions

Empirical evidence regarding the health and environmental impacts caused by the Singapore electronic industry in term production is meager as the volume of import and export good is not recorded. These figures are useful in estimating the impact caused by disposing of EOL product

4 ENVIRONMENTAL IMPACTS CAUSED BY SEMICONDUCTOR INDUSTRY

4.1 Introduction

The semiconductor industry is an important sub-industry of the Singapore electronics industry. There are 12 wafer fabrication plants, 18 integrated circuit (IC) assembly and test facilities, and over 30 IC design firms in Singapore.

Estimates place the overall economic scale of the semiconductor at US$140 billion in 2000 with an average 16 percent growth per year over the past few decades (Williams, Ayres & Heller 2002).

The electronics and computer industry is comprised of five major groups: semiconductor, industrial electronics, consumer electronics, computers and telecommunications. Its products include integrated circuits, electronic components and accessories, PWBs, consumer electronics, computer and peripherals, televisions, information communication technology products and other electronic equipment and supplies. The phases of making them have the highest environmental impact as some hazardous chemicals used or by-products are being released into the environment during the manufacture, and lots of natural resources and energy have been consumed.

The environmental impacts especially caused by air pollutants may not just confine within Singapore, as Singapore’s area is small. The neighboring countries such Malaysia and Indonesia will always the ones to get them first.

This chapter focuses on the distinct equipment and products that raise environmental issues in semiconductor industry. ICs are the part and parcel of electronics but the phases of making them could emit lots of hazardous pollutants and consume lots of natural resources such water and energy that generates electricity . For example, Williams, Ayers & Hellers (2002) estimated that the total weight of secondary fossil fuel and chemical inputs to produce a single 2 grams 32 Megabytes Dynamic Random Access Memory package die was 1672 grams, or more than 630 times the weight of the final product. In 2002, there were about 65.9 millions 8 inches wafer equivalents processed worldwide (Semiconductor Industry Association. 2002). Based on Williams, Ayers & Hellers (2002), a wafer area of 1 centimeter square consumes 1.5 Kilowatts hour of electricity, and water use of 20 liters while producing 17 Kilograms of wastewater and 7.8 Kilogram of solid wastes. This can result in an estimated consumption of 3.10×10^{10} of electricity and 4.14×10^{11} liters of water and production 3.52×10^{11} Kilograms of wastewater and 1.61×10^{11} Kilograms of solid wastes. Beside that, air pollutants such CO_2 and CFCs are also emitted from the manufacture. These substantially large amount of resource consumption, waste production and air pollutants could severely damage our eco-system and health.

4. 2 Semiconductors

Semiconductors are made of solid crystalline material, usually silicon. It can form into a simple diode or an IC. ICs are the major products of the semiconductor industry and are combinations of resistors, capacitors and transistors in a single semiconductor crystal. MCC (1996) claims that the complex process of manufacturing semiconductor ICs often consists of over a hundred steps, during which many copies of an individual IC are formed on a single wafer.

A very clean environment is essential to the manufacture of the semiconductors as semiconductor devices cease to function properly if they are contaminated by any microscopic residue, chemical, or dust on the surface of the base material or circuit path. The U.S. EPA, Office Of Pollution Prevention And Toxics, Design For The Environment (1995) highlights the cleaning operations usually occur before and after each manufacturing process step:

- Design;
- Crystal processing;
- Wafer fabrication;
- Final layering and cleaning. And;
- Assembly .

4.2.1 Design

Circuit design is the initial step in creation of a microchip. A designer starts with a block functional diagram of the circuit such as a logic diagram. This lays out the primary functions and operation required of the circuit. Next, the functional diagram is translated into a schematic diagram, which identifies the connection of the various circuit components. The third step, circuit layout, is unique to semiconductor circuits. Layout starts with using computer aided design systems to translate each circuit component into physical shape and size. Through computer aided design system, the circuit pattern mask is built, exactly the duplicating size.

4.2.2 Crystal Processing

The initial step in the fabrication process is to grow a single crystal from a seed crystal (ingot). Various materials are used but the most common is silicon. Ingot is normally grown into 2 feet long by 6 inches in diameter with preferred orientations of the arrangement of atoms in order to take advantage of certain properties associated with specific direction in these solids (Cook 1996). The ingot is sliced into round, thin slices of 75 to 300 mm in diameter and 0.36 to 0.76mm thick before polishing to a mirror-smooth finish (Singapore Ministry Of Manpower 1998). This is achieved using a combination of mechanical polishing and chemical etching until the surface of the wafer is optically flat, and free of oxides and contaminants to form disk with precise control of crystallographic orientation that servers as the *substrate* (silicon), followed by a deionized water rinse and drying with compressed air or nitrogen. The use of silicon is currently the most popular but gallium arsenide technology is rapidly gaining popularity as gallium arsenide can transfer electricity faster than silicon and can generate light impulses which silicon cannot (Singapore Ministry Of Manpower 1998).

Once the ingot is grown, it is sliced into wafers, smoothed, polished and cleaned. Dopants (impurities) are introduced into the crystal lattice of semiconductor to increase the conductivity of semiconductor. They are applied through diffusion or ion implantation processes. Most commonly used dopants for silicon-based semiconductor are P-type materials such as aluminum, boron and gallium, and N-type materials such as Antimony, Arsenic and phosphorus. Other dopants may include beryllium, copper, germanium, gold, iron, lithium, manganese, nickel, sodium, tellurium and zinc. The emission and waste generated from diffusion and ion implantation operations can be found in Table 4-1.

Table 4-1: Emission And Waste Generated From Diffusion And Ion Implantation Operations

Emission And Waste Generated
Wastes and emissions containing antimony, arsenic boron and phosphorous might be generated as a result of diffusion or ion implantation. And;
Excess dopant gases, contaminated carrier gases, and out-gassed dopant gases from semiconductor materials may also be generated.

(Source: U.S. EPA, Office Of Pollution Prevention And Toxics, Design For The Environment 1995)

Etching refers to the removal of material from the surface of a wafer using a chemical or mechanical process, or a combination of both. Wet etching uses acid solution to cut (etch) some materials more quickly than others while dry (mechanical) etching uses radicals formed by exposing gases to radio frequency radiation (Singapore Ministry Of Manpower 1998). As semiconductor technology moves in the direction of smaller features, the advantage associated with anisotropic etching such as dry plasma etching, reactive ion etching, and ion milling process become increasingly important. The emission and waste generated from etching can be found in Table 4-2.

Table 4-2: Emission And Waste Generated From Etching Operations

Emission And Waste Generated
Acid fumes and organic solvent vapors etchings. And;
Hydrogen chloride vapors may also be emitted during the wet etching process.

(Source: U.S. EPA, Office Of Pollution Prevention And Toxics, Design For The Environment. 1995)

4.2.3 Wafer Fabrication

The manufacture of a circuit starts with a polished wafer. The building starts with an oxidation of the wafer to form a thin protective layer and to serve as a doping barrier. This silicon oxide is called the field oxide. The wafer is thoroughly rinsed and dried after oxidation. Certain impurities, particularly chlorine from hydrochloric acid, are included in the oxidizing atmosphere. Other impurities may include hydrogen chloride, nitrogen, oxygen and solvents. These impurities influence the growth rate. The emission and waste generated from oxidation operation can be found in Table 4-3.

Table 4-3: Emission And Waste Generated From Oxidation Operation

Emission And Waste Generated
Spent solvents and acids

(Source: U.S. EPA, Office Of Pollution Prevention And Toxics, Design For The Environment. 1995)

Next, patterns are imprinted onto the substrate using photolithography and etching processes. Photolithography is one the most critical operations in semiconductor processing as it sets the surface (horizontal) dimensions on the various parts of the devices and circuits. The process begins by coating a thin film of protective or resistant material, photoresist (in liquid form), onto the wafer. The film is irradiated through a mask (a glass plate etched with circuit pattern), using photos (photolithography), electrons (e-beam lithography), or x-rays (x-ray lithography). The pattern, area exposed to radiation, is then developed.

The following step is etching and stripping. The exposed region of the wafer – the area from which the photoresist has been dissolved – is etched by a wet chemical step or by dry methods such as plasma or reactive ion etching. Finally, the resist is stripped with liquid or dry strippers. In certain cases, strippers may be chlorinated solvents or acids, but stripping using oxygen plasma is becoming the method of choice. The U.S. EPA, Office Of Pollution Prevention And Toxics, Design for the Environment (1993) illustrates a list of chemicals used in photolithography in Table 4-4.

Table 4-4: Chemicals Used In Photolithography Operation

Photoresists	**Developer**	**Solvents And Cleaning Agents**
Positive: Ortho-diazoketone[1] Polymethacrylate[1] Polyfluoroalkylmethacrylate Polyalkylaldehyde[1] Polycyanoethylacrylate[1] Polymethylmethacrylate Poly (hexafluorobutylmethacrylate) [1] Negative: Isoprene[1] Ethyl acrylate[1] Glycidylmetharcylate[1] Copolymer-ethylacrylate[1]	Positive: Sodium hydroxide Potassium hydroxide Silicates Ethylene glycol[1] Ethanolamine[1] Isopropyl alcohol[1] Tetramethyl-ammonium hydroxide Phosphates Alkyl amine[1] Ethyl acetate[1] Methyl isobutyl ketone[1] Negative: Xylene[1] Aliphatic hydrocarbons[1] *n*-Butyl acetate[1] Cellosolve acetate[1] Isopropyl alcohol[1] Stoddard solvent[1] Glycol ethers[1]	Deionized water Detergent Isopropyl alcohol[1] Acetone[1] Ethanol[1] Hydrofluoric acid Sulfuric acid Hydrogen peroxide Hydrochloric acid Nitric acid Chromic acid Ammonium hydroxide Hexamethyldisilazane[1] Xylene[1] Cellosolve acetate[1] *n*-Butyl acetate[1] Styrene[1] Chlorotoluene[1] Glycol ethers[1]

[1] *Volatile organic compound (VOC)*

(Source: U.S. EPA, Office Of Pollution Prevention And Toxics, Design For The Environment 1993)

The next step is to "dope" the lattice with impurities to change the electronic conductivity of the semiconductor (silicon) through diffusion or ion implantation. See crystal processing for a list of materials used and emitted during the doping process.

The final step is layering: a thin layer of material, which may be conductor, semiconductor or insulator, is deposited through epitaxial growth or chemical vapor deposition over the wafer's surface. The emission and waste generated from photolithography operation can be found in Table 4-5.

Table 4-5: Emission And Waste Generated From Photolithography Operation

Emissions And Wastes Generated
Acid fumes from etching operations;
Organic solvent vapors from cleaning, resist drying, developing, and resist stripping;
Hydrogen chloride vapors from etching;
Rinsewaters containing acids and organic solvents from cleaning, developing, etching, and resist stripping processes;
Rinsewaters from aqueous developing systems. And;
Spent etchant solutions; spent solvents and spent acid baths.

(Source: U.S. EPA, Office Of Pollution Prevention And Toxics, Design For The Environment. 1995)

The oxidation, photolithography, doping layering steps may be repeated several times until the desired circuit has been fabricated.

4.2.4 Final Layering And Cleaning

Once the wafer pattern is formed, thin deposited metal films are patterned to interconnect the various devices to each other by a process called metallization. Wires are used to connect some of these patterns to metal pins (or leads) in a package that protect the circuit.

Various types of elemental metal (for example, aluminum, platinum, titanium, nickel, chromium, silver, copper, tungsten, gold, germanium, and tantalum), metal alloys, and other metal compounds are used to from interconnection layers in semiconductor fabrication.

Almost every metal can be used to make this electrical connection to the silicon. Metals are generally deposited through sputtering and high vacuum evaporation to cover the entire wafer before being patterned to form all interconnections in one process step (a step per metal layer).

Etching process, in conjunction with photolithography, is used to polish the metal using chlorinated solvents or acid solutions. The emission and waste generated from metallization operation can be found in Table 4-6.

Table 4-6: Emission And Waste Generated From Metallization Operation

Emissions And Wastes Generated
Acid fumes and organic solvent vapors from cleaning, etching, resist drying, developing, and resist stripping;
Liquid organic wastes;
Aqueous metals. And;
Wastewater contaminated with spent cleaning solutions.

(Source: U.S. EPA, Office Of Pollution Prevention And Toxics, Design For The Environment. 1995)

Next, a process called passivation is used to apply a final layer of silicon dioxide or silicon nitride over the wafer surface to form a protective seal over the circuit. Electrical testing of finished wafers is conducted to screen grossly faulty chips - chips that do not meet the design specifications are marked for discard during assembly operations so that time and money are not spent on packaging them. The tested wafer is rinsed. The emission and waste generated from metallization operation can be found in Table 4-7.

Table 4-7: Emission And Waste Generated From Passivation Operation

Emissions And Wastes Generated
Spent solvents and acids in the wastewater and rinsewaters from cleaning, developing, etching, resist stripping, and rinsing processes;
Acid fumes and organic solvent vapors from cleaning, rinsing, resist drying, developing, and resist stripping;
Spent silicon dioxide or nitride;
Hydrogen chloride vapors from etching;
Rinsewaters from aqueous developing systems;
Spent etchant solutions;
Spent acid; baths. And
Spent solvents.

(Source: U.S. EPA, Office Of Pollution Prevention And Toxics, Design For The Environment. 1995)

4.2.5 Assembly

The success of semiconductor industry and its present status has been possible amongst other thing, due to advances made in semiconductor assembly. The reduction in price of parts has been possible owing to constant automation, yield improvement and development in semiconductor assembly.

Assembly (packaging) is the final step in semiconductor manufacturing. At the initial of the assembly process, some wafers have to be thinned (wafer thinning) to fit in the package; wafers whose dies are going to be attached to the package by a gold-silicon eutectic will receive a deposited layer of gold.

The wafer is then separated into individual die (chip). Faulty chips are removed; good ones are put in correct package. Each chip on the wafer is separated from each other by at least 3 to 4 mils. Laser cutting or sawing with diamond-edge blade is used to separate chips. The cut chips are then rinsed again using solvents such as deionized water.

Next, using the wafer map created in probe, the good chips are identified and attached onto the leadframe of a package. This attach may be with an epoxy adhesive or with a gold-silicon metal eutectic bond.

In the next step, thin aluminum or gold wires are bonded between the chip bonding pads and inner leads of the package. The wires provide the communication (circuitry connection) between the chip and the computer. The methods of bonding include thermocompresssion and thermosonic.

The bonded chips are optically checked for alignment and attachment of the chip, bonding quality and placement, and contamination before encapsulating the package. During encapsulation, the chip and a small portion of the leadframe are covered with a hard plastic compound to protect the chip.

In the coming step, the outer package leads are plated with additional layer of conductive metal to improve their solderability before going through a trim-and-form operation where the leadfingers are formed to the desired shape for use in applications before severing from the leadframes. After that, the leadframe is coated with a layer of photoresist, exposed, and developed. The developed leadframe is then being etched to remove the photoresist. It is again cleaned with water based cleaning systems to remove excessive etchant solution. The emission and waste generated from chips separation and leadframes attachment operations can be found in Table 4-8.

Table 4-8: Emission And Waste Generated In Chips Separation And Leadframes Attachment Operation

Emissions And Wastes Generated
Spent organic vapors generated from cleaning, resist drying, developing, and resist stripping;
Spent cleaning solutions;
Rinsewaters contaminated with organic solvents. And;
Spent aqueous developing solutions.

(Source: U.S. EPA, Office Of Pollution Prevention And Toxics, Design For The Environment. 1995)

A series of tests, including electrical and environmental, are then conducted to evaluate whether each package meets specification.

Finally, product identification is either marked using ink or engrave with a laser scriber on the device package. Laser engraving is more preferred in many applications because of its higher throughput and better resolution.

4.3 Health Risks And Environmental Impacts

Most of the environmental issues in semiconductors revolve around the production process and assembling of ICs. The interactions of the primary actors of evolving cluster with the environment could be expressed in terms of resource consumption/depletion, hazardous emissions, hazardous waste generation, occupants' heath risks and environmental impact.

4.3.1 Estimated Environmental Impacts

In 2004 Singapore exported US$136.993 billions worth of electronic commodities. Assuming Singapore only manufactured semiconductors in 2004 and simulate using the Economic Input-Output Life Cycle Assessment model, developed at Carnegie University, was built on the U.S. Department of Commerce Bureau of Economic Analysis' input-output model of the U.S. economy (currently for 1992 and 1997), the implicit and explicit effects of providing US$136.933 billions of goods and service in the semiconductor industry can be estimated in Tables 4-9 to 4-12. The implicit contributors refer to the industry production that can emit/generate some kind of pollutants, for example, the semiconductor plant emits air pollutants while manufacturing semiconductor. The explicit contributors could be resulted from other industries associated in the supply chain for semiconductor industry. The power plant, which supplies electricity to semiconductor industry, emits some air pollutants, for example. Hence, the data presented in Tables 4-9 to 4-12 is not simply about semiconductor industry alone, it may comprise of other industries associated in the supply chain for semiconductor industry as well.

Table 4-9 highlights some of the conventional air pollutants generated by top 10 explicit contributors to the supply chain for semiconductor industry. Power generation and supply emits a lot of sulfur dioxide and carbon monoxide as compared to other contributors.

Table 4-9: Conventional Air Pollutants Of Providing US$136.933 Billion Of Semiconductor

Conventional Air pollutants Sector	SO2 mt	CO mt	NOx mt	VOC mt	Lead mt	PM10 mt
Total for all sectors	123000	289000	87800	72100	225.	26200
Power generation and supply	96100	4750	43400	422.	0.552	2030
Other basic inorganic chemical manufacturing	5540	583.	377.	301.	0	346.
Primary smelting and refining of copper	4640	131.	0	217.	1.55	495.
Alumina refining	2040	0.012	502.	461.	0	192.
Other miscellaneous chemical product manufacturing	1560	1.36	1750	352.	0	147.
Iron and steel mills	1190	10100	930	563.	7.18	836.
Primary aluminum production	1140	6320	0.023	61.9	0	285.
Architectural and engineering services	992.	1450	766.	400	0	230
Oil and gas extraction	834.	1420	621.	954.	0	29.3
Petrochemical manufacturing	769.	246.	578.	1830	0	43.3

(Source: Carnegie Mellon University Green Design Institute 2005)

Table 4-10 identifies the top 10 sources of greenhouse gases. As usual, the power generation and supply has topped of list for generation greenhouse gases, follow by, the semiconductors and related device manufacturing. Other relevant gaseous discharges from electronics manufacturing facilities may include CFCs, CO2, oxides of nitrogen and others. These emissions may not be of relatively high importance, as compared to other pollutants which are toxic in nature. Nevertheless, their impacts can be recognized as global scale. For example CFCs would destroy stratospheric ozone. Increased intensities of ground-level ultraviolet radiation caused by stratospheric ozone destruction could have some substantial adverse consequences. Of major concern is increased skin cancer in humans resulting from greater ultraviolet radiation reaching the earth's surface. Another greenhouse gases of concern is CO_2, it is known to cause "global warning" – it can severely increase in Earth's atmospheric and surface temperatures, with dire consequences.

Houghton, Jenkins & Ephraums (1990) claim that Intergovernmental Panel on Climate Change reviewed 22 numerical models of the global circulation of the atmosphere and oceans and concluded as follows:

- Global mean surface air temperature will be about $1^{o}C$ higher by 2025 than in 1990, and $3^{o}C$ higher by the end of the 21^{st} century. If control measures are introduced promptly, they may slow this warming but are likely to stop it (because reductions of 60 percent will need even to hold concentrations at present level;

- The warming may be more pronounced over southern Europe and central North America, accompanied by reduced summer rainfall and soil moisture for crops;

- Global seal level is expected to rise by about 20 cm by 2030 and by 65 cm by the end of 21^{st} century . And;
- Global mean surface air temperature has risen between 0.3 and 0.6 Kelvin in the past century, and sea level has risen by 10 to 20 cm.

Table 4-10: Greenhouse Gases Of Providing US$136.933 Billion Of Semiconductor

Greenhouse gases **Sector**	**GWP MTCO2E**	**CO2 MTCO2E**	**CH4 MTCO2E**	**N2O MTCO2E**	**CFCs MTCO2E**
Total for all sectors	61200000	39600000	3420000	4760000	13500000
Power generation and supply	17800000	17500000	3510	116000	213000
Semiconductors and related device manufacturing	14700000	2260000	2980	333000	12100000
Other basic inorganic chemical manufacturing	3560000	3190000	1900	59300	304000
Industrial gas manufacturing	3370000	3020000	1800	161000	186000
Natural gas distribution	2420000	2010000	264000	142000	0
Wholesale trade	2330000	220000	1580	2110000	0
Waste management and remediation services	1700000	51500	1650000	2610	47.9
Air transportation	915000	755000	677.	159000	0
Oil and gas extraction	910000	146000	745000	8810	9890
Petroleum refineries	899000	445000	98500	356000	103.

(Source: Carnegie Mellon University Green Design Institute 2005)

Manufacturing semiconductors and the industries supplied to it can consume vast amount of electricity, and hence, approximately the same amount of fossil fuel, or even greater, might be needed to generate that same amount of electricity. Table 4-11 shows different type of fossil fuel needed to generate electricity and where the electricity is consumed. Fossil fuel takes thousands to millions of years to generate but manufacture of semiconductor alone can consume such a large amount. If scientists or engineers still had not invented any medium that could substitute fossil fuel, perhaps in the coming 100 years or lesser, fossil fuel such as petroleum might be exhausted.

Table 4-11: Energy Consumption Of Providing US$136.933 Billion Of Semiconductor

Sector / Energy	Total TJ	Elec MkWh	Coal TJ	NatGas TJ	LNG TJ	LPG TJ	MotGas TJ	Diesel TJ	Kero TJ	AvFuel TJ	JetFuel TJ	LFO TJ	HFO TJ
Total for all sectors	607000	39800	177000	267000	509.	16400	24000	7920	49.3	657.	12700	34100	21900
Power generation and supply	172000	16.9	142000	20600	0	70.3	569.	0	0	6.46	0	380	8150
Semiconductors and related device manufacturing	69500	19800	925.	41600	0	520	3350	0	0	0	0	565.	436.
Other basic inorganic chemical manufacturing	65900	2210	6300	53100	0	3120	564.	0	0	0	0	155.	194.
Industrial gas manufacturing	62000	2080	6200	49500	0	3060	565.	0	0	0	0	155.	194.
Natural gas distribution	36800	5.96	7420	28900	0	20.1	44.9	0	0	2.89	0	19.6	427.
Iron and steel mills	16500	660	3560	11500	0	28.0	96.4	0	0	2.69	0	76.2	442.
Real estate	12700	967.	0	0	0	27.9	752.	93.3	0	0	0	10800	23.2
Air transportation	10500	10.7	0	0	0	1.40	32.0	0	0	126.	5310	4960	16.0
Rail transportation	9970	3.93	38.8	0	0	1.12	6.01	0	0	0	0	726.	9200
Petroleum refineries	8670	146.	0	4210	0	3930	30.0	0	0	0.785	0	17.8	311.

(Source: Carnegie Mellon University Green Design Institute 2005)

Manufacturing semiconductor and the industries supplied to it can generated and emit toxic pollutants to air, water and soil if they are not well-managed. Usually, the eco-system near the source of pollution will get to suffer first since such area is not resided in by human by regulations. Table 4-12 illustrates the total toxic release to air, water and soil by top 10 contributors to semiconductor manufacture .

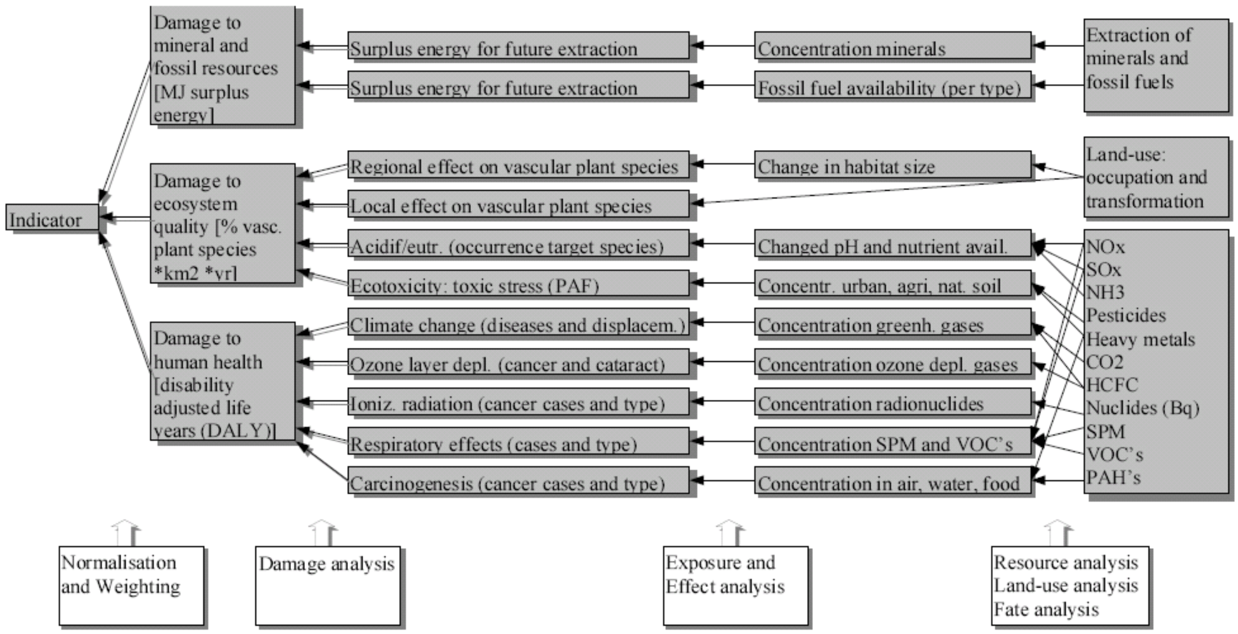
Table 4-12: Toxic Release Of Providing US$136.933 Billion Of Semiconductor

Toxic release Sector	Non-Point Air kg	Point Air kg	Tot Air Releases kg	Water Releases kg	Land Releases kg	U'ground Releases kg	Total Releases kg	POTW Transfers kg	Offsite Transfers kg	Total Rel/Trans kg
Total for all sectors	2180000	13500000	15700000	4670000	86900000	5290000	113000000	14600000	10500000	138000000
Industrial gas manufacturing	587000	675000	1260000	723000	37400	1630000	3650000	1110000	420000	5180000
Other basic inorganic chemical manufacturing	416000	1410000	1830000	573000	1150000	1640000	5200000	899000	683000	6780000
Primary nonferrous metal, except copper and aluminum	162000	5050000	5210000	403000	6950000	0	12600000	51400	3790000	16400000
Other basic organic chemical manufacturing	96000	163000	259000	97200	5600	277000	639000	221000	82000	942000
Semiconductors and related device manufacturing	75400	861000	937000	1920000	1080000	211.	3940000	10400000	1640000	16000000
Petrochemical manufacturing	63200	88200	151000	62600	3570	214000	432000	175000	66300	673000
Secondary processing of other nonferrous	50200	76200	126000	14300	76000	49.3	217000	290000	674000	1180000
Plastics material and resin manufacturing	48500	105000	154000	11500	619.	56000	222000	91300	13500	326000
Ferroalloy and related product manufacturing	42300	9100	51400	10100	154000	0	215000	70.1	17000	233000
Commercial printing	38800	44600	83400	1.63	1.11	0	83400	501.	1590	85500

(Source: Carnegie Mellon University Green Design Institute 2005)

Goedkoop & Spriensma (2001) developed a method of measuring the possible social costs as a result of environmental impacts. Figure 4-1 illustrates the schematics of the impact model. It shows the consequence of extraction of minerals and fossil fuel, and the emission of certain pollutants such as CO_2, heavy metal and etc. The possible effects are damage to mineral and fossil fuel resources, pollute eco-system and threaten human health.

Figure 4-1: Detail Representation Of Impact Model



(Source: Goedkoop & Spriensma 2001)

4.3.2 Health Risks In Associated In Semiconductor Industry

The workers are subjected to some forms of exposure to emission in their workplace. The emission may result from poor ventilation, inappropriate operation procedures, and etc. Table 4-13 describes some health risks in the electronics industries. However, according to Harrison (1994), almost all of the health problems currently observable among semiconductor workers are directly attributable to the "clean room" environment rather than to any of the process chemicals. The possible health risks are respiratory problems, skin problems and eye problem, namely due to the hot, dry and windy conditions in the clean room.

Table 4-13: Health Risks In Electronics Industries

Hazard	Process	Immediate Effect	Chronic Effects
Acids	Electroplating Etching Crystal polishing	Skin burns Eye irritation	Lung disease Bone damage Erosion of teeth
Metals	Electroplating Etching Soldering Tinning Sealing	Breathing problems Skin irritation Headaches Insomnia Stomach pain Miscarriage	Cancer Liver damage Sterilization Dermatitis
Gases	Doping Crystal growing Cap testing	Dizziness Nausea Vomiting Diarrhea Coma and death	Anemia Jaundice Liver damage
Resins	Cutting Grinding Encapsulation Laminating Packaging	Breathing problems Skin irritation	Cancer Liver damage Allergies Asthma
Solvents	Basically every job and process: used as cleaning, degreasing and thinning agents	Skin irritation Cough Breathing problems Sore throat Dizziness Headache Nausea	Liver damage Kidney damage Heart damage Paralysis Cancer Allergies Menstrual disorders

(Source: United Nations Environment Programme - United Nations Industrial Development Organization 1993)

4.3.3 Wastewater Found In Semiconductor Industry

The U.S. EPA, Office Of Pesticides And Toxic Substances (1988) highlights the substances found in the untreated wastewater from the U.S. semiconductor manufacturing facilities in Table 4-14. Metcalf & Eddy, Inc. (1991) identifies the typical composition of untreated domestic wastewater in the U.S.. It is clearly shown that the untreated wastewater from semiconductor industry contains lots of chemicals – some of them are poison such as arsenic and cyanide, or human carcinogen such as arsenic, beryllium, cadmium and etc. A list of health risks associated with beryllium, cadmium, chromium, lead and mercury can be found in Chapter 2.4. The microbiological parameters include coliforms, specific pathogens and viruses should be greater than in untreated domestic wastewater, although they are not reflected in Table 4-14, since electronics industrial wastewater is normally be pretreated by regulations with microbes or microorganisms to reduce the toxicity of wastewater before allowing to be discharged into public sewers. The records shown in Tables 4-14 and 4-15 are outdated. There should be more substances found in the untreated wastewater from semiconductor industry and domestic wastewater because of the increasingly human activities.

Table 4-14: Substances Found In Untreated Wastewater From United States Semiconductor Manufacturing Facilities

Substance	Minimum Concentration (mg/L)	Maximum Concentration (mg/L)
Benzene	< 0.01	0.190
Chloroform	0.004	2.6
Dichloromethane (methylene chloride)	0.005	2.4
Phenol	0.0004	5.7
Bis (2-ethylhexyl) phthalate	0.002	0.75
Ethylbenzene	0.0002	0.107
Tetrachloroethylene (perchloroethylene)	0.0002	0.8
Toluene	0.0002	0.14
Trichloroethylene	0.0049	3.5
Antimony	< 0.0005	0.187
Arsenic	< 0.003	0.067
Beryllium	< 0.001	< 0.015
Cadmium	< 0.001	0.008
Chromium (total)	< 0.001	1.150
Cobalt	< 0.001	0.48
Copper	< 0.005	2.588
Cyanide	< 0.005	0.01
Lead	< 0.04	1.459
Manganese	< 0.001	0.209
Mercury	< 0.001	0.051
Nickel	0.005	4.964
Selenium	< 0.002	0.045
Zinc	0.001	0.289

(Source: U.S. EPA, Office Of Pesticides And Toxic Substances 1988)

Table 4-15: Typical Composition Of Untreated Domestic Wastewater In The United States

Contaminants	Unit	Concentration		
		Weak	Medium	Strong
Total solids (TS)	mg/l	350	720	1200
Total dissolved solids (TDS)	mg/l	250	500	850
Fixed	mg/l	145	300	525
Volatile	mg/l	105	200	325
Suspended solids (SS)	mg/l	100	220	350
Fixed	mg/l	20	55	75
Volatile	mL/l	80	165	275
Settleable solids	mg/l	5	10	20
BOD: 5-day, 20°C (BOD_5, 20°C)	mg/l	110	220	400
TOC	mg/l	80	160	290
COD	mg/l	250	500	1000
Nitrogen (total as N)	mg/l	20	40	85
Organic	mg/l	8	15	35
Free ammonia	mg/l	12	25	50
Nitrites	mg/l	0	0	0
Nitrates	mg/l	0	0	0
Phosphorus (total as P)	mg/l	4	8	15
Organic	mg/l	1	3	5
Inorganic	mg/l	3	5	10
Chlorides[a]	mg/l	30	50	100
Sulfate[a]	mg/l	20	30	50
Alkalinity (as $CaCO_3$)	mg/l	50	100	200
Grease	mg/l	50	100	150
Total coliform	$no/100ml$	10^6-10^7	10^7-10^8	10^7-10^9
Volatile organic compounds	$\mu g/L$	<100	100-400	>400

[a]*Value should be increased by the amount present in the domestic water supply*

(Source: Metcalf & Eddy, Inc. 1991)

4.4 Conclusions

As the electronics and computer industries evolve and grow, it will be possible to expect a significant increase in use of hazardous materials, chemicals, water, energy and as well as generation of hazardous wastes and wastewater. Because of the large amount of chemicals used in the processes, their use, control, by-products, emission and disposal are of a principal environmental concern. Any leakage or accidental spill might be very dangerous. Therefore, improvements in current technologies are needed to reduce environmental burden by reducing or phasing out these hazardous chemicals. Continuous improvement in these rather settling a precise threshold to be obtained. Companies can also set their own pace and focus attention on the most cost-effective improvements.

The treatment and disposal of electronics industrial wastewater and solid waste will be discussed in Chapter 7.

5 Electronic-Waste In Singapore

5.1 Introduction

Like many other cities in rapidly industrializing East and Southeast Asia, a tiny island state of Singapore has had to address issues related to the provision for both fast urban growth and industrialization. Being a small and densely populated country, she ought to be careful with protection of her environment, at the same time, she has to promote economic and industrial growth.

Singapore has been enjoyed steady economic growth since her independence in 1965 except global recession in 1985 to 1986. Such rapid growth brought in its wake several problems, not the least of which the impact it had on the environment. Fortunately, problems were recognized early and the government proceeded to institute environmental pollution control with the formation of SOME in1972 to ensure that economic growth and rapid industrialization were not achieved at the expense of the environment.

The emergence and growth of the environmental awareness in Singapore are driven mainly by government policies and national legislations as she seeks to maintain the standard of the environment at a level that protects the well being of her population and environment. They are regulatory measures, planning controls, economic incentive and encouragement public awareness and participation.

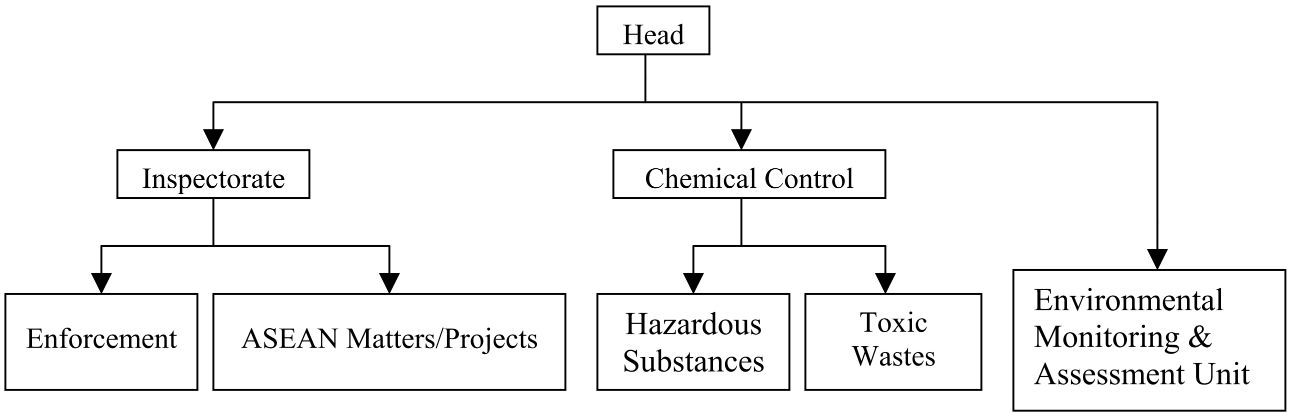
Singapore is among the most progressive user of environmental technologies in the Asian region. Over the years, Singapore companies have developed the requisite technical expertise and know-how in the application of environmental technologies. The strengths of these Singapore companies are in the areas of water technology, waste and wastewater treatment, clean air, consulting and engineering services. Most of Singapore environmental technology and know-how are imported from technologically advanced countries such as Australia, Germany, Japan, United Kingdom and the U.S..

The chapter sees how she has managed rapid economic development and industrial growth while enhancing environmental quality for her citizens. The success of the environmental protection is evident today and Singapore has an environment that compares well with major city in the globe.

5.2 Singapore Environmental Planning

Environmental planning can be divided into three phases. The phase one spans between the colonial period and 1972, which focuses more on land usage and environmental impact. The second phase is between 1972 to 1992. SMOE was set up in 1972. It was formed to oversee the environmental planning in Singapore. An approach evolved that was based on awareness campaigns, land use, pollution monitor, inspection, and strict enforcement. Finally, the "Green Plan" period from 1992 to present, it introduced a strategic and participatory vision of environmental management beyond the classic focus on environmental health, infrastructure and pollution control. In 2002, the Singapore National Environment Agency (SNEA), a new statutory board, was formed to relief some of SMOE's responsibilities. The SNEA took over the operational functions of environmental protection and public health from SMOE so that SMOE could focus on strategic and policy planning. Within SNEA, the Environmental Protection Division's role is to ensure that Singaporeans continue to enjoy a good quality living environment for generations to come. It will continue to implement programs to monitor, reduce and prevent environmental pollution. PCD, a subsidiary depart of Environmental Protection Division, is tasked with the overall responsibility for air, water and noise pollution control and hazardous substances and toxic waste control. It has the responsibility of monitoring ambient air, and inland and coastal water quality. It is also responsible for the formulation and implementation of joint programs on transboundary pollution with the neighboring countries. Problems encountered by regulatory agencies and polluters are addressed, with particular emphasis on the impacts the system may or may not have on future economic development. Figure 5-1 offered a road map to be followed through this maze. The above is the official Singapore governments description in the environmental protection in Singapore. The environmental laws or controls have helped to address some environmental issues historically associated with expansion of electronics industrial growth. With proper planning and control, the environmental input of industrial activities can be minimized to the extend that it becomes benign. However, they are an increasingly inept to address the electronics industry. For one thing, currently pollution controlled laws impose uniform standards across an industry that is heterogeneous in its product, processes, and types and quantity of pollution. Thus, the status quo is expensive, inflexible, and ill suited fir an industry in which manufacturing increasingly is decentralized and products change in a matter of months.

Figure 5-1: Organization Chart Of Pollution Control Department



Enforcement

- Enforce pollution control legislation;
- Implement air and water pollution control programs e.g. inspections, water samplings & emission testing, surveillances

ASEAN Matters/Projects

- Formulate and implement programs/projects on environmental management for the ASEAN Working Group on Environmental Management;
- Formulate and implement programs/projects on environmental co-operation for the Malaysia-Singapore Joint Committee on the Environment and the Indonesia-Singapore Joint Committee on the Environment;
- Control vehicular emissions and fuel quality.

Hazardous Substances

- Plan and implements programs such as hazard analysis, safety review, wastes audit, emergency & spill response, to control hazardous substances;
- Approve and checks on the transportation of hazardous substances.

Toxic Wastes

- Plan and implements
- programs such as hazard analysis, safety review, wastes audit, emergency & spill
- response, to control toxic wastes;
- Approve and checks on the transportation and disposal of toxic wastes;
- Implement programs to phase-out ozone depleting substances.

Environmental Monitoring & Assessment Unit

- Undertake monitoring programs to assess air quality and the quality of the inland and coastal waters;
- Monitor toxic trace contaminants in the environment;
- Track air and water quality trends to identify emerging environmental problems;
- Provide laboratory services for investigations and enforcement action.
- Undertake studies and projects related to environmental quality;
- Develop and upgrade monitoring methods for air and water quality assessment.

(Source: SNEA 2004.)

5.2.1 Regulatory Measures

Enforcement of legislative is crucial to any environmental management strategy. It is imperative that environmental legislative be strictly enforced to ensure that any infringement is quickly detected and duly penalized. Sources that generate the pollution are responsible for the cost of pollution. Environmental legislations require industries to install and operate control equipment in order to comply with the emission limits air pollutant and trade effluent limits stipulated in their respective regulations.

5.2.2 Planning Controls

Singapore's long term planning and preventive controls are extremely important to the success of environmental management strategy. These controls are factored into land use planning to ensure that developments are properly sited and are compatible with surrounding land uses. For example, SMOE carries out an environmental impact assessment on new industrial developments.

5.2.3 Economic Incentive

Economic incentives used for environmental management are user fees licensing and fiscal measures. User charges are levied for waste collection and treatment. Singapore government provides fiscal incentives, grants and financial assistance to oversea companies setting up environmental service businesses in Singapore. Their presence in Singapore will help build up a critical mass for environmental industry and thus reinforce Singapore's reputation as a hub for environmental technology. The example include setting the Environmental Technology Institute in 1996 to help the local environmental industry in developing of more greener technologies and products, and investment in modifying existing technology to product high quality greener product.

5.2.4 Public Awareness And Participation

Public awareness about the environmental issues is developed in Singapore through specialized campaigns, education system and "Singapore Green Plan". Ever since the launching of her first campaign, "Keep Singapore Clean" in 1968, there have been focused campaigns to develop public awareness about pollution, infectious diseases and global environment matters. The government has also worked closely with retail sector to promote minimal packaging for consumer products and introduce programs to educate consumers to be less wasteful in their consumption patterns.

Schools are important conveyors of environmental information. Government jointly with polytechnics and universities conducts environmental management courses. Government institutions conduct seminar and workshop on Green Productivity and International Organization of Standardization (ISO) 14000s (for example, Singapore Standard, SS ISO 14004:2004 Environmental Management Systems – General guidelines on principles, System and Support Techniques, and Singapore Standard, SS ISO 14001:2004 Environmental Management Systems – Requirements With Guidance For Use) for industry developer. The increase in the knowledge-based professionals will eventually lead to increased competency of local companies.

5.3 Water Pollution Control

The main types of water pollution in Singapore are domestic wastewater, industrial effluent and farm wastewater. The protection of water resources in Singapore is complemented by the provision of comprehensive sewage wastewater treatment facilities for all wastewater generated within Singapore.

Industrial effluent is generated from the use of in manufacturing activities. Its composition varies according to industries but in general has considerable organic matter, suspended solids and significant quantities of heavy metals compared domestic wastewater. The bulk of industrial of discharges in Singapore are from Jurong Industrial Estate on the western part of the island and from some light industries scattered over other parts of the island. Industrial effluent is to be discharge into the public sewer.

Industrial effluent control is a highly regulated field. Regulation has driven considerable developments to minimize the impact of industrial on the environment. The principal legislation controlling industrial discharges to sewer is Environmental Pollution Control Act (Chapter 94A, Section 77(1) Environmental Pollution Control (Trade Effluent) Regulations. It is used to control the discharge of wastewater from domestic, industrial, agricultural and other premises into public sewers and watercourses (SNEA 1999).

Some of the constituents of effluents will remain in the liquid phase and may be discharged as part of the sewage works effluent. The PCD will set the appropriate stipulated limits in the consent to protect the quality of the watercourse. Industries that discharge their wastewater into sewage are required to ensure the quality of the industrial wastewater complies with the stipulated limits listed in the Trade Effluent Regulations (TER) found in Appendix B before discharging into the public sewer. They are charged a fee if their trade effluents exceed the total suspended solids (TSS) and biochemical demand (BOD) level stipulated in the TER. The tariff, could be found in Appendix C, based on the concentration of the TSS and BOD and the volume of effluent discharge, is levied to recover the higher cost incurred in treating the excess pollution loads at sewage treatment work. The schedule of tariffs is revised regularly to reflect the market cost in treating the wastewater. Apart from the above two parameters, TSS and BOD, the trade effluent discharged into the sewage must be free of certain materials mentioned in the Table 5-1.

Table 5-1: Materials Not Be Found In The Trade Effluent

S/No	Materials
1.	Radioactive material;
2.	Any pesticide, fungicide, herbicide, insecticide, rodenticide or fumigant;
3.	Refuse, garbage, sawdust, timber, human or animal waste or solid matter;
4.	Petroleum or other inflammable solvent. And;
5.	A substance that either by itself or in combination or by reaction with other waste or refuse may give rise to any gas, fume, or odor or substance which is or is likely to be a hazard to human life, a public nuisance, injurious or otherwise objectionable.

(Source: SNEA 1999)

All industries should install in-house treatment plant to treats their trade effluent prior to meet that stipulated standard of TER. The common treatment plants installed by industries may include balancing, chemical treatment, ion-exchanger, neutralization, oil interceptor, precipitation of heavy metals and sedimentation. Those, which generate large quantities of acidic effluent, are required to install continuous pH monitoring and recording instruments to monitor the pH of effluent discharged and pH activated control valve, which will prevent accidentally discharged of acidic effluent into the sewers that would cause extensive damage of sewer.

Certain effluents can contain particularly persistent or toxic compounds such as cadmium, mercury, and persistent pesticides such as pentachlorophenol or γ-hexachlorocyclohexane. Some of these organic chemicals may undergo bioremediation through treatment process. A portion, however, will remain unaffected and retain its pesticidal properties. Its discharge into the receiving environment must be minimized at source. Release of pollutants must be prevented where possible or minimized, and all emissions must be rendered harmless to the environment. Again in order to minimize the impact on the environment, certain industries may need targeting to reduce their inputs.

Companies or individuals who contravenes of the Regulations may be liable for prosecution. The penalty can be found in Table 5-2.

Table 5-2: Penalty For Offenders In Trade Effluent

1.	On the first conviction to a fine not exceeding $10,000 and, in the case of a continuing offence, to a further fine not exceeding $300 for every day or part thereof during which the offence continues after conviction; and
2.	On a second or subsequent conviction to a fine not exceeding $20,000 and, in the case of a continuing offence, to a further fine not exceeding $500 for every day or part thereof during which the offence continues after conviction.

(Source: SNEA 1999)

5.4 Air Pollution Control

As with waster pollution, a complex system of regulations governs the use of air pollution abatement technologies. Under the Environmental Pollution Control Act (Chapter 94A, Section 77(1) Environmental Pollution Control (Air Impurities) Regulations, which came into force on 1 January 2001, PCD has the authority to set national emission standards for hazardous air pollutants for all sources of those pollutants (SNEA 2001). The 2001 Environmental Pollution Control (Air Impurities) Regulations required that PCD develop a list of substances to be regulated. Substances can be added to and removed from the list as a result of ongoing research. The levels of all the air pollutants monitored were within the acceptable limits prescribed by the World Health Organization and the U.S. EPA.

Currently, the stipulated emission limits list can be found in Appendix D. On case-by-case basis, PCD could require a facility to install control equipment, change work practices, and train and certify operators and workers. The penalty is similar to that for trade effluent, which can be found in Table 5-2.

In addition, Singapore has adopted the Pollutant Standards Index (PSI) developed by the USEPA, which reports the daily pollutant measurements in ambient air using a simple scale of 0 to 500. Table 5-3 gives a good illustration of PSI Scale. The ambient air in Singapore is routinely monitored in an island of monitoring stations situated in the urban, industrial and rural areas.

Table 5-3: PSI Scale And Its Related Air Quality Level And Health Effects

PSI Range	**EPA Color Scale**	**EPA Descriptor**	**Clean Air Campaign Health Advisory**
0 to 50	Green	Good	The air quality is good and you can engage in outdoor physical activity without health concerns.
51 to 100	Yellow	Moderate	At this level the air is probably safe for most people. However, some people are unusually sensitive and react to ozone in this range, especially at the higher levels (in the 80s and 90s). People with heart and lung diseases such as asthma, and children, are especially susceptible. People in these categories, or people who develop symptoms when they exercise at "yellow" ozone levels, should consider avoiding prolonged outdoor exertion during the late afternoon or early evening when the ozone is at its highest.
101 to 150	Orange	Unhealthy for Sensitive Groups	In this range the outdoor air is more likely to be unhealthy for more people. Children, people who are sensitive to ozone, and people with heart or lung disease should limit prolonged outdoor exertion during the afternoon or early evening when ozone levels are highest.
151 to 200	Red	Unhealthy	In this range even more people will be affected by ozone. Most people should restrict their outdoor exertion to morning or late evening hours when the ozone is low, to avoid high ozone exposures.
201 to 300	Purple	Very Unhealthy	Increasingly more people will be affected by ozone. Most people should restrict their outdoor exertion to morning or late evening hours when the ozone is low, to avoid high ozone exposures.
Over 300	Black	Hazardous	Everyone should avoid all outdoor exertion.

(Source: U.S. EPA 1998b)

Singapore had signed with accession to both 1995 Vienna Convention on the Protection of the Ozone Layer and the 1987 London The Montreal Protocol On Substances That Deplete the Ozone in 1989 (United Nations Environment Programme, Ozone Secretariat 2005). Implemented control measures are summarized in Table 5-4.

Table 5-4: Implemented Control Measures

Date	Measure
5 Oct 1989	Quota Allocation System implemented for Chlorofluorocarbons (CFCs).
5 Feb 1991	Prohibit the import and manufacture of non-pharmaceutical aerosol products and polystyrene sheets/products containing controlled CFCs.
1 Jan 1992	Prohibit the use of Halon 1301 for new fire-protection systems. Prohibit the import of Halon 2402.
1 Jan1993	Prohibit the import of new air-conditioning and refrigeration equipment using CFC 11 and CFC 12.
1 Jan 1994	Prohibit the import of Halon 1211 and Halon 1301.
15 Apr1994	Prohibit the import of fire extinguishers filled with Halon 1211.
1 Jan 1995	All new cars must be equipped with non-CFC air-conditioning systems.
1 Apr 1995	Prohibit the import of HBFCs.
1 Jan 1996	Prohibit the import of CFCs, carbon tetrachloride and 1,1,1-trichloroethane (methyl chloroform).
1 Jan 2002	Freeze the consumption of Methyl Bromide (MeBr) for non-quarantine and pre-shipment (non-QPS) applications*.

Note: Quarantine applications – Include treatments to prevent the introduction, establishment, and/or spread of quarantine pests, or to ensure their official control.

Pre-shipment applications – These include non-quarantine methyl bromide applications within 21 days prior to export that are required to meet the official requirements of the importing or exporting countries.

(Source: SNEA 2004)

5.5 Toxic Substances And Hazardous Wastes Control

SNEA (2005a) claimed that the E-Waste was classified as a hazardous waste under the Basel Convention Act. The Hazardous Waste(control of export, import and transit) Act and its regulation were enacted and came into operation on 16th March 1998 and continued to take effect - this act has enable Singapore to fulfill its obligations under the Basel Convention, which it acceded to on a 2nd January 1996. The Hazardous Waste (Control of Export, Import and Transit) Bill was passed by Parliament in November 1997 to ensure sound and effective management, transportation and disposal of hazardous wastes in Singapore. Under the Hazardous Waste (Control of Export, Import and Transit) Act and its

Regulations, any companies or individuals who export, import or transit any hazardous waste listed under the Basel Convention will have to apply a clearance from PCD unless they do no contain the following materials found in Table 5-5.

Table 5-5: Materials Found In Electronic-Waste

1.	Electronics waste/scrap mixed with or containing any hazardous components such as accumulators and other batteries, mercury switches, glass from CRTs, activated glass, capacitors containing PCB, et cetera;
2	Plastic waste/scrap containing oil, grease or industrial chemicals or mixed with household garbage;
3	Scrap metal or metal slag containing toxic or heavy metals such as cadmium, nickel, mercury, lead, et cetera. And;
4.	Waste paper contaminated with hazardous substances/waste or mixed with household garbage.

(Source: SNEA 2005.)

PCD adopts the Prior Informed Consent procedure of the Basel Convention in granting any clearance for the export, import or transit of hazardous wastes as E-Waste is classified as hazardous waste under Singaporean hazardous (control of export, import and transit) Act and its regulation 1998, exports, imports or transits to other countries for recycling are legal after the person-in-charge has applied for and been granted a clearance by PCD. Companies or individuals who export, import or transit any hazardous waste in contravention of the Convention Act may be liable for prosecution. The penalty can be found in Table 5-6.

Table 5-6: Penalty Of Conviction

1	In the case of a body corporate, to a fine not exceeding S$300,000. Or;
2.	In the case of individual, to a fine not exceeding S$100,000 or to imprisonment for a term not exceeding two years or to both.

(Source: SNEA 2005a)

There is no offenders being prosecuted at the moment. But that does not mean there will be nobody engaged in the activities (export the E-Waste to other countries). Puckett et al. (2002) mentioned that Singapore did dump her E-Waste in China, India or Pakistan. According to the amended Basel Convention to which India has ratified prohibits only the OECD countries from exporting the hazardous E-Waste to non-OECD countries for final disposal (Secretariat Of The Basel Convention, United Nations Environment Programme n.d). Singapore does not consider breaching the Convention as she does not belong to OECD country nor she has ratified to the Convention. Moreover, she is just a signatory to the Convention with acceptance, and the recipient, Indians accept the dumped E-Waste willing. What Singapore needs to accede to fulfill her obligations to the Convention is up to level as declared for "acceptance". SNEA (2004) stated that in 2003, PCD processed and issued 14 export, 4 import and 34 transit clearances under the Basel Convention. In Singapore, hazardous wastes are treated and disposed locally.

5.6 Management Of Hazardous Substances

As industries developed and diversified into specialist chemicals, computers and electronics, technology processes over the years, the quantity and variety of chemicals and electronics imported, transported and handle in have increased. Some of these industries also generate toxic wastes from their processes which need to be disposed of in a safe manner. To reduce the risks associated with the storage, transport and handling of hazardous substances and toxic wastes, such industries are normally either situated far away from residential areas or sited on off-shore islands.

PCD has set up controls to ensure the safe and proper management of hazardous substances and toxic wastes. Under the Environmental Public Health (Hazardous

Substances) Regulations, any individual or company engaged in the such activities is required to obtain a hazardous substance license or clearance from PCD (SNEA 2004). The hazardous substances currently controlled by PCD are listed in the Appendix E. Additional transport approval is also required to transport hazardous substances which exceed the quantities stipulated in the Regulations. The specified limits for each hazardous substance are listed in Appendix F. Only drivers who have successfully undergone and passed the Hazardous Materials Drivers Course jointly organized by PCD, Singapore Civil Defense Academy and Port of Singapore Authority Institute are allowed to drive road tanker carrying hazardous substance (SNEA 2002).

5.7 Toxic Industrial Wastes Control

The Environmental Public Health (Toxic Industrial Waste) Regulations require all toxic industrial waste collectors to be licensed (SNEA 2004). Approval is also required to transport toxic industrial wastes which exceed the quantities stipulated in the Regulations. The types of toxic industrial wastes controlled under the Regulations are listed in Appendix G.

SMOE (2001) states that in 2000, about 121,500 tons of toxic industrial wastes were generated and collected by licensed hazardous waste treatment companies for recycling, treatment and/or disposal in Singapore, 70 percent of them was recovered or reclaimed for reuse and the remaining was treated for disposal by landfill.

In Singapore, people either sell their electronics (many of them are faulty) to garbage collector or trade-in them while buying a new product. The licensed recycler would then buy E-Waste from the garbage collector and electronic manufacturers. Most of the time, the electronic manufacturer would contract the recycler to handle their.

In the recycling process, only metals such as gold, silver, palladium, iron, solder, copper and platinum are recovered. Plastics are normally grinded into very small piece or melted for storage. Other non-recyclables are simply incinerated.

Apart from in-house processing, semi-processed materials may be exported for further refining and extraction whenever there is a need. Those recovered precious metals such as gold and silver are either sold to jewelers makers or in the open commodities markets. Other metals may sell to metal smelter. Table 5-7 indicates the licensed dealers in electronic-scraps.

Table 5-7: Licensed Dealers In Electronic-Wastes

Company's Name	Types Of Materials Dispose Of	Remarks
Altvator Jakob Pte Ltd	Scrap electronics and components, electronics memory chips, IC boards and PWDs	Collect from school, commercial and residential areas; Minimum quantity is 500Kg.
Citiraya Industries Pte Ltd	Computer and electronic scraps	No collection services; Arrangements to be made with company before delivery of materials.
EC-Asia International Pte Ltd	Electronic memory chip scraps or off-specification rejects	Collects from local chip manufacturers.
ELMS Industrial Pte Ltd	Electronic scraps and IC trays	Collects from commercial and industrial areas.
Green World Holdings Ltd	Scrap electronic and computer components, and IC boards	Collects based on contracts; Buys and accepts from local waste dealers.
HLS Electronics Pte Ltd	Scrap electronic and computer components, and IC boards	Collects from companies; Exports overseas.
Ohgitani Kogyo (S) Pte Ltd	Scrap electronic and computer components, and IC boards	Collects from companies.
Recycling Point Dot Com	Computer electronic scraps, electronic memory chip scraps or off-specification rejects	Collects from all areas; Collects from commercial areas and industries; Reimburse owners.
SPM Refinery Pte Ltd	Scrap electronic and computer components, and IC boards	Collects from existing companies; Exports overseas.
Union Steel Pte Ltd	Scrap electronic and computer components, and IC boards	Local buying from waste dealers; No collection services provided.

(Source: Singapore National Environment Agency 2005b.)

5.8 Conclusions

The electronics industry is covered by a mass of rules, regulations and agreed corking practices, many of which are archaic. If simply followed, they would make production difficult, lower profit margin, a vast of funds would be needed, and in some case the whole process plant might be needed to change. Therefore, the resistances to change, lead to malpractice in many cases. In order to achieve the goals of the organization, workers must often violate regulations, resort to their own techniques of doing things, and disregard lines of authority. It is often forgotten that many of these rules were introduced to safeguard management liability in the event of industrial accidents, for example. Managements are quite prepared to close their eyes when these rules are broken in the interests of keeping production going. In many situations the selective application of rules can be a very potent weapon in the workers hands. Even the modest overtime ban can be effective, if used critically. This is particularly so in industries which have an uneven work pattern. SMOE (2001), for example, will conduct surprise inspections of strong hazardous substances to audit the inventory records of hazardous substances, those who fail to comply with the regulations, will either be prosecuted or given be verbal warning.

Industries should be given incentives to modify their processes plants instead of merely being penalized. Incentive could be in the form of liability risk avoidance or tax credit. In return for industry support of such a program, mandated take initiatives of obsolete electronics would not be instituted.

6 ELECTRONIC-WASTE IN INDIA

6.1 Introduction

Computing and its related information technologies have become a crucial to the infrastructure of advanced countries; they are the heart and soul of day-to-day business operations. Rapid technological and innovation advances in computer technology has brought with it shorter useful equipment life for each successive generation of equipment. Based on information from "*Computer Display Industry and Technology Profile*", and figures presented in "*Electronic Product Recovery and Recycling Baseline Report*", the useful life of a desktop computer purchased in 1997 was expected to be 6 to 7 years, and by 2005, the average life span of a new desktop computer is expected to be 2 years.

Accelerating technological innovation and the associated decline in equipment useful life expectancy have inevitably accompanied by an increase in the amount of waste generated when the product reaches its EOL. Management of obsolete electronics (E-Waste) becomes an important and growing issue facing the electronics industry. Unlike living creatures, obsolete electronics do not degrade by themselves. They require proper disposal, and are often salvaged and recycled for base materials. Embedded in the current production of semiconductors, PWB and computers are highly toxic substances include carcinogenic substances such as lead, mercury, cadmium beryllium, and etc, which can pose threats to worker and environment.

Puckett et al. (2002) accuse the U.S. and many other rich nations which use most of the world electronic products and generate most of the E-Waste, rather than having to face the problem squarely, have made use of a convenient, and until now, hidden escape valve –

exporting the E-Waste crisis to the developing countries of Asia such as China, India and Pakistan by flouting the international laws, the Basel Convention.

According to the Basel Convention to which India has ratified, the Convention prohibits the OECD countries from exporting the hazardous E-Waste to non-OECD countries for final disposal (Secretariat of the Basel Convention 1992). It also calls for effective steps to control E-Waste within the boundaries of the countries concerned. However, India has only paid a lip service to this international agreement.

China's top legislature is deliberating the draft amendment to the Law on Solid Waste Pollution Prevention to avoid becoming the "World's Largest Dumping Ground" by tightening control over the mounting trafficking of foreign garbage (People's Daily Online 2004). If it were to enact, such regulations would impede the dumping of e-waste by foreigners in China. Therefore, the foreign dumpers will choose to dump their E-Waste in India since India legislations has no specific guidelines or laws for E-Waste or its handling, recycling or trading (Wankhade 2004). This could mean that the more than 90 percent of the exported E-Waste will be dumped into India in the near future.

Singapore did export E-Waste to China, India & Pakistan as accused by Puckett et al. (2002), and parts of the E-Waste dumped by the U.S. or many nations into India were made in Singapore such as hard disk disks, computer parts and consumer electronics. Would it mean that Singapore producer should "take-back" their manufactured products for disposal if there were international laws that mandated such take-back? In term of ethic, of course, it would be best if the producers really take-back their products. But such things would get very complicated, as this would mean that the producers of virgin materials should take back theirs too. Ultimately, the developing nations would then be the ones that are exploited since most of virgin materials were extracted from them. These could mean that the developing nations should take-back “their E-Waste” from the “dumpers” instead.

Generally, the components and subcomponents of electronics are made in different countries, often by different manufacturers, before being assembled into the finished product and sold to the end-user. This fact is very true, especially applied to Singapore, as she does not have any virgin materials needed in making the products.

This is a very highly controversial issue especially when that Singapore’s product is not 100 percent made in Singapore as most of the virgin materials are imported. This kind of shifting responsibility has no ends, as it is very difficult to point an accusing finger at a specific producer. A simple fact would be “Goods sold are not refundable nor returnable”. Those Singapore’s products (or simply any country’s product) where their useful life end in, that country should bear the fully responsibility in disposing of them. Perhaps this is an ultimate reason why people from the entire world are dumping their hazardous wastes (e-waste is just one kind) into another person’s country for disposing even at the risk being prosecuted.

Normally, the rich nations would extract their virgin materials from developing countries, reap the benefits of the products developed from those virgin materials, and then send the no longer useful products back to the developing nations which then have to deal with the waste problem.

All discarded obsolete electronics, found in Singapore irregardless of their origins, are disposed of locally by some of licensed E-Waste dealers in Singapore (see Table 5-7 for a list of electronics recycler found in Singapore). However, Puckett et al. (2002) mentioned Singapore exported her E-Waste too. This is because Singapore has yet to ratify the Basel

Convention. Moreover, the exported E-Wastes were not disassembled and Singapore does not belonged to the OECD country – the amended Convention only prohibits OECD countries from exporting the hazardous E-Waste in disassembled from to non-OECD countries.

In 1995-2000, the Indian Information Technology industry recorded a compounded annual growth rate of more than 42.4 per cent (Majumdar et al. 2005). Presently, the Indians use about 12 million PCs, 13 million mobile phones and 70 million televisions (Jamwal, N. 2003). Besides handling its own computer waste – of the nearly 5 million PCs in India – 1.38 million PCs emanating from the business sector and individual households are estimated to be outdated and could soon be added to the waste stream (Keshav 2005). India now also has to manage the E-Waste being dumped by other countries.

The evolution of the international market into a global economy permits companies to take advantage of cheaper labor in less developed nations. The conventional practice of dumping E-Waste in developing countries in India can exacerbate poor environmental practices and contribute to the exploitation of the workers engaged in the recycling process. In addition, Sudhakar (2004) claimed that E-Waste is brought into India under various guises, and official estimates of the magnitude of the problem are purely tip of the iceberg guesses.

6.2 Management Of Electronic-Waste By The United States

The U.S. EPA estimates in its June 2001 report, “Electronics: A New Opportunity for Waste Prevention, Reuse, and Recycling”, that 20 million computers became obsolete in 1998, while only 13 percent were reused or recycled. In 1998, only 6 percent of computers were recycled compared to the numbers of new computers put on the market that year (National Safety Council 1999). National Safety Council (1999) calculated that 41 million personal computers would be come obsolete in 2001, that’s more than double the amount from 3 years earlier.

A Carnegie Mellon University study estimated that in 2002, 12.75 million computers units would go to recyclers in the U.S., about 10 million computer units would be sent to Asia for recycling, keeping only about three million on its own shores. The Carnegie Mellon University study also projected that the number of obsolete computers in the U.S. will soon be as high as 315 to 680 million units after the year 2005.

Up to June 2005, the U.S. is the only developed country in the world that has yet to ratify and accede the Basel Convention, even 13 years after its entry in force in 1992, but she has joined in the consensus decision (Ban Decision III/1) (Basel Action Network 2005). In fact, The typical computer recycling system flow chart shown in Figure 6-1 appeared to be designed to encourage disposing of the E-Waste (CRTs and computer peripherals, for example) by exporting to foreign countries such as Asia and Latin America at the expense of others’ fortune.

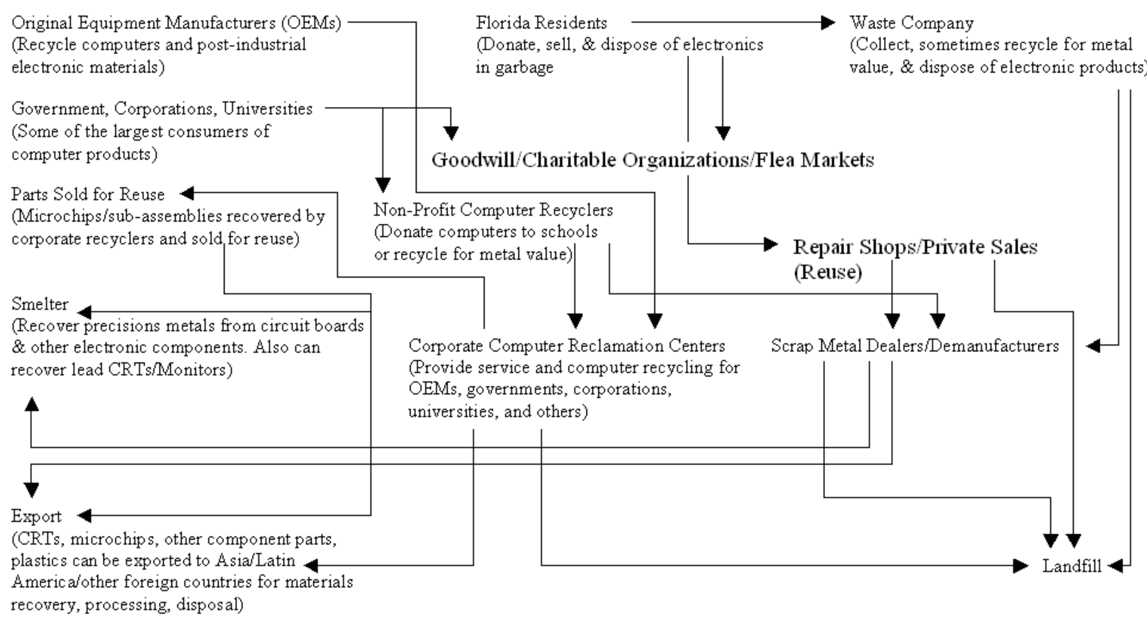
Because electronic components contain many substances which are considered harmful if released in to the environment, the disposal of electronic scrap is regulated and governed by the U.S. Resource Conservation and Recovery Act (RCRA) and is enforced by the U.S.

EPA.

The RCRA restricts and prohibits improper disposal of many E-Waste components but E-waste is not explicitly regulated as hazardous waste at the national level even though, the RCRA Subtitle C was established to ensure that hazardous waste is managed in a manner that is protective of human health and the environment (U.S. EPA 2002).

In the U.S., not only it is legal to export E-Waste but also in fact the RCRA has encouraged its export by exempting it from export regulations as E-Waste it stated in the Act's listed hazardous waste (Puckett et al. 2002).

Figure 6-1: Typical Electronic Management System Flow In Florida, United States Of America



(Source: Southern Waste Information Exchange, Inc. 1999.)

6.3 Export Of Electronic-Waste To India

The most easy and cost-effective way of disposing of the hazardous E-Waste generated by industrial markets and economies is to export them to less developed countries like China, India and Pakistan in Asia under the pretext of donating from the rich and recycling. Countries that dumped their E-Waste into the above countries include Australia, Japan, England, the U.S., Kuwait, Saudi Arabia, Singapore, and Dubai in the United Arab Emirates (Puckett et al. 2002).

Empirical evidence regarding E-Waste imports into less developed countries is meager. The most notably is the trade classification of E-Waste. E-Waste is not classified under the global Harmonized Tariff System (HTS), which the U.S. government and many other nations use to monitor their imports and exports (Bortner 2004). Tong (2004) explains that whenever a shipment of E-Waste occurs, it is included under the HTS category for new computers and electronics, or as a recyclable good, graded by the metals contained. Hence, data regarding the exact amount of E-Waste export is always difficult to obtain as the data export of obsolete computers also includes the data for new computers. In addition, E-Waste from a developed country will often be rerouted through a regional hub such as Dubai and Singapore as they serve as transit points for e-waste from OECD countries to evade customs scrutiny (Wankhade 2004). All these "legal" loopholes make the empirical analysis of the quantity of E-Waste imports even more difficult to obtain and trace.

Despite a lack of quantifiable data, Puckett et al. (2002) estimate that 50-to-80 percent of the E-Waste collected in the United States and destined for "recycling" was exported to developing countries, mainly to China, India, and Pakistan, where they are processed in operations that are extremely harmful to human health and the environment. A technical study conducted by Carnegie Mellon University projected that in 1997, estimated approximately 143 million computers in the US would be recycled by the year 2005 and the number of obsolete computers will soon be as high as 315 to 680 million units. With 80 percent export rate (Puckett et al. 2002), a tenuous estimate of 114 million computers exported from the US for recycling by the year 2005 can be estimated. In addition, According to the U.S. EPA (1998a), it is 10 times cheaper to ship CRT monitors to China than it is to recycle them domestically. While it costs US$20 to recycle an old computer in the US, waste brokers sell the computer for export and make US$5 per piece, and recycling a computer in India costs around US$4 (Alokananda 2004).

Reimer, Sodhi & Knight (2000) discuss the economic problems of recycling electronic products in the U.S. and suggest that generally, the profit from component recovery is low because of high labor cost despite the recovery of gold and silver in the recycling, and the recycler would make a loss in cases of wastes containing hazardous materials such cadmium and lead. They also show that the ratio of profit to cost of a materials recovery process varies throughout the normal process and is negative for several stages in the process.

Puckett et al. (2002) state that the U.S. informed industry insiders have indicated that around 80 percent of what comes through their doors will be exported to Asia, and 90 percent of that has been destined for China. The rest is sent to India, Pakistan and other developing countries.

In Europe the volume of E-Waste is increasing by 3-5 percent per annum, almost three times faster than the growth in municipal solid waste (Arensman 2000). Britain is throwing out more than 1 million tons of E-Waste such as broken computer monitors and discarded mobile phones every year, and new government figures show that more than ever is going abroad, and in 2003, 23,000 tons of E-Waste worth hundreds of millions of pounds was shipped out illegally, mostly to China, west Africa, Pakistan and India to be dismantled by hand for its lead and other valuable toxic contents (Vidal 2004).

Waste electronic equipment containing hazardous material and is destined for minor repair may be exported but must first be authorized by the British Environment Agency (Recycling Today Online 2004). Yet, the government's pollution watchdog, the British Environment Agency admits it has no idea how much of the waste is being deliberately dumped on poor countries by companies trying to avoid paying increasingly high disposal costs in the UK, and how much is only technically illegal because companies have filled in the forms incorrectly (Vidal 2004).

United Kingdom, belongs to the OECD country, yet has not fulfilled her obligations as ratified nation to the Convention.

The export of scrap is profitable in India because of:

- The labor costs are very low (with 44.2 percent out of 472 million workers earning under Rs$1 per day and 86.2 percent under Rs$2 per day in 2003) (NationMaster.com 2005);

- It is allowed in US to export hazardous E-Waste with no restrictions at all (Puckett et al. 2002). And;

- Exportation of E-Waste technically seems legal – the amended Basel Convention agreement does not restrict the export of such wastes from countries that have not ratified the Convention. The Convention restricts only the export of the E-Waste that is disassembled. For example, disassembled computers into different parts are restricted.

6.4 Electronic-Waste Dumped In India Came From Singapore

Parts of the E-Waste dumped by the Americans or others in India were produced in Singapore. On top of that, Singapore also dumped theirs too in India. According to the Basel Convention to which India has ratified, the Convention and its Amendment prohibits only the OECD countries from exporting the hazardous E-Waste to non-OECD countries for final disposal (Secretariat of the Basel Convention n.d.). But Singapore does not consider breaching the Convention as she does not belong to OECD country nor she has ratified to the Convention. Moreover, she is just a signatory to the Convention with acceptance, and the Indians accept the dumped E-Waste willing. What she needs is to accede to fulfill her obligations to the Convention is up to level as declared for "acceptance".

6.5 Recycling Of Electronic-Waste In India

Monitor (2004) claims that there would be a net loss in recycling a computer in the US. However, Alokananda (2004) stated that India generates $1.5 billion worth of E-Waste annually, while Bangalore alone contributes 6000 tons per year. Manufacturers and assemblers add another 1,050 tons of e-scraps in a single calendar year (Keshav 2005). E-Waste generates jobs. Table 6.1 indicates the economy of computer recycling in India.

Table 6-1: Economy Of Computer Recycling In India

Component	**Cost Of Buying**	**Recovered Components**	**Selling Price**
Monochrome Monitors	Rs 200-250 (working) They generally won't buy non-working, but sometimes it comes along with other scrap.	Sold as a whole Sold as a whole or copper from yoke recovered	Rs 300 Rs 80-120 Rs 20-25 for 50–200 gms
Color Monitors	Rs 300-350/piece or in bulk (working) Non-working generally in bulk	CRT Copper from yoke	Rs 500 Rs 20-25 for 150-200 gms
Hard Disks	Rs 25-650/piece or in lots	Actuator Aluminum casings Circuit boards	Rs 25/piece Rs 25/Kg
Printers	Rs 150-300 based on working condition.	Plastics and metal by weight Motor	Rs 100-125
Circuit And Mother boards 486 boards And Processor (Working/Non-Working) Motherboard	Buy in bulk	Gold from circuit boards, processor pins, etc	Rs 150 Rs 300
Keyboard			Rs 15
Mouse			Rs 10
ABS plastics from computers is sold at Rs 15/Kg Recovered copper is sold at Rs 125/Kg to the smelter			

(Source: Sudhakar 2004)

Recycling of E-Waste such as computer requires sophisticated technology and a high degree of safety conscious but the Indian recyclers currently engaged in material salvaging do not have these capabilities. In spite of that, thousands to millions of men and women, irregardless of their age are toiling under primitive conditions, often unaware of the health and environmental hazardous involved in archaic operation which include open burning of plastic and wires, acid treatment to extract gold, and cracking of toxic laden CRTs (Puckett et al. 2002).

E-Waste recycling involves employing people to dismantle the computers and extract parts that can be used again in machine to be sold on the high street. The rest is then burnt in open areas, both of which are highly potentially hazardous to the occupants and environment. The possible occupant and environmental hazards are illustrated by Puckett et al. (2002.) can be found in Table 6-2 when various E-Wastes are rudimentary dismantled.

Table 6-2: Recycling Processed And Their Associated Occupational And Environment Hazards

E-Waste Component	Process	Potential Occupational Hazard	Potential Environmental Hazard
Monitor	Tin and lead inhalation. And; Possible brominated dioxin, beryllium, cadmium, and mercury inhalation.	Silicosis; Cuts from CRT glass in case of implosion. And; Inhalation or contact with phosphor containing cadmium or other metals.	Lead, barium and other heavy metals leaching into groundwater, release of toxic phosphor.
Dismantled printed wiring board processing	Open burning of waste boards that have had chips removed to remove final metals.	Toxicity to workers and nearby residents from tin, lead, brominated dioxin, beryllium, cadmium, and mercury inhalation. And; Respiratory irritation	Tin and lead contamination of immediate environment including surface and groundwaters. Brominated dioxins, beryllium, cadmium, and mercury emissions.
Chips and other gold plated components	Chemical stripping using nitric and hydrochloric acid.	Acid contact with eyes, skin may result in permanent injury. And; Inhalation of mists and fumes of acids, chlorine and sulphur dioxide gases can cause respiratory irritation to severe effects including pulmonary edema, circulatory failure, and death.	Hydrocarbons, heavy metals, brominated substances, discharged directly into river and banks. And; Acidifies the river destroying fish and flora.

Plastics from computer and peripherals, e.g. printers, keyboards, etc.	Shredding and low temperature melting to be reutilized in poor grade plastics.	Probable hydrocarbon, brominated dioxin, and heavy metal exposures.	Emissions of brominated dioxins, heavy metals, and hydrocarbons.
Computer wires	Open burning to recover copper	Brominated and chlorinated dioxin, polycyclic aromatic hydrocarbons (PAH) (carcinogenic) exposure to workers living in the burning works area.	Hydrocarbon ashes including PAHs discharged to air, water, and soil.
Miscellaneous computer parts encased in rubber or plastic, e.g. steel rollers	Open burning to recover steel and other metals.	Hydrocarbon including PAHs and potential dioxin exposure.	Hydrocarbon ashes including PAHs discharged to air, water, and soil.
Toner cartridges	Use of paintbrushes to recover toner without any protection.	Respiratory tract irritation; Carbon black possible human carcinogen. And; Cyan, yellow, and magenta toners unknown toxicity.	Cyan, yellow, and magenta toners unknown toxicity.
Secondary steel or copper and precious metal smelting	Furnace recovers steel or copper from waste including organics.	Exposure to dioxins and heavy metals.	Emissions of dioxins and heavy metals.

(Source: Puckett et al. 2002.)

6.6 Electronic-Waste Legislation In India

India legislation had no specific guidelines or laws for electronic waste or its handling, recycling or trading (Wankhade 2004), which led to proliferation of trade in used computers (E-Waste) though parts of the used computer could be considered as hazardous waste. Although there were several regulation enacted to abate the hazardous waste problem in the country, none of them deals directly and specifically with E-Waste. (Majumdar et al. 2005).

In 1992, the Indian Government issued a Policy Statement on the Abatement of Pollution, in which it reiterated their commitment to Waste Minimization and Control of Hazardous Wastes The Hazardous Waste Management and Handling Rules of 1989, was amended in 2000 and 2002, are the main regulatory framework for hazardous wastes, including the export and import of hazardous waste. These rules define “hazardous waste as any waste which by reason of any of its physical, chemical, reactive, toxic, flammable, explosive or corrosive characteristics causes danger or is likely to cause danger to health or environment, whether alone or when on contact with other wastes or substances” (Ministry Of Environment And Forest, New Delhi. 2002a). The schedule 1 of Hazardous Waste Management and Handling Rules, “indicates wastes generated from different electronic industrial processes are deemed hazardous on the basis of use of carcinogenic substances such as arsenic, beryllium, cadmium, mercury, lead, et cetera in production” (Ministry Of Environment And Forest, New Delhi 2002b). Table 6-3 lists some electronic industrial processes that generate hazardous waste in production as well as disposal process, which are included in schedule 1.

Table 6-3: Manufacturing Process And Its Associated Wastes

Schedule 1	
Process	**Waste**
Production or use of lead.	Lead ashes, lead slags, and lead-containing filter material.
Production or use of cadmium.	Cadmium-containing filter material.
Production or use of arsenic	Arsenic-containing filter material.
Metalworking.	Selenium-containing metal waste Beryllium containing metal waste. Mercury containing metal waste.
Industrial printing and copying with liquid toner.	Printing ink residue, silkscreen printing ink residue, and liquid toner residue.
Production or use of materials made with silicones excluding cement.	Silicon-containing residues.
Production or use of plastics or raw materials for them.	Halogen free residue of additives plastics (e.g. dyestuffs, stabilizers or flame retardants).

(Source: Ministry Of Environment And Forest, New Delhi 2002b.)

Schedule 2 of the Hazardous Waste Management and Handling Rules lists the concentration limits of constituents in the wastes. Waste substances are classified as hazardous if their concentrations exceed the stipulated standard found the schedule. There are two classes (Class A: 50mg/kg and Class B: 5000mg/kg) in the schedule.

Class A – Should 1 kg of any substances contain 50 mg of listed items in Class A, it would be classified as hazardous waste. Table 6-4 presents a list of substances found in typical desktop computer, weighing ~ 60 lbs that are classified hazardous in Class A of the schedule.

Table 6-4: Substances In Class A

Substances In Class A[1]	Weight (lbs)[2]
A1 Antimony and antimony compound	< 0.1
A2 Arsenic and arsenic compound	< 0.1
A3 Beryllium and cadmium compound	< 0.1
A4 Cadmium and beryllium compound	< 0.2
A5 Chromium (VI) compound	< 0.1
A6 Mercury and mercury compound	< 0.1
A17 Halogenated aromatic compounds (plastics)	13.8
A7 Selenium and selenium compound	< 0.00096

[1](Source: Ministry Of Environment And Forest, New Delhi. 2002c.)

[2](Source: Microelectronics and Computer Technology Corporation. 1996.)

Class B - Should 1 kg of any substances contains 5000 mg of listed items in Class B, it would be classified as hazardous waste. Table 6-5 presents a list of substances found in typical desktop computer, weighing ~ 60 lbs that are classified hazardous in Class B of the schedule.

Table 6-5: Substances In Class B

Substances In Class B[1]	Weight (lbs)[2]
B2 Cobalt compound	<0.1
B3 Copper	<4.2
B4 Lead	<3.8
B6 Nickel compound	<0.51
B7 Tin compound	<0.6
B8 Vanadium	<0.1
B10 Silver compound	<0.1
B11 Organic halogen compound (found in plastic casing)	
B30 manganese-silicon	<0.1

[1](Source: Ministry Of Environment And Forest, New Delhi 2002c)

[2](Source: MCC 1996)

Hence, should the concentration of the substances present in desktop computers exceed 50mg and 5000mg as stated in the limit of Class A and B of schedule respectively, then the desktop computer should be deemed hazardous.

Schedule 3 addresses the export and import of hazardous waste from any part of the world into India. It defines "hazardous waste as wastes listed in Lists 'A' and 'B' of Part A Schedule-3 applicable only in case(s) of export/import of hazardous wastes in accordance with rules12, 13 and 14 only if they possess any of the hazard characteristics listed in Part-B of the Schedule" (Ministry Of Environment And Forest, New Delhi. 2002a).

Part A deals with two lists (List A and B) of wastes to be applicable for imports and exports purpose. Table 6-6 gives an illustration of export and import substances found in electronics deem hazardous in List A and B of part A. Some of wastes listed in List A and B are similar to those define in Annex VIII or IX of the Basel Convention.

Table 6-6: List A And B In Part A Of Schedule 3

Basel No	**Description Of Material**	**Annex I**	**Annex III**
A1010	***Metal waste and waste consisting of alloys of the following metals, but excluding such wastes specified on list B***		6.1,11,12
	Cadmium (see B1020)	Y26	
	Antimony (see B1020)	Y27	
	Tellurium (see B1020)	Y28	
A1020	**Waste having as constituent or contaminants excluding metal wastes in massive form**		6.1,11,12
	Cadmium, cadmium compounds. (see B1020)	Y27	
	Tellurium, tellurium compounds. (see	Y28	

	B1020) Lead, lead compounds. (see B1020)	 Y31	
A1030	Wastes having as constituents or contaminants any of the following: arsenic, arsenic compounds, mercury, mercury compound, thallium, thallium compounds.		
A1090	Ashes from the incineration of insulated copper wire.	Y22	12
A1150	Precious metal ash from incineration of printed circuit boards not included on list 'B'.		
A1160	Waste lead-acid batteries, whole or crushed.	Y31	6.1,11,12
A1170	Unsorted wastes batteries excluding mixtures of only List B batteries. Waste batteries not specified on List B containing schedule 2 constituents to an extent to exhibit hazard characteristics indicated in part B of this Schedule (see B 1090)	Y26 Y29 Y31	6.1,11,12
A1180	Electrical and electronic assembles or scrap containing, compounds such as accumulators and other batteries included on list B, mercury-switches, glass from cathode-ray tubes and other activated glass and PCB-capacitors, or contaminated with schedule 2 constituents (i.e. cadmium, mercury, lead, polychlorinated biphenyl) to an extent that they exhibit hazard characteristics indicated in part B of this schedule (see B1110)		
A2010	Glass waste from CRT and other activated glass destined.	Y31	6.1,11.12
A3180	Wastes, substances and articles containing, consisting of or contaminated with polychlorinated biphenyls and/or polychlorinated naphthalene and / or polybrominated biphenyl including any other polybrominated analogues of these compounds, at a concentration level of 50 mg/kg or more		
B1110	Electrical and electronic assemblies		

	Electronic assemblies consisting only of metals or alloys. Electrical and electronic assemblies (including printed circuit board, electronic components and wires) not valid for direct re-use, but for recycling.		

(Source: Ministry Of Environment And Forest, New Delhi. 2002d.)

Part B of schedule 3 characterizes the handling, or recycling of any substance as hazardous. Table 6-7 quotes some examples hazardous characteristics used to describe handling, or recycling of E-Waste in India.

Table 6-7: Part B Of Schedule 3

List of Hazardous Characteristics	
H6.1 Poisonous (Acute)	Substances or wastes liable either to cause death or serious injury or to harm health if swallowed or inhaled or by skin contact.
H8 Corrosives	Substances or wastes which, by chemical action, will cause severe damage when in contact with living tissue, or, in the case of leakage, will materially damage, or even destroy, other goods or the means of transport, they may also cause other hazards.
H10 Liberation of toxic gases in contact with air or water	Substances or wastes, by interaction with air or water, are liable to give off toxic gases in dangerous quantities.
H11 Toxic (Delayed or chronic)	Substances or wastes, if they are inhaled or ingested or if they penetrate the skin, may involve delayed or chronic effects, including carcinogenicity).
H12 Ecotoxic	Substances or wastes which if released present or may present immediate or delayed adverse impacts to the environment by means of bioaccumulation and/or toxic effects upon biotic systems.
H13 Capable	By any means, after disposal, of yielding another material, e.g., leachate, which possesses any of the characteristics listed above.

(Source: Ministry Of Environment And Forest, New Delhi. 2002d.)

With a set of stringent regulations regarding the import and export of these wastes defined in the Hazardous Waste Management and Handling Rules of 1989, the import of hazardous waste is strictly illegal unless a clearance is obtained from the Ministry Of Environment And Forest, New Delhi. However, E-Waste imports technically seem legal – the Basel Convention agreement does not restrict the import of such wastes from countries that have not ratified the Convention

6.7 Conclusions

It seems that the Basel Convention does not serve its purpose in controlling the transboundary of E-Waste between the U.S. and India because it is difficult to point an accusing finger at the U.S. (exporter) or India (recipient). First. The U.S. has not taken responsibility for their E-Waste because they have been able to dump it in India. Second. The India government does not wish to want to acknowledge the problem because the recycling of E-Waste is a lucrative business and those engaged in it are quite happy irregardless of health treats pose to them. Finally, the trading of E-Waste is conducted under camouflaged and is a thriving business in India. Thus, Basel Convention should further redefine its definitions and protocols.

The growing E-Waste problem is largely attributable to the patchy environmental performance of electronic and computer manufacturers worldwide and the lack of voluntarily take back program worldwide. The manufacturer would extract virgin materials from the Third World nations, reap the harvest of the products made from those materials, and then send the useless products back to them under the pretext of “valuable material recovery” or “donations from the developed nations”. Such non-humane act could exacerbate poor environmental practices and contribute to the exploitation of the workers engaged in the recycling process. Generally, under such arrangement, the rich Americans would become richer, and the poor Indians would become poorer.

Take back program may be good incentive but do the manufacturers really dispose of the take back products themselves? They might export the take back products to the Third World nations. Same problem would still persist.

Should incentives be given to industry, mandated product take back initiatives of EOL electronics would not have been instituted.

7 TREATMENT, STORAGE AND DISPOSAL OF HAZARDOUS EFFLUENT AND WASTE FROM ELECTRONICS INDUSTRY

7.1 Introduction

Electronic products are made up of a multitude of components ranging from precious metal such as gold and silver and toxin substances such as BFRS and mercury to carcinogenic substances such as arsenic, beryllium, cadmium, chromium, dioxins and lead. Most of these toxic substances in E-Waste could have posed severe threat to eco-system or scavengers' health in dismantling the discarded electronic products. For greater detail regarding the human health impact associated with the above mention toxic chemicals and where they are found, for example, in a typical PC, refer to Chapter 2.4.

Hence, treatment, storage and disposal facilities are the vital link in the cradle-to-grave hazardous waste management system in electronics industry, especially, when the phases of making product have the highest environmental impact as some chemicals and by-products are being released into the environment during the manufacture. In semiconductor industry, according to Williams, Ayers & Hellers (2002) a fabricated wafer area of 1 centimeter square generate 17 Kilograms of wastewater and 7.8 Kilogram of solid wastes. The wastewater and solid waste may contain high level of spent acid, spent organic solvent and other chemicals used in the manufacture. The substances found in untreated wastewater from a U.S. semiconductor manufacturing facilities can be found in Table 4-14 in Chapter 4. For greater detail regarding the waste generated in semiconductor processes, refer to Chapter 4.

Before the commencing the waste treatment process, all sorts of wastes are segregated, ranging from non-hazardous, flammable, hazardous, and explosive to corrosive. Segregation aids the subsequent waste handling, treatment and disposal processes. Segregated wastes are either treated by in-house treatment facilities or picked up by a service company for transporting to government specially designed treatment plant for non-hazardous hazardous waste. All treated wastes from in-house treatment plants are then picked up service companies for transporting to government specially designed disposal plant for both non-hazardous and hazardous wastes. To conserve water, wastewater is recycled in-house. The below mention waste treatments and disposal technologies are adopted in Singapore.

The disposal of obsolete and off-specification products is also discussed.

7.2 Waste Minimization Approach

The main issue concerning our present system of industrial manufacturing is what to do with all waste that is generated. The ultimate solution is the prevention of waste generation in the first place than "clean up" the waste after its production. Polprasert (1996) identifies waste minimization includes any **source reduction**, **recycling** activities undertaken by a waste generator that results in the reduction of total volume or quantity of waste , and the **disposal of waste.**

- **Source reduction.** As the name implies, waste reduction at source usually involves the used processes and materials to reduce the impact of wastes on the environment to the greatest extent.

- **Recycling.** The next most desirable approach waste minimization through recycling/reuse. The recovered material may be "downcycled" from its original product cycle to another product cycle with less demanding requirements (Keoleian & Menercy 1993). See Figure 7-1.

- **Disposal.** The last minimization approach is disposal of wastes. Before the final disposal of waste, waste needs to be treated with any method that render it less hazardous cum more manageable.

The U.S. EPA (1988) claims that waste minimization has the following advantages in the U.S.

- Save money by reducing waste treatment and disposal costs, raw material purchases, and other operating cost;

- Meet state and national waste minimization policy goals;

- Reduce potential environmental liabilities;

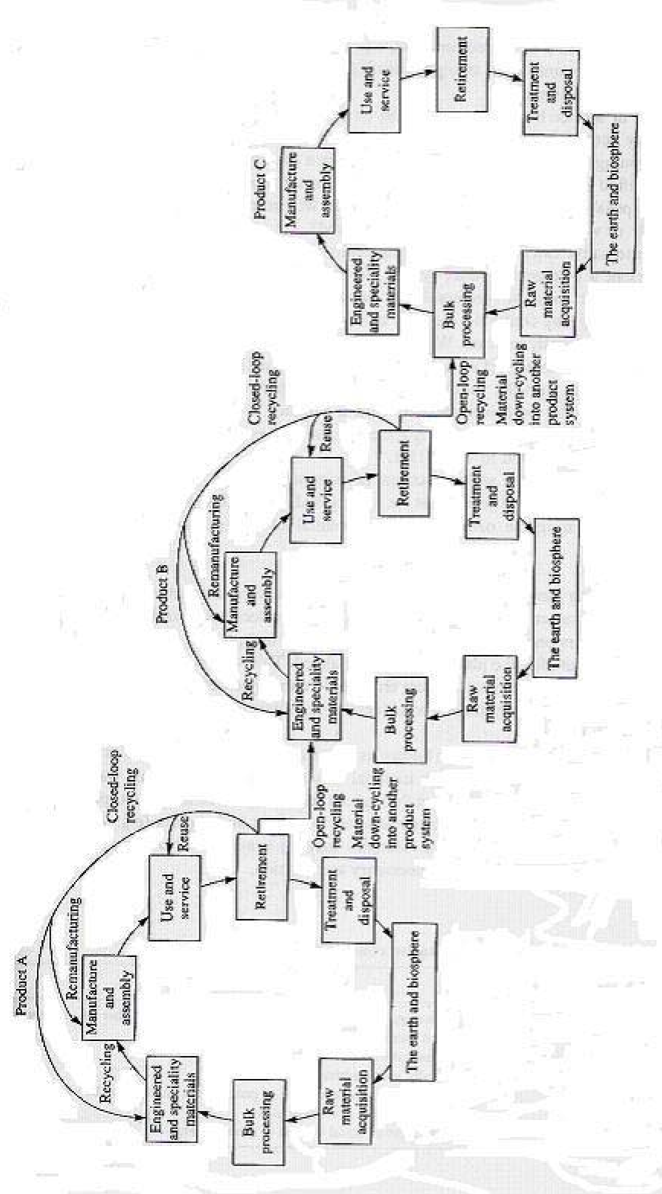
- Protect public health and worker health and safety ;

- Enhance public image. And ;

- Protect the environment.

However, very often the benefits are not seen. Namely due to the following reasons. First, once waste is created cannot be destroyed as Murphy Laws are in action. For example, incineration may use to reduce the volume and toxicity of hazardous waste but there are ashes needed to landfill and dioxins needed to be trapped. Landfill and the trapped dioxins need to be treated too. Thus, waste management process is a cyclical process. Second, a large initial fund is needed to change the processes and product design. Small business operators may not have such a large capital. Final, many choose to opt the end-of-pipe solutions (a very cost-effective method) – let other people to handles their waste such as exporting to the Third World countries for final disposal.

Figure 7-1: Material Downcycling



(Source: Keoleian & Menercy 1993

7.3 Waste Reduction Technique

The success of waste minimization approach is dependent upon the implementation various waste reduction techniques at source reduction and recycling. Crittenden & Kolaczkowski (1995) come up with a flow chart of hazardous waste minimization technique (see Figure 7-2), the techniques for bringing about waste reduction can be broken into few categories follows:

- Inventory management;
- Product process modifications. And;
- Resources recovery.

Inventory Management. Proper inventory control over input materials is one of most important waste reduction technique as this control may involve technique to reduce inventory size and chemical use which eventually leads to a reduction in , or avoidance of, the formation of hazardous waste.

Product process modifications. Various waste reduction technique such as good practice, input material changes, product changes and technological changes may be implemented at the source.

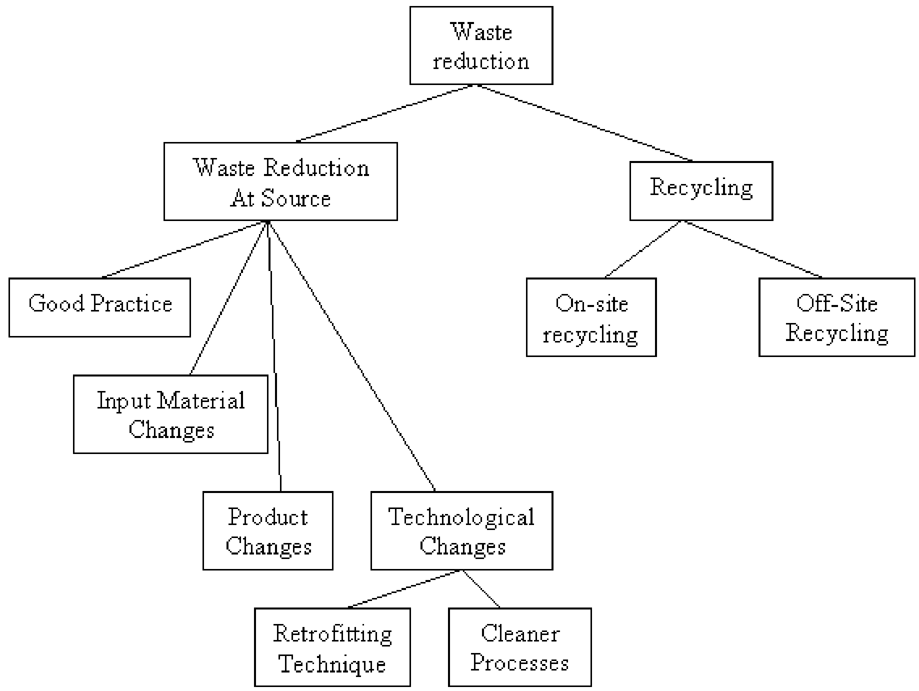
Good operational practice involving management is exemplified by company which adopted a corporate policy to minimize the hazardous waste generation, can often be implemented relatively quickly at minimal capital cost and with short playback.

Product changes with the use of less hazardous materials (input changes) can lead to a significant reduce in waste generation. Product reformulation is not an easy task as some hazardous material has own unique property. For example, lead can use to shield radiation.

Technological changes involve retrofitting technique and cleaner processes in order to reduce waste generation. The modification may involve the installation new or modified processes and equipment.

Resources recovery. Waste recovery is the last viable approach within waste reduction hierarchy. It may carry out on-site or off-site. Onsite recovery may involve reusing the recovered materials as raw materials. Keoleian & Menercy (1993) has found that the volume of waste could be further reduced if the waste materials were to be "downcycled" from its original product cycle to another product cycle with less demanding requirements (see Figure 7-1). One of the most basic and frequent application of on-site waste recycling is the distillation of spent solvent. The waste residue may be either processed for further recovery or handled by another company (off-site recovery). Off-site recovery is usually practiced amongst small organizations. The success of recycling program may depend on an available market for recovered materials.

Figure 7-2: Hazardous Waste Minimization Technique



(Source: Crittenden & Kolaczkowski 1995)

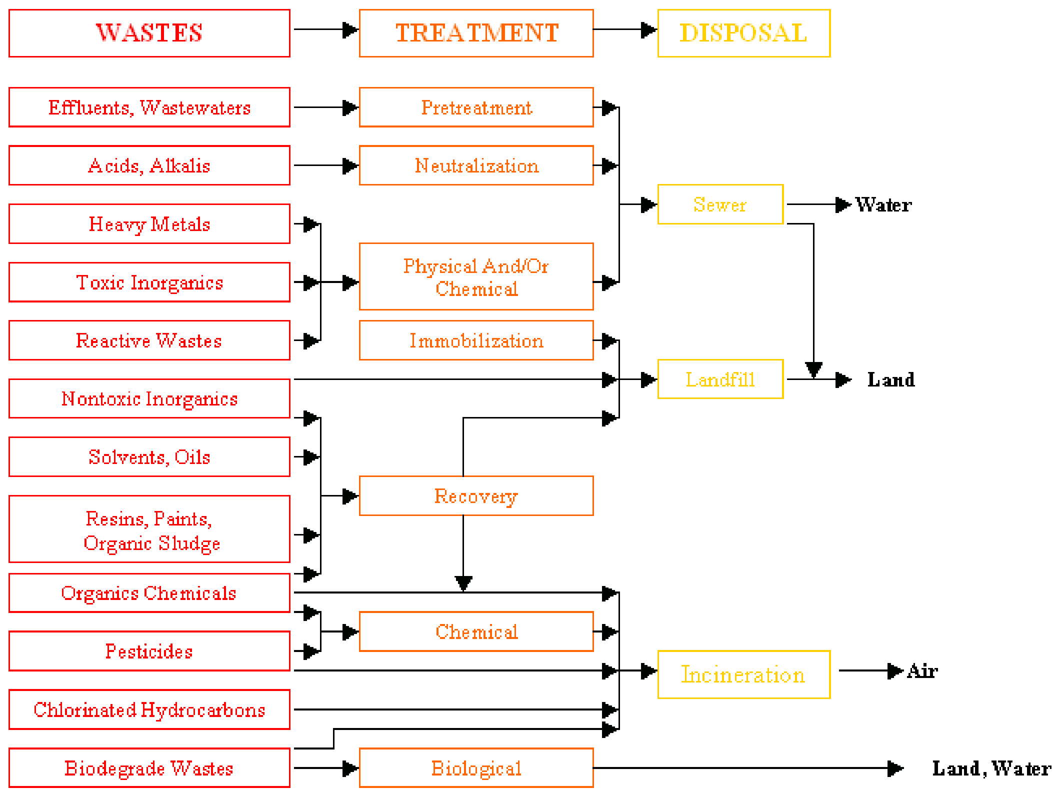
7.4 Hazardous Waste Treatment

Treatment of hazardous wastewater and solid waste by electronics manufacturers themselves, is an important aspect. First, some materials can be reclaimed through the treatment of waste and wastewater. Second, it can lighten the municipal waste burden – reduce municipal disposal cost. Final, if regulations were to mandate electronics manufacturers to treat their waste themselves, they would try to reduce the generation of waste and its toxicity through waste minimization approach.

In Singapore, electronics manufacturers are encouraged to treat their wastewater to the stipulated standards as defined in Appendix B before it can be discharged into public sewer. They are charged a fee if their trade effluents exceed the TSS and BOD level stipulated in the TER. The tariff, can be found in Appendix C, based on the concentration of the TSS and BOD and the volume of effluent discharge, is levied to recover the higher cost incurred in treating the excess pollution loads at sewage treatment work.

Hazardous waste is first treated prior to final disposal. Hazardous waste treatment is the application of physical, chemical, or biological process to hazardous waste or contaminated material (irregardless the order of application, depend on waste constituent, sometimes a combination of three applications are used), to permanently reduce the quantity of toxic chemical to a small fraction of the original amount and render it non-hazardous or less hazardous form. As a result, the waste is neutralized, energy or material resources may be recovered from waste, or the treated waste may be less hazardous and more manageable for storage or disposal. A hierarchy of general waste management options can be constructed as shown in Figure 7-3. The most desirable option, of course, would be source reduction through process modification or product design.

Figure 7-3: Treatment And Disposal Methods For Industrial Wastes



(Source: Wentz 1989).

7.4.1 Physical Treatment Methods

Physical treatment involves the removal of semi-solid or soluble hazardous waste from other process wastewater for subsequent special handling. The waste is not detoxified but only concentrated for further treatment or ultimate disposal. It separates components of a waste stream or changes the physical form of the waste without altering the chemical structure of the constituent materials. Separation is a cost-effective process and it is the most straightforward means of physical waste treatment. In wastewater treatment, the segregation is aided by mechanical means of **screening, sedimentation, centrifugation, air floatation, carbon absorption, filtration, air and steam stripping, reverse osmosis,** and **ultraviolet radiation.**

Screening is a process whereby the wastewater is sifted through a screen to remove debris. It is usually the initial step in wastewater treatment and is used to protect the downstream processes.

Sedimentation is accomplished by gravity settling of particle matters in a treatment tank where the wastewater is held in quiescent state. Harleman (1991) concludes that the addition of chemical coagulating agents such as alum and lime before sedimentation promotes flocculation of fine suspended matter into more readily settle flocs and sustains the high removal efficiency over a wide range of removal rates. Settled sludge is periodically removed from the bottom for further treatment or disposal.

Centrifugation involves physical separation of sludge particles from solution based on relatively density. It is effectively identical to gravity settler (sedimentation) except the centripetal force used is many times stronger than gravity. Centrifugation is often used to dewater sludge prior to disposing.

Air floatation is achieved by releasing very fine air bubbles that attach to low-density particles and hydrocarbons from wastewater and rise to the surface, where they are removed by skimming. Floatation is use when suspended particles have a settling velocity so low that they are not settleable in sedimentation tanks. Vrablik (1960) makes an extensive study of the three different processes by which floatation may be caused:

- Adhesion of a gas bubble to a suspended liquor or solid phase;
- Trapping of gas bubbles in a floc structure as the gas bubble rises. And;
- Absorption of a gas bubble in a floc structure as the floc structure is formed.

Carbon adsorption is the binding of organic and inorganic compounds to carbon atoms. The absorption is analogous to adhesion. Activated carbon is an excellent absorbed for both organic and inorganic compounds including VOCs from both air and water stream. The organic/inorganic compound accumulates at the interface because of physical binding of the molecules to the carbon surface as it passes the carbon. The carbon needs to regenerate whenever it is saturated.

Heating the carbon above the boiling point of the absorbed organic/inorganic compound to desorb the volatiles can regenerate spent carbon. These volatiles can then be either disposed of in an incinerator or passed through a condenser and collected as a useable liquid. Carbon regeneration may be costly than simple replacement with new carbon. Spent carbon will leach back its bound substances into the solution and is not easily distinguished from new ones.

Filtration is the separation and removal of residual suspended solids including the unsettled microorganisms from a wastewater by passing the wastewater through a porous medium such as a bed of sand. Removing microorganisms also reduces the biochemical oxygen demand. Filter medium acts as an impassable barrier that collects residual suspended solids but which allows liquid to pass through.

Air and steam stripping utilize the transfer of organics from the liquid phase in to the gas phase. Air stripping of VOCs (sometimes semi-volatile compounds) occurs in aerobic systems. CO_2 and VOCs are emitted to the surrounding through the breaking down of carbonaceous material. VOCs are given almost in every process in semiconductor industry as in detail in Chapter 5. Steam, rather than air, is used as the stripping gas in treating very concentrated VOCs because a very higher temperature is required to remove higher concentration VOCs. The U.S. EPA, Office Of Underground Storage Tanks (1988) claims the packed tower is able to produce greater than 99.9 percent removal efficiency for wastewater contaminants.

Dupont, Thoeodore & Ganesan (2000) observes that the efficiency of air stripping depends upon a variety of conditions including:

- The volatility of the compounds to be removed from the water expressed by the chemical property *Henry's Law* (estimated by the vapor pressure or water solubility;

- The contact efficiency between the contaminated water and the injected air/water (affected by the configuration of the air stripper and the air/water ratio). And;

- Water temperature (affecting a compound's Henry's Law.

Reverse osmosis involves the flow of solution through a semi-permeable membrane that acts as a barrier against dissolved salt, organic, or inorganic molecules with a molecule mass higher approximately 10 Dalton (Dalton: mass of a hypothetical atom with an atom mass 1 on the chemical mass scale). On the other hand, the water molecule can pass through the membrane and constitutes the product stream. The process, the last second phase of treating wastewater, can be used to produce high purity water from aqueous salt wastes. It is normally used to produce ultra-pure water in the semiconductor industry. However, the use of reverse osmosis to reduce high concentrations of organics and inorganics solids is limited.

Lonsdale & Podall describe some limitations of membrane:

- Flux decline is serious with high-flux membranes;
- Certain species are inadequately rejected, for example, boric acid, phenol and nitrates. And;

Ultraviolet radiation, the last phase of treating wastewater, uses ultraviolet light to disinfect the water. The ultraviolet light spans the wavelength of 200 to 390 nm. The ultraviolet radiation involves no chemical handlings and oxidation of compounds, do chlorine and ozone systems, thereby greatly minimizing chemical safety concern. A proper dosage of ultraviolet is an effective bactericide and virucide, and does not contribute to the formation of toxic compounds (U.S. EPA, Office Of Wastewater Enforcement And Compliance 1992). Ultraviolet radiation, rather than chlorine and ozone, is normally to sanitize the water to rinse the wafer in semiconductor industry.

7.4.2 Chemical Treatments

Chemical treatment processes are used to detoxify the semi-liquid hazardous waste by altering the chemical properties of the constituents of the waste to produce either an innocuous or less toxic by-products prior to transport or disposal. The processes include **oxidation and reduction, precipitation, ion exchange,** and **neutralization,**

Oxidation and reduction can be used for treating and removing a variety of inorganic and organic wastes - render hazardous waste to less toxic. An oxidation-reduction reaction, also known as redox reaction, is one that involves the transfer of electrons. Oxidation reaction increases the valence of an ion with a loss of electrons. Reduction reaction decreases the valence with a gain of electrons.

Oxidation and reduction technique is good at treating cyanide-bearing wastewater in electronics industry as cyanide is widely used in PWB manufacture (U.S. EPA, Office of Pollution Prevention and Toxics, Design for the Environment 1995). The cyanide-bearing waste is destroyed by oxidation with chlorine or hydrochlorite solution under alkaline conditions to avoid the generation of hydrogen cyanic gas. Highly toxic sodium cyanide is first oxidized to a less toxic sodium cyanate, and then re-oxidizes to non-toxic nitrogen gas and carbon dioxide (Wentz 1989).

$$\mathbf{NaCN + Cl_2 + 2NaOH \rightarrow NaCNO + 2NaCl + H_2O}$$

(Na-cyanide) (An alkali) (Na-cyanate)

$$\mathbf{2NaCNO + 3Cl_2 + 4NaOH \rightarrow 2CO_2 + N_2 + 6NaCl + 2H_2O}$$

Highly toxic hexavalent chromium is first reduced to a less toxic trivalent chromium with sulfurous acid, and then precipitate with slaked lime to chromium hydroxide, which is far less toxic (Wentz 1989).

$$SO_2 + H_2O \rightarrow H_2SO_3$$

(Sulfurous acid)

$$\mathbf{2CrO_3 + 3H_2SO_3 \rightarrow Cr_2\,(SO_4)_3 + 3H_2O}$$

(trivalent Cr)

$$\mathbf{Cr_2(SO_4)_3 + 3Ca(OH)_2 \rightarrow 2Cr(OH)_3 + 3CaSO_4}$$

(Cr-hydroxide, trivalent)

Precipitation is always used to treat heavy metal such lead and mercury in untreated wastewater from the electronics industry. Lead is widely used in making CRTs and PWBs, and mercury is commonly used in making batteries and PWBs (MCC 1996). Precipitation is a pH adjustment process in which certain chemicals are added to liquid hazardous waste that cause undesirable heavy metals to form a precipitate, which can be easily removed. Alkaline agents, such as lime or caustic soda, are added to precipitate heavy metal by raising the pH of the solution, which in turn reduce the solubility of the heavy metal. Heavy metal ions precipitate out of solution as hydroxide.

Ion exchange is a process whereby inorganic (such as arsenic – a dopant in semiconductor) or organic contaminants are removed as the wastewater passes over a resin bed, which exchanges ions for the ionic contaminants to be removed. The resins are inorganic or organic matters or liquid that contain movable ions and are able to exchange these with other ions of the same parity. The exchange takes place in aqueous solutions in which ion exchange resins are basically insoluble. Special designed resins are able to remove specific cations and anions from the solution.

When the bed becomes saturated with the exchanged ion, it can be regenerated by exposure to a concentrated solution of the original ion, causing a reverse exchange. This process is used to remove toxic metal ions from solution to recover concentrated metal for recycling. Ion exchanger is usually produced deionized water in semiconductor industry. The demerit of this process is flow rate has to be kept to minimum to obtain maximum ion exchange.

Neutralization, also known as pH adjustment, is a process for reducing the acidity or alkalinity of a waste stream by mixing acids and bases to produce a neutral solution (pH 6-8). Dupont, Thoeodore & Ganesan (2000) state that some common neutralizing wastes include:

- Mixing acidic and alkaline streams together;
- Passing acid wastes through packed beds of limestone;
- Mixing acid waste with lime slurries;

- Adding solutions of concentrated bases such as caustic soda and soda ash to acid streams;
- Passing waste flue gas from a boiler through alkaline waste liquid. And
- Adding acids such as sulfur acid or hydrochloric acid to alkaline waste stream.

Sulfuric or hydrochloric acid is relatively inexpensive acid for neutralizing spent alkaline cleaning solution in electronics industry, but excess acid would produce highly acidic products.

7.4.3 Biological Treatments

Biological treatment utilizes the action of living microorganism to degrade and render hazardous waste (all forms except gaseous pollutants) or treated waste by physical, chemical or a combination of both into a less toxic or non-hazardous material, and some metal can be recovered especially bioremediated with plants. Hence, biodegradation of the hazardous constituents is a viable waste management nowadays. Microbes utilize the organic matters as food for their growth and survival. Depending on application, the cultures used can be indigenous microbes, adapted microbes, and genetically modified microbes. The possible processes include **bioremediation, phytoremediation,** and **landfarming.**

Bioremediation is a process whereby organic hazardous waste, such as chlorinated solvent used as a cleaning solvent in semiconductor, is degraded by microorganisms through utilization or transformation of the substances - break them down into less toxic or non-toxic materials. In principle, there are two processes: aerobic digestion and anaerobic digestion. The microorganisms, include bacteria, algae, and fungi, utilize the organic matter as nutrients for their growth and survival. The microorganisms may be indigenous to a contaminated area or they may be isolated from elsewhere and brought to the contaminated site. The process is highly dependent on biodegradability and bioavailability of contaminants as well as environmental conditions including pH, temperature, and nutrient availability. Bioremediation can be effective only where environmental conditions permit microbial growth and activity; its application often involves the manipulation of environmental parameters to allow microbial growth and degradation to proceed at a faster rate.

Bouwer et al. (1994) find that bioremediation can be an attractive, environmentally friendly, and relatively cost-effective option as compare to conventional physicochemical soil and water treatment techniques. However, like other technologies, bioremediation has its own limitations. The range of contaminants on which it is effective is limited, the time scales involved are relatively long, and the residual contaminant levels achievable may not always be appropriate. For example, some contaminants, such as chlorinated organic aromatic hydrocarbons, are resistant to microbial attack. They are degraded either slowly or not at all, hence it is not easy to predict the rates of clean up for a bioremediation exercise

Microbes are not the only species that can be enhanced by genetic modification for bioremediatory purposes. Plants have also been studied and used. Bioremediation by plants is called phytoremediation.

Phytoremediation is the use of certain green plants to clean up soil, sediment, and water contaminated with heavy metals and/or organic contaminants such as solvents and polyaromatic hydrocarbons (use make to wire insulation).

Phytoremediation is evolving as a cost-effective green technology alternative to high-energy, high-cost conventional methods and when properly implemented is both environmentally friendly and aesthetically pleasing to the public. It is best suited for in situ and ex situ application. It cleans up over a wide area, with contaminants in low to medium concentrations. If the concentration of contaminants is too high, phytotoxicity results, with no or poor plant growth. Remediation with plants is a lengthy process, which might take several years or longer to clean up a highly contaminated site. Nevertheless, the plants can then be harvested and process for their metal content. Maureen (1997) finds that alpine pennycress will absorbs zinc, cadmium and nickel.

7.4.4 Thermal Treatments

Heating hazardous waste to some elevated temperatures can bring about changes on biological, chemical, and physical properties of the constituents of waste to produce either an innocuous or less toxic by-products prior to disposing in a landfill. Thermal disposal of hazardous waste (or post-treated wastes) can be used to reduce the volume of waste; detoxify the hazardous waste; destroy pathogenic waste (post-treated waste with biological method); and reclaim some energy. Thermal disposal methods include **gasification, incineration,** and **wet air oxidation.**

Gasification is a process that utilizes heat, pressure, and steam to convert hazardous oil-bearing secondary materials (organic waste) directly into materials composed primarily of carbon monoxide and hydrogen such as hydrocarbon gases (syngas) and liquids, carbonaceous chars, and non-fuel chemical by-products. Syngas is then burnt to produce electricity and heat. Gasification differs from pyrolysis in that oxygen in the form air, steam or pure oxygen is reacted at high temperature (1500^oC and above) with the available carbon in the waste to produce a gas product, ash and tar product.

Incineration, the most conventional thermal process of waste disposal, is a high-temperature burning process whereby combustible wastes are reduced to inert residues (ashes). The primary products from combustible organic wastes are carbon dioxide, inert ash, and water vapor. However, there are a multitude of other products such as dioxin than can be formed. High temperatures (over 900^oC) will decompose or oxidize organics compounds. Temperatures over 1100^oC will vitrify soils. Hazardous wastes incinerators may include rotary kiln, fluidized bed incinerators, fixed-hearth incinerators, and liquid injector incinerators, are available for burning wastes in either solid, sludge or liquid form. Grasso (1993) finds that rotary kiln incinerators are the most common type since they are designed to handle large waste volumes with large particle size, and residence times can be increased to ensure complete oxidation.

The main advantage of incineration is that it reduces the volumes. Incineration of waste with energy recovery would be the preferred option for sustainable disposal of hazardous waste as the costs of running cum maintaining it are extremely expensive. An example would be the flue gas emissions from the emissions from the incinerators require extensive clean-up using a variety of systems such as electrostatic precipitators, scrubbers and bag filters to remove the potentially highly toxic pollutants. The flue gas treatment systems are expensive, and consequently disposal cost via incineration are high and can represent between 10 and 50 times the equivalent cost of landfill depending on the degree of hazard associate with the waste. The flue gas harm local populations and pollute groundwater.

Wet air oxidation, the patented Zimmerman process, destroys a wide range of organic, oxidizable inorganics such as cyanide and hazardous industrial wastewater by oxidizing to carbon dioxide and water with the addition of air oxygen in aqueous dispersion in enclosed reactor at a temperature range of 175-327^{o}C and pressure range of 300-3000 psig.

7.4.5 Waste Immobilization/Stabilization And Solidification

Immobilization, a viable approach in management and disposal of hazardous waste, after usually enhances the handling and physical properties of wastes by isolating them from their environment through physically cum chemically means. Immobilization processes can include solidification and stabilization with Portland cement, fly ash, and silicate materials, sorption to a solid material.

Stabilization and **solidification** techniques are viable in-situ and ex-situ treatment options, which accomplish one or more of the following objectives for liquid hazardous wastes (Cullinene and Jone1985)

- Improve waste handling or physical characteristics;
- Decrease action surface for contaminant transfer or loss. And;
- Limit contaminant solubility or toxicity.

Wastes that may require stabilization and solidification treatments include wastewater treatment residues and incinerator ash. They are very effective at immobilizing most heavy metals present in sludge. But they are ineffective against toxic organic material such as mercury.

Solidification is the production of monolithic treated waste with high structural integrity, and does not necessarily involve a chemical interaction between the contaminants and the solidifying additives. It may involve, sorption onto solid material, reaction with cement or silicates, encapsulation in thermoplastic or organic polymers, and evaporation of aqueous wastes. Precipitated waste can be solidified with Portland cement or fly ash to form cementitious products, for example.

Stabilization converts hazardous waste to a less soluble, mobile, and/or toxic form through the addition of materials. It generally increases the volume of waste but in conjunction with solidification the treated waste can be more easily and safely transported to a disposal facility, and can be disposed of in a conventional landfill.

7.5 Disposal Technologies For Hazardous Waste

Waste disposal technologies are the last vital link in the cradle-to-grave hazardous waste management. Ultimately, regardless of the treatment technologies (such as immobilization, biodegradation, or incineration) used and the success in treating hazardous waste, there will always remain a residue from hazardous waste that must be sent to disposal. Should the treatment have been succeeded, the residue will always be benign and easily be disposable. However, this is not the case as Murphy's Law is always in action. **Landfill** and **secure landfill** are typical examples of land disposal.

Landfill involves in burying of wastes in the ground and historically has been the most efficient way of disposing of solid hazardous waste and some liquids but it is now severely limited in many developed countries by regulations.

Secure landfill is the repository for all hazardous waste residues where the site is equipped with double liners and capped with watertight impermeable barrier to prevent leakage or leaching. For maximum safety, leachate detection and collection, and a network of monitoring wells for sampling of ground water are to build in.

7.6 Disposal Of Obsolete Product And Off-Specification Product

There are a few methods of disposing of obsolete products in electronics industry. First, the leased products would be take back by their owners once the lease term has ended. The leaser may re-lease their products (the leased items may new) to industry once their contracts are renew. The take back items might recycle. Second, the obsolete item can be used as trade-in commodity for new products. Finally, obsolete item can be sold to some of the E-Waste dealers in Singapore (the list of dealer can be found in Table 5-6). They will then dispose of according to the dealers' strategies.

As off-specification manufactured products, the manufacturers will either contract with recycling companies to handle them or recycle them themselves.

7.7 Conclusions

There is no fixed methods of disposing of wastewater, semi-solid or solid wastes. Wastes should first segregated into non-hazardous, flammable, hazardous, explosive and corrosive before treating them. After segregation, wastes should be treated according to its nature. For example, should the waste be very acidic, lime or caustic soda is to add to neutralize it first before treating it further.

Disposal technologies could not be considered the last phase of waste management. The waste management is not a linear process; it is a cyclical process. The collected leachate from a secure landfill needs to go through the waste treatment process for further treatment, for example. It seems like there is always some residue left after each treatment or even disposal, no matter what sophisticated technologies are used. Such fact also applies to management of obsolete or off-specification electronics, even with the design for environment (DfE) electronics with EOL strategies incorporated in it. Therefore, the cycle of waste management would only come to an end if we as a consumer could stop buying.

In a nutshell, waste treatment or disposal technologies only transfer the waste's toxin from one place to another and concentrate it to particular place where it is more manageable. However, some malpractices, such open incineration, ocean incineration on board a vessel and dumping into oceans, actually disperse the waste's toxin into the ocean and hope that the eco-system will "consume" the toxin for them.

8 EXTENDED PRODUCER RESPONSIBILITY IN THE ELECTRONICS INDUSTRY

8.1 Introduction

Environmental care in electronic industry has already existed for few decades. Although there were legislations, regulations and voluntary commitment to abate pollution, the aim focus had been on production processes.

In early the 1990s, environmental issues in the electronics and computer industry have been getting more attention, particularly about the extensive use of some toxic substances. The detrimental effect of emission to air, water and soil during all stages of a computer's life cycle is recognized as a global scale.

Up to date, costs from design, manufacture to sell a product is solely borne by OEMS, while governments and consumers are left with cost of disposal. Sadly to say, as the ownership of electronics shifts from resource extractor, OEM, retailer and to the final consumer - responsibility for waste, pollution and destruction at each stage also shifts.

To close up the loop of the product life cycle, extended producer responsibility (EPR) is phased in. EPR emerged as a concept to incorporate negative externalities from product use and EOL in product costs. OECD Working Party On Pollution Prevention And Control (1999) claims that EPR is 'an environmental policy approach where the producers' responsibility, physical and/or financial, for a product is extended to the post consumer stage of a product's life cycle'. It means that producers are made responsible for environmental effects over entire product life cycle – cost of compliance cannot be shifted to a third party and must thus be incorporated in product costs.

As EPR gains ascendancy in sustainable development, proper management of the life cycle of a product is becoming more and more important. Life cycle assessment (LCA) was developed to identify and evaluate the full environmental burdens that arise from products throughout their life cycle to meet the growing demand by large institutional purchasers to buy greener electronics or rather DfE with EOL strategies incorporated in it.

8.2 Life Cycle Assessment

LCA is a holistic methodology for identifying and evaluating the full environmental burdens that arise from product throughout their life cycle from cradle-to-grave, including raw material extraction, processing, transportation, manufacturing, distribution, use, maintenance, recycling and waste treatment (U.S. EPA Office of Research and Development 1993), thereby increasing resource-use efficiency and decreasing liabilities. It was developed to assist environmental analysis of technical systems, and is extremely useful when we consider the overall impact of products and assess its sustainability. LCA's four key elements are based ISO 14040 to 14043 (NAHB Research Center, Inc. 2001):

- **ISO 14040.** Environmental management – Life cycle assessment – Principles and framework: Specifies the general framework, principles, and requirements for conducting and reporting life cycle assessment studies, but does not describe the life cycle assessment technique in detail;

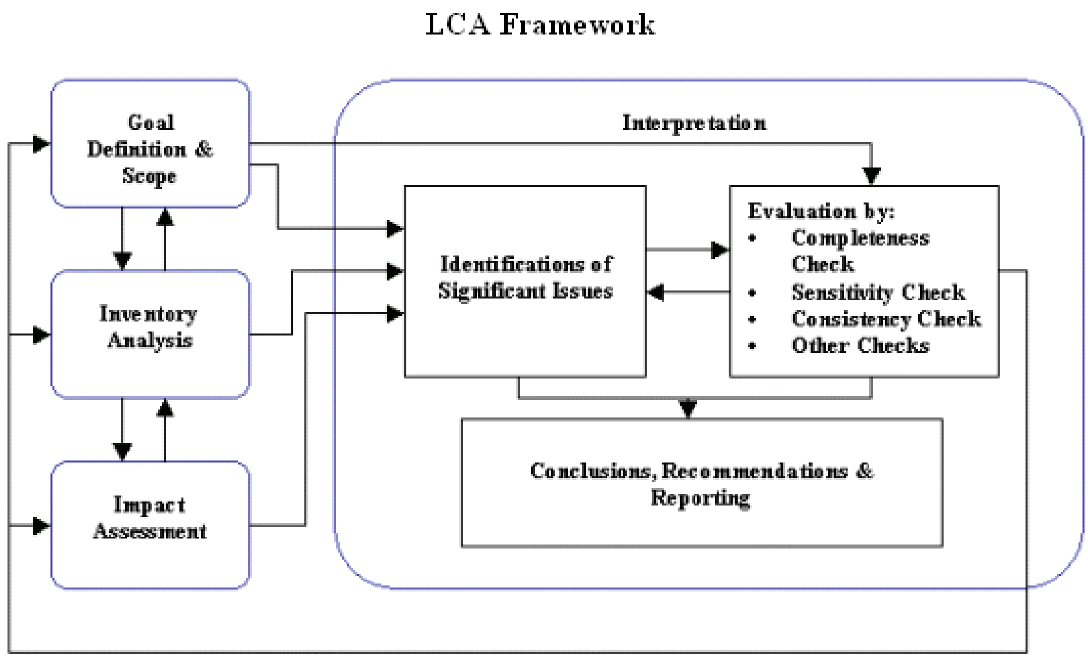
- **ISO 14041.** Environmental management – Life cycle assessment – Goal scope and definition and inventory analysis: Specifies the requirements and procedures for the compilation and preparation of the definition of goal and scope for an LCA and for performing, interpreting, and reporting a life cycle inventory (LCI) analysis;

- **ISO 14042.** Environmental management – Life cycle assessment – Life cycle impact assessment: Describes and gives guidance on the general framework for the life cycle impact assessment (LCIA) phase of LCA, and the key features and inherent limitations of LCIA. It specifies requirements for conducting the LCIA phase and the relationship of LCIA to other LCA phases. And;

- **ISO 14043.** Environmental management – Life cycle assessment – Life cycle interpretation: Provides requirements and recommendations for conducting the life cycle interpretation in LCA or LCI studies. It does not describe specific methodologies for the life cycle interpretation phase of LCA and LCI studies.

The LCA framework with the above 4 mentioned key elements are illustrated in Figure 8-1. The completeness, sensitivity, and consistency of the data are evaluated in the life cycle interpretation.

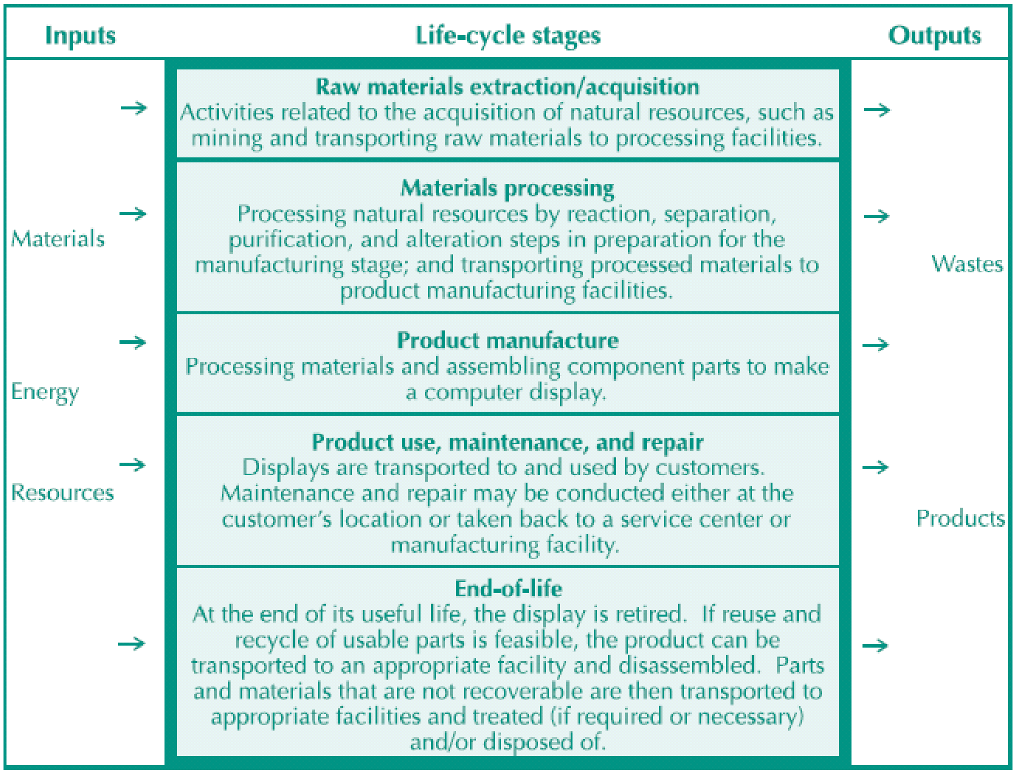
Figure 8-1: Relationship Of Interpretation Steps With Other Phases Of Life Cycle Assessment



(Source: ISO 1998)

Figure 8-2 describes generically the possible life cycle stages (the raw material extraction, processing, manufacturing, distribution, use, maintenance, recycling and EOL) of a computer display that can be considered in an LCA and the typical inputs/outputs measured. The decision made concerning the life cycles stages can be influenced by critical decision made during product design. Impact assessment includes both modeling the natural systems and cause effect chains there in, and weighting, which takes values held in the social system into account.

Figure 8-2: Life Cycle Assessment Of A Computer Display



(Source: U.S. EPA Office of Research and Development 2004.)

Criticisms of the LCA methodology focus on conflicts between depth and applicability. For example, Rose (1998) criticizes LCA has limited applicability because, as a holistic approach, it requires delineation of all environment effects irrespective of their position in the life or their origin. However, LCA may evaluate the effects that a product has on the environment over the entire period of its life and assess its sustainability that is not considered historically. MCC (1996) jots down some points needed to take not when using LCA to analyze environmental impact and eco-efficiency:

- LCA is one of a number of environmental management/DFE tools and should be used in conjunction with other tools and techniques;

- The scope/system boundaries of the LCA is subjective and dependent upon a number of variables (e.g., target of the LCA);

- The potential subjectivity of assumptions and choices within the LCA framework may limit the models used for the LCA;
- The applicability of results is often limited to the original scope (e.g., cannot globally apply results of an LCA conducted in a small town or for one product);
- Relevant data is limited and collection techniques may not be adequate, thereby affecting the accuracy of results. And;
- The LCA process and results are complex and may not lend themselves to a simplified conclusion.
- At each stage, there is waste that is treated or untreated before dispose of. Keoleian & Menercy (1993) has found that the volume of waste could be reduce if the waste materials were to be "downcycled" from its original product cycle to another product cycle with less demanding requirements (see Figure 7-1). For example, white paper to printout paper to packaging material.

Harada & Miyamoto (2003) have conducted a LCA to evaluate the environmental loads such carbon dioxide (CO_2) emission from second-generation cellular phone networks and personal handphone system networks in Japan. The result was concluded that networks with small number of higher power base stations produced lesser CO_2 than those networks with larger number of lower power base stations. EPSON (2005) also claimed that through LCA, they are able to enhance the product's environmental performance and promote the disclosure of environmental information that meets the various needs of their customers around the world.

8.3 Design For Environment

DfE provides a unique opportunity to make critical interventions early in the design stage to eliminate, avoid or reduce downstream environmental impacts unlike in the past, electronics design has been based on a correct-by-verification approach, in which the environmental ramifications of a product (from the manufacturing process through disposition) are not considered until the product design is complete (MCC 1996). DfE, an integral component of the Design for X paradigm, covers all life cycle stages including material extraction, manufacturing, transportation usage and EOL phases. It aims to avoid or minimize significant environmental impacts and increase resource efficiency at all stages of a product's life cycle. Carolien (1998) finds that there are numerous DFE strategies and principles can be introduced during the design stage, including:

- Selection of low-impact materials. This includes materials that have reduced impacts throughout their life cycle, low energy content materials and material that are recyclable;

- Reduction of material use. This refers to reducing material weight and volume in the design of products;

- Optimization of production techniques. This includes utilizing cleaner production techniques, eliminating where possible production steps, and production practices that use less energy and consumables and produce less waste;

- Optimization of distribution system. This includes optimization of distribution and logistics from an energy perspective and more environmentally sound packaging;

- Reduction of use phase impacts. This includes designing products, which use less energy, can run on cleaner forms of energy use and less consumables;

- Optimization of initial lifetime. This refers to increasing the reliability and durability of the product, designing products with modular or adaptable components, and ensuring ease of maintenance and repair;

- Optimization of end-of-life system. This refers to using design to increase the opportunities for recycling, reuse or remanufacturing. It also includes consideration of the safe ultimate disposal of the product. And;

- A final design strategy or principle is related to new product or concept development. Under this principle designers are encouraged to produce products which lead to less material use (dematerialization), to pursue shared product use, (e.g. rental services), to integrate product functions (e.g. combined scanner, printer, copier, fax) and to optimize functions (e.g. better design to reduce over packaging). New concept development is ideally where each new product development process should begin.

Al-Okush, Caudill & Thomas (1999) give several aspects of DfE which are applicable to Electronics. There are:

- **Material conservation.** Can materials use be minimized by improved mechanical design?;

- **Energy conservation.** Is the product designed to minimize the use of materials whose extraction is energy intensive?

  Has the product been design to minimize energy use wile in service?

Is the product designed to minimize the use of energy-intensive process stem in disassembly?

Is the product designed for reuse of materials while retaining their embodied energy?;

- **Environmental burdens.** Has manufacturing gaseous emissions been minimized to the greatest extent possible?

- **Service extensive.** Are subassemblies designed for ready maintainability rather than solely for disposal after malfunction? Are modules designed for ready removal?. And;

- **Demanufacturing.** Are all plastic components identified by IS0 markings as to their content?.

Environmental compatible products minimize the adverse effects on the environment resulting from the manufacture, use and disposal. Engineers should maintain the quality and function of the product, while changing the product design to prevent or reduce impacts, To be most effective, DFE should begin at the earliest conceptual stages of design and continue through preliminary engineering to final design. Fundamental to DfE is the use of LCA to identify the key environmental aspects of products throughout the product life cycle. Table 8-1 provides an overview of obstacles and success factor on DfE approach. The obstacles are often compounded by unfamiliarity with environmental issues among product development personnel, and a lack of reliable data on environmental impact of materials needed for tradeoff decisions.

Table 8-1: Overview Of Obstacles And Success Factors On Design For Environment Approach

	Success factors	Obstacles
Relevance for dissemination of ecodesign information to appropriate people in appropriate departments	• Customized ecodesign tools tailor made for company's needs • In general good contacts between departments about environmental issues • Good international network • Good management commitment and support • Clear environmental goals and vision • Alignment of operational and strategic dimensions • Use of environmental checkpoints, reviews, milestones and roadmaps • Presence of a so-called 'environmental champion' • Cross-functional teamwork • Environmental design guidelines, rules and standards that are very specific to a company	• Available tools are too complex • Organizational complexities, lack of appropriate infrastructure • Lack of cooperation between departments • Too big a 'gap' between ecodesign promoters and those that have to execute it • Lack of management commitment and support • Lack of environmental goals and vision for the development organization as a whole • Lack of industrial context in general/ not connecting environmental with business considerations
Relevance for ecodesign principles materializing in products brought on market	• Market research • Ecodesign considerations early in the product development process • Inclusion of environmental issues in our company's technology strategy • Adopting a strong consumer focus, good market research • Goals & targets at managerial level • Training consumers and customers in environmental issues • Good involvement of supplier expertise in product development process • Environmental issues play a role in all business activities • Good environmental education and training programs for all product development personnel • We make good use of examples of good design solutions, also from other companies. • Use of environmental checkpoints, reviews, milestones and roadmaps • Presence of a so-called 'environmental champion' • Cross-functional teamwork • Environmental design guidelines, rules and standards that are very specific to the company • Follow up studies; learn from previous experiences on a systematic way	• A lack of life-cycle thinking • Organizational complexities • Lack of innovative thinking • Lack of testing • Lack of experience • Lack of appropriate marketing studies • Issues too much material-related • Issues too much addressed in terms of end-of-life or recyclability • Too little involvement of sales and marketing departments • Because of supply chain problems • No demand from the market • Lack of follow-up of projects • Lack of time/too time-consuming • Lack of (quality of) data • Not enough legislative incentives • Lack of environmental goals and vision for individual development projects

(Source: Boks & Pascual 2004)

Achieving good eco-design in electronics may involve different actions on the part of managers of electronics companies. Some of these according to Pascual, Stevels & Boks (2003) are:

- Define clear goals about materials and energy use;
- Supplying staffs with constant training. And;
- Providing staffs with latest design tool such as software;

8.4 End-Of-Life Management Of Products

EOL management describes a set of feasible options available to a product after its useful life. EOL attempts to recover reusable material from EOL products through the six recovery options described by Rose (2000) well as reducing the volume EOL products being disposed of:

- **Reuse.** Reuse is the second hand trading of product for use as originally designed.
- **Service.** Servicing the product is another way of extending the life of a durable product or component parts by repairing or rebuilding the product using service parts at the location where the product is being used.
- **Remanufacture.** Remanufacturing is a process in which reasonably large quantities of similar products are brought into a central facility and disassembled. Parts from a specific product are not kept with the product but instead they are collected by part type, cleaned, inspected for possible repair and reuse. Remanufactured products are then reassembled on an assembly line using those recovered parts and new parts where necessary.
- **Recycling with disassembly.** Recycling reclaims material streams useful for application in products. Disassembly into material fractions increases the value of the materials recycled by removing material contaminants, hazardous materials, or high value components. The components are separated mostly by manual disassembly methods.
- **Recycling without disassembly.** The purpose of shredding is to reduce material size to facilitate sorting. The shredded material is separated using methods based on

magnetic, density or other properties of the materials.

- **Disposal.** This end-of-life strategy is to landfill or incinerate the product with or without energy recovery.

The environmental impact of products increases from reuse to disposal. Materials that are not recovered from any of the above mentioned strategies will be disposed of either through landfill or incineration in an environmentally sound manner in accordance with regulations set by legislative. Rose (1998) also has illustrated how the EOL strategy depends on the characteristics of the products and the effectiveness of EOL is to maximize the usability of recovered material from EOL product. Despite that, the ultimate aim of the EOL is to minimize the environmental impact by reducing the volume of products being disposed of. EOL also helps to reduce the depletion of virgin materials through material recovery and reuse. Material recovered can be used to produce new or other products. The useful life of the faulty product is extended slightly.

This type of management has its own constraints too. Firstly, reuse repair or working obsolete products may be good approach but it poses some problems. For example, Griese (1999) quote some constraints of secondhand PC market in Germany such as availability of compatible new software for older PC is limited, availability of used PCs for resale is limited, and used PCs have to come with quality assurance, and reliable services and supports from retailers. Hence, to minimize these constraints, stronger retailer-customer relationship needs to be fostered.

Reimer, Sodhi & Knight (2000) discuss the economic problems of recycling electronic products in the U.S. and suggest that generally, the profit from component recovery is low because of high labor cost despite the recovery of gold and silver in the recycling, and the recycler would make a loss in cases of wastes containing hazardous materials such cadmium and lead. They also show that the ratio of profit to cost of a materials recovery process varies throughout the normal process and is negative for several stages in the process.

Resale refurbished products in the Third World countries (such resale is not popular in developed countries) may improve business. But ethically, we are "dumping" or "exporting" our trash (used products) to the people of that country; thereby liability would pass to the recipient. Such export is legal in worldwide unless the products are disassembled in parts. At the end of product's useful life, the responsibility of disposing of it would then fall in the hands of the Third World countries unless OEMs are willing to take back their products at no charges. Worst of all, the hazardous materials found in the reuse parts are not removed – they will still pose the same environmental and health impacts when they are disposed of. Secondly, the quality in term of useful life and performance of new products might be lowered since certain parts are reuse. Thirdly, perhaps the obsolete products were not designed for recyclability in the first place. Finally, some reused parts might be obsolete due to technologically advances and innovation.

The success of EOL management is wholly dependent upon collection of information associated with EOL products. However, much of the information is often irrecoverable after the point of sale (Thomas, Neckel & Wagner 2003). Sometimes, it is the producers that refuse to give because they do not wish leak their trade secrets to any ones. Moreover, the product may make up of more than one producer around the globe. The worst of it is that components or parts may not have labels indicated their identification.

Increased environmental awareness amongst environmentalist, customer, people and government, and legislative developments have compelled HP to focus more on the product EOL management. The HP approaches are donation, trade-in, asset recovery and leasing (HP 2005).

- **Donation.** HP aids consumers to donate their working computer to charitable organization. A fee of US$13 to 34 will be imposed upon the consumer to have their computers (any brand) pickup (Waste News. 2001) in the U.S.. HP also provides some country with Post Reply Paid labels on their web site to allow customers to mail used laser jet print cartridges and drum kits back to HP for recycling at no charge.

- **Trade-In.** Consumers may trade-in their used HP products for upgrading to new HP products while receiving credit for the value of the used equipment. It is applicable only to selected products or models, and on special occasion (such on exhibition or the launch of new product). The credit might include purchasing of new designated HP product at a discountable rate, for example. Trade-in products will be management according HP's recycling standards.

- **Asset recovery.** In this HP's asset recovery program, corporate customers' used qualifying computer products may be take-back by HP for cash or credit. All company data and identification are removed prior to recycle or reuse.

- **Leasing.** HP leases computers and printers to business customers around the globe. HP has the obligations to design its product fully recyclable as the lease term ends all loan equipments are take back to recycle.

The above approaches are subjected to vary from country to country. Donation on behalf of consumer with a fee imposed upon the consumer – such program will not be overwhelmed. Consumer would rather throw their products into a trash bin or sell them to second-hand dealer. Trade-in used products for upgrading to new a product while receiving credit for the value of the used equipment may be good initiative. But it is applicable only to selected products or models, and on special occasion (such on exhibition or the launch of new product).

8.5 Eco-Label

Eco-label or environmental label serves as a guide to consumers that helps them make informed environmental choices about the products and services that they require. It sets criteria for products and services that avoids detrimental effects on the environment. Its initiative is to ensure that OEMs and their products meet environmental performance standards and gain recognition on market for the work they have done. ISO classifies environmental labels into three categories: **Type I** (**ISO 14024**), **II** (**ISO 14021**) and **III** (**ISO 14025**). The general criteria used to select product categories for eco-label as follows:

- Minimal environmental impact from use;

    1. significant potential for improvement in the environment by using the product;

    2. minimal environmental impact from disposal after use. And;

3. other significant contributions to the environment.

- Additional criteria that are required for approval include:

1. appropriate pollution control measure at the product manufacture;

2. ease of treatment for disposal of product;

3. energy conservation during the use of the product. And;

4. compliance with regulations and standards for quality and safety.

Table 8-2 indicates the various attributes that have been certified for various computer products under specified eco-label. If OEMs' products meet the required standards, they will receive a particular eco-label based on test protocols. The main benefits of environmental benchmarking of products include awareness raising, learning from others, environmental improvement option generation, and facilitation of embedding environmental activities in business processes (Boks & Stevels 2003). EPSON (2005) is looking into compliance with Eco Mark, Blue Angel and other Type I environmental labels used in other countries.

Table 8-2: Environmental Labeling and Certification Declaration Programs

Environmental Labeling and Certification Declaration Programs								
	Type I Eco-Labels					Environmental Declaration Formats		
	Blue Angel (Germany)	White Swan (Nordics)	TCO'95 (Sweden)	TCO '99 (Sweden)	Eco Mark (Japan)	ECMA TR/70	NITO (Nordics)	PC Green Label (Japan)
Products Covered								
Personal Computer Workstations	X	X	X	X	X	X	X	X
Notebook Computers	X	X	X	X	X	X	X	X
Monitors	X	X	X	X	X	X	X	X
Printers	X	X		X	X	X	X	
Keyboard/Mouse	X			X	X	X		X
Issues Covered								
Hazardous Substances	X	X	X	X	X	X	X	X
Use of Hazardous Materials - Plastics	X	X	X	X	X	X	X	X
Use of Hazardous Materials - Product Packaging	X	X	X	X	X	X	X	X
Use of Hazardous Materials - Monitors/CRTs	X	X	X	X	X	X	X	X
Batteries - Hazardous Materials Content	X	X	X	X	X	X	X	X
Batteries - Easy Removal	X				X		X	X
Batteries - Labeling	X				X	X	X	X
Product Chemical Emissions	X					X		
Finishes	X	X			X		X	X
Energy Efficiency	X	X	X	X	X	X	X	X
Acoustics	X	X	X	X	X	X	X	X
Electromagnetic Compatibility (EMC)	X	X	X	X	X	X	X	X
Electromagnetic Fields	X			X		X		
Modularity/Upgradeability	X	X			X	X	X	X
Design for Assembly/Disassembly	X	X			X	X	X	X
Use of Fewer Materials	X	X	X	X	X		X	X
Labels	X	X			X			X
Marking/Coding of Plastic Parts	X	X	X	X	X	X	X	X
Use of Recycled Materials	X				X			X
Product "Takeback"	X	X		X	X	X	X	X
Ergonomics	X	X	X	X			X	
Product Safety	X	X	X	X	X		X	X
Product Warranty	X				X			X
Environmental Certification (ISO 14001 or EMAS)				X		X	X	

(Source: Electronic Product Environmental Assessment Tool. 2003

8.6 Design For Energy Efficient

The main environmental impact for a computer is related to the electrical energy consumption necessary to power-up the device. Electrical energy is even being consumed when they turned off because of lacking of energy in "standby" and "sleep" mode. The EPA study estimated that 90 percent of energy used in ICT product over its life is consumed in "standby" mode, and an European Commission study estimated that "standby" mode consumption of electricity at 5-15 percent (Matthews 2003). Thus achieving maximum energy efficiency is of top priority. The most widespread is the U.S. EPA's Energy Star, which sets criteria for energy efficiency. HP has more than 300 office products including computers, monitors, printers, scanners, and multifunction device are accredit to U.S. EPA's ENERGY STAR® and nearly all eligible LaserJet products meet and carry the German Blue Angel eco-label (HP 2002). In addition, HP is replacing mercury-containing lamps in some scanners with light-emitting diodes. Philips (2005) aims to offer consumers products with superior environmental performance, including minimal energy use in standby mode or lower energy consumption during use, compared to predecessor products or commercial competitors such as the introduction of backlight in LCD. The EPSON's objective and testing performance of various printers, scanners and LCD projector in energy saving can be found in Table 8-3.

Table 8-3: Energy-Saving Design Objectives and Results

Product group	Energy-saving objective	FY2003 result
Inkjet printers	Low-energy mode power consumption: 50% lower (based on the PM-970C)	↘92• • PX-G900• •
Impact printers	Power consumption/day: 10% lower (based on the FX-2170)	↗137• • FX-2190• •
Page printers	Power consumption/day: 10% lower (based on the LP-7100)	↗100• • LP-6100• •
Scanners	Low-energy mode power consumption: 10% lower (based on the GT-9800F)	↗101• • GT-X700• •
Printers with scanners	Low-energy mode power consumption: 10% lower (based on the CC-600PX)	↗165• • CX-6400• •
POS printers	Standby mode power consumption: Below 1 W	↗100• • TM-P60• •
LCD projectors	Power use per unit of brightness: Below 20 W/100 lm	↗133• • EMP-S1• •

(Source: EPSON 2005)

8.7 Hazardous Substances

Selection of materials is one the most crucial step in a product design or development stage. Which chemicals or materials are used can influence how consumers perceive a product and its impact on human health and the environment. HP (2005d) will try to eliminate lead, mercury, cadmium and hexavalent chromium in 100 percent of electronic products sold worldwide as defined by the European Union’s restriction of the use of certain hazardous substances Directive by 2006. JVC (2005) has been abolished the use of ozone depleting substances such as specified chlorofluorocarbons and alternatives for chlorofluorocarbons, in addition to 1,1,1-trichloroethane from production processes since 1994.

Some OEMs often make available information regarding the use of certain hazardous materials or chemicals in the products environmental declaration through their web site. Consumers can also find that information through accredit eco-label for that product.

8.8 Packing Reduction

The packaging of products play a multitude of roles in handling, communication of messages to the consumers, creating a brand image and theft prevention but the environment as well. The environmental impacts caused by disposal of packaging are sometimes neglected. These issues should be mapped out in detail before starting reduction operations. Environmentally sound packaging seeks to increase handling while addressing the environmental concerns that surround product packaging. The program ensures compliance with applicable regulations, and creates packaging that utilizing environmental friendly virgin material with high post consumer recycled content that can be recycled at the end of its useful life

Computers were packaged in expanded polystyrene or polystyrene foam. This material is declining as a packaging choice as it dose not degrade. HP (2005) 'developed molded foam cushion with built-in accessory trays to protect products shipment and to conserve natural resources – increases the number of PCs per pallet by 33 percent, ultimately conserving fuel energy and reducing vehicle emissions.' Philips (2005) claimed that packaging materials in 2004 decreased by 7 percent, in compared terms with respect to 2001.

8.9 Design For Recycling And Design For Disassembly

Environmental strategies are best addressed at the design strategy, where there is the most freedom to consider all issues, much emphasis has been placed on design methodologies. To ease the management of EOL products, one example is to incorporate the concept of Design-for-recyclability (DfR) with design-for-disassembly (DfD) ability. DfR means both design for easy disassembly and design with recyclable contents. DfD would increase scrap value by facilitating the product and its parts to be easily reused, re-manufactured or recycled at end of life. New design concept is not only necessary to avoid increased regulation and potential liability, but to maintain competitiveness in a marketplace full of increasingly environmentally conscious consumers. The EU directive on Waste Electrical and Electronic Equipment stated that the information technology and telecommunication and consumer equipment the recycling rate (reuse) is targeted at 65 percent and the rate of recovery shall be increased to a minimum of 75 percent by an average weight per appliance.

In a study of various electronics recycling facilities in the U.S., Kirchain & Atlee (2004) found that the fraction of lifecycle energy saved by recycling was:

1. 8.6 percent if some parts were reused;
2. 5.2 percent if some products were upgraded. And;
3. 0.43 percent if materials were recycled.

With that growing concerns of an appropriate disposal method of used products, HP came up with their DfR features. They are (HP 2005):

- Modular design to allow components to be removed, upgraded or replaced;
- Eliminating glues and adhesives, for example, by using snap-in features;
- Marking plastic parts weighing more than 25g according to ISO 11469;
- International standards, to speed up materials identification during recycling;
- Reducing the number and types of materials used;

- Using single plastic polymers;

- Using molded-in colors and finishes instead of paint, coatings or plating. And;

- Relying on modular designs for ease of disassembly of dissimilar recyclable materials.

Griese et al. (2004) illustrate an oxygen supplying machine, Oxymat, for people with breathing problem, which was re-designed to improve its ability to be refurbished. A major improvement was to reduce the number parts and of different materials used as shown in Table 8-4. In the new design, assembly time was reduced by 50 percent, disassembly time by 80 percent and maintenance by 80 percent, hence, producing not only an environmental benefit but also an economic benefit.

Table 8-4: Overview Of Obstacles And Success Factors On Design For Environment Approach

	Conventional Design	**New Design "Design For Refurbishment"**
Parts	293	125
Different Parts	148	101
Material	47	15
Recyclable Plastics	14	10
Not Recyclable Plastics	14	2
PWB	4	1
Warranty	1 year	3 years compressor and PWB
Lifetime Compressor	5 h	25 h
Assembly Tools	46	9

(Source: Griese et al. 2004)

Eco-design has its own limitation. For example, Pascual & Boks (2004) conclude that the performance of Japanese electronics manufacturing companies in eco-design is currently less than satisfactory in several ways, namely:

- With the compiled information, economic benefits of eco design practices can not been assured.

- Stricter definitions on guidelines would lead to better comparability between companies environmental accounting performance.
- Economic effects (monetary units) of related investments are in a immature stage

and need further research.

8.10 Conclusions

If consumers were to pay to have their obsolete electronics collected by OEMs, they would rather throw them in a trash bin or sell them to second-hand dealer. The dire consequences are:

- If dumped into a trash bin, it would increase the burden of disposing of municipal solid wastes. Consumer would have to pay more in disposing of municipal solid wastes in the end.

- If sold to second-hand dealer, the dealer would refurbish them before selling to the Third World countries – it is like exporting them (E-Waste) except through a legal mean; thereby liability would pass to the recipient. OEMs would then have more difficulties in taking them if they were interested.

Refurbish obsolete products may be good approach but it is just a temporary measure as the hazardous materials found them are still present, and they would leach out when dispose of. And resale such products in a Third World country should not be encouraged unless the OEMs are willing take back their products at the end of their useful life at no charge at consumers.

Obsolete products take back in a form trade-in business should be encourage because it can provide numerous benefits to business as well as improve consumer satisfaction. For example, old model products can be clear off the shelf, which in turn, improves business and warehouse space. The models may be old but consumer can purchase them at a discountable price and may include other free gifts. The OEMs should impose less stringent conditions on such program.

DFE should begin at the earliest conceptual stages of design and continue through preliminary engineering to final design, and LCA should be incorporated to identify the key environmental aspects of products throughout the product life cycle. EOL strategies should be incorporated into the design too. Since nearly all-possible environmental impacts are known, OEM should then explore all means to root them out. However, they are more interested in increasing the speed of the central processing unit of a computer and building it in the smallest chip area than replacing the hazardous material with non-hazardous material, for example. Worst of all, faster speed would inevitably consume more electricity even the chip areas is reduced.

If LCA were to be completely identified all possible environmental impacts of a product through its life cycle, would the OEMs be able phase out the chemicals used to make it and replace all processes that emit pollutants? DfE would only be maximized once the above two tasks are fulfilled.

Irregardless of the merits of the electronic product environmental assessment tools that are integrating environmental considerations into core business functions such as strategy, product development, sales and marketing, supply chain management, procurement, capital expenditures and interactions with investors and financial markets, there is still plenty of room for improvement as the development at present does not turn out amiable. One area, in particular, that it is important to the future of the industry is the support and promotion of highs standards of environmental quality and compliance.

9 CONCLUSIONS

The Earth is the only place where humans and animals are living but most of the human activities involving the manufacture, use and disposing of electronics are destroying their place of living, because electronics have become a part and parcel of our life, especially the people living in advanced countries.

Singapore is one of world largest manufacturer of electronics. In 2004 Singapore exported US$136.993 billions worth of electronic commodities, integrated circuits, color televisions, picture tubes, cathode ray tube, TV camera tubes, ink cartridges, printed wiring boards, personal computers, and etc.

Empirical evidence regarding the health and environmental impacts caused by the Singapore electronic industry in term production is meager as the volume of import and export good is not recorded. These figures are useful in estimating the impact caused by disposing of EOL product.

The manufacture of electronics has the highest environmental impact as some hazardous chemicals used or by-products are being released into the environment. Also during the manufacture, lots of natural resources have been consumed such as virgin materials, water and fossil fuel that generates electricity. For example, based on Williams, Ayers & Hellers (2002), a wafer area of 1 centimeter square consumes 1.5 Kilowatts hour of electricity, and water use of 20 liters while producing 17 Kilograms of wastewater and 7.8 Kilogram of solid wastes. Beside that, air pollutants such CO_2 and CFCs are also emitted from the manufacture. CFCs would destroy stratospheric ozone and CO_2 is known to cause global warning. The impact is not simply contributed by semiconductor industry alone, it may comprise of other industries associated in the supply chain for semiconductor industry as well.

The disposal of electronics industrial wastewater and solid wastes could pose some severe impacts on human health and the environment since a variety of hazardous chemicals are used in the manufacture. Hence, treatment, storage and disposal facilities are the vital link in the cradle-to-grave hazardous waste management system in electronics industry

Treatment of hazardous wastewater and solid wastes by electronics manufacturers themselves, is an important aspect. First, some materials can be reclaimed through the treatment of waste and wastewater. Second, it can lighten the municipal waste burden – reduce municipal disposal cost. Final, if regulations were to mandate electronics manufacturers to treat their waste themselves, they would try to reduce the generation of waste and its toxicity through waste minimization approach.

The use of electronics also consume vast amount of electricity. The fossil fuel required to generate electricity for the use of electronics could severely deplete the sources of fossil fuel.

Disposing of end-of-life electronics and could pose some severe impacts on human health and the environment when they are not well managed as many parts of electronics are made up hazardous materials such beryllium, brominated flame retardants, cadmium, chromium, lead and mercury. Lead and mercury are found in PWBs, for example. Exposure to some of these hazardous materials may damage human health. For example, chronic beryllium disease may cause death and increase the risk of developing lung cancer in people, and acute beryllium disease may include rashes and ulcers.

Puckett et al. (2002) accuse the U.S. and many other rich nations which use most of the world electronic products and generate most of the E-Waste, rather than having to face the problem squarely, have made use of a convenient, and until now, hidden escape valve – exporting the E-Waste crisis to the developing countries of Asia such as China, India and Pakistan by flouting the international laws, the Basel Convention.

The amended Basel Convention prohibits the OECD countries from exporting the hazardous E-Waste to non-OECD countries for final disposal (Secretariat Of The Basel Convention, United Nations Environment Programme n.d).

Therefore, improvements in current technologies in electronics industry are needed to reduce environmental burden by reducing or phasing out these hazardous chemicals. Continuous improvement in these rather settling a precise threshold to be obtained. Companies can also set their own pace and focus attention on the most cost-effective improvements.

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APPENDIXES

Appendix A – Project Specifications

University of Southern Queensland

Faculty of Engineering and Surveying

ENG 4111/4112 Research Project
PROJECT SPECIFICATION

FOR:	TEO KIAN PENG
TOPIC:	ELECTRONICS AND THE ENVIRONMENT – SINGAPORE PERSPECTIVE
SUPERVISOR:	Mr. DAVID PARSONS
ENROLMENT:	ENG 4111 - S1 2005; ENG 4112 - S2 2005
PROJECT AIM:	The project aims to find out the impacts of electronic products during manufacture, during useful life and after their end of useful life have had on the environment and human health when they are not well managed in Singapore and some countries in Asia.

PROGRAMME: <u>**Issue B, 11th October 2005**</u>

1. Evaluate the size and significant Singapore electronics industry;
2. Identify the environmental impact of various aspects of the Singapore electronics industry;
3. Document the relevant environmental regulations adopted in Singapore;
4. Document the current practices in other country regarding disposal of obsolete equipment;
5. Assess the possible ways in which better environmental management might be implemented in the electronics industry;
6. Review and critique the strategies being suggested by some of the world larger electronic original equipment manufacturers for better overall management of electronics industry environmental impact.

AGREED:

______________ (Student) ______________ (Supervisor)

11/10/2005

Appendix B – Allowable Limits For Trade Effluent Discharged Into A Public Sewer, Watercourse And Controlled Watercourse In Singapore

Items Of Analysis	**Public Sewer**	**Watercourse**	**Controlled Watercourse**
	Units in milligram per liter or otherwise stated		
Temperature of discharge	45ºC	45ºC	45ºC
Color		7 Lovibond Units	7 Lovibond Units
PH Value	6-9	6-9	6-9
BOD (5 days at 20ºC)	400	50	20
COD	600	100	60
Total Suspended Solids	400	50	30
Total Dissolved Solids	3000	2000	1000
Chloride (as chloride ion)	1000	600	400
Sulphate (as SO4)	1000	500	200
Sulphide (as sulphur)	1	0.2	0.2
Cyanide (as CN)	2	0.1	0.1
Detergents (linear alkylate sulphonate as methylene blue active substances)	30	15	5
Grease and Oil		10	5
Grease and Oil (Hydrocarbon)	60		
Grease and Oil (Non-hydrocarbon)	100		
Arsenic	5	1	0.05
Barium	10	5	5
Tin	10	10	5
Iron (as Fe)	50	20	1
Beryllium	5	0.5	0.5
Boron	5	5	0.5
Manganese	10	5	0.5
Phenolic Compounds (expressed as phenol)	0.5	0.2	
*Cadmium	1	0.1	0.01
*Chromium (trivalent and hexavalent)	5	1	0.05
*Copper	5	0.1	0.1
*Lead	5	0.1	0.1
*Mercury	0.5	0.05	0.001
*Nickel	10	1	0.1
*Selenium	10	0.5	0.01
*Silver	5	0.1	0.1
*Zinc	10	1	0.5
*Metals In Total	10	1	0.5
Chlorine (Free)		1	1
Phosphate (As PO4)		5	2
Calcium (As Ca)		200	150

Magnesium (as Mg)		200	150
Nitrate (NO3)			20

***** The concentration of Toxic Metal shall not exceed the limits as shown, individually or in total.**

'Controlled Watercourse' means a watercourse from which potable water supplied by Public Utilities Board (PUB) under the Public Utilities Act is obtained but does not include a watercourse from which water is pumped into a main of the PUB.

The trade effluent discharged must not include: -

(1) Calcium carbide;
(2) Petroleum spirit or other inflammable solvents;
(3) Materials that may give rise to fire or explosion hazards;
(4) Materials that may be a hazard to human life, a public nuisance, injurious to health or otherwise objectionable;
(5) Refuse, garbage, sawdust, timber, or any solid matter;
(6) Pesticides, fungicides, insecticides, herbicide, rodenticide or fumigants. And;
(7) Radioactive material.

The trade effluent discharged into a public sewer must not include rainwater, storm water, ground water or other form of street drainage, subsurface drainage, roof drainage or yard drainage.

The trade effluent shall be analyzed in accordance with the latest edition of 'Standard Methods for the Examination of Water and Wastewater' published jointly by the American Water Works Association and the Water Pollution Control Federation of the United States.

(Source: Singapore National Environment Agency 2004.)

Appendix C – Trade Effluent Tariff Scheme In Singapore

The fees to be levied for discharge of biodegradable trade effluent into the public sewers are as follows:

Concentration (mg/l)	**Fee at S$ per cubic meter or part thereof**	
	BOD (5 days at 20°C)	**TSS**
400 - 600	0.21	0.15
601 - 800	0.42	0.30
801- 1000	0.63	0.45
1001 – 1200	0.84	0.60
1201 – 1400	1.05	0.75
1401 - 1600	1.26	0.90
1601 - 1800	1.47	1.05
1801 – 2000	1.68	1.20
2001 – 2200	1.89	1.35
2201 - 2400	2.10	1.50
2401 – 2600	2.31	1.65
2601 – 2800	2.52	1.80
2801 – 3000	2.73	1.95
3001 - 3200	2.94	2.10
3201 – 3400	3.15	2.25
3401 – 3600	3.36	2.40
3601 – 3800	3.57	2.55
3801 - 4000	3.78	2.70

(Source: Singapore National Environment Agency 2004.)

Appendix D – Standard Of Concentration Of Air Impurities In Singapore

Substance	**Trade, Industry, Process, Fuel Burning Equipment Or Industrial Plant**	**Emission Limits**
Ammonia and ammonium compounds	Any trade, industry or process	76 mg/Nm^3 expressed as ammonia
Antimony and its compounds	Any trade, industry or process	5 mg/Nm^3 expressed as antimony
Arsenic and its compounds	Any trade, industry or process	1 mg/Nm^3 expressed as arsenic
Benzene	Any trade, industry or process	5 mg/Nm^3
Cadmium and its compounds	Any trade, industry or process	3 mg/Nm^3 expressed as cadmium
Carbon monoxide	Any trade, industry, process or fuel burning equipment	625 mg/Nm^3
Chlorine	Any trade, industry or process	32 mg/Nm^3
Copper and its compounds	Any trade, industry or process	5 mg/Nm^3 expressed as copper
Dioxins and furans	Any waste incinerator	1.0 ng TEQ/N Nm^3 for waste incinerators commissioned before 1st Jan 2001 0.1 ng TEQ/N Nm^3 for waste incinerators commissioned on or after 1st Jan 2001
Ethylene oxide	Any trade, industry or process	5 mg/Nm^3
Fluorine, hydrofluoric acid or inorganic fluorine compounds	Any trade, industry or process	50 mg/Nm^3 expressed as hydrofluoric acid
Formaldehyde	Any trade, industry or process	20 mg/Nm^3
Hydrogen chloride	Any trade, industry or process	200 mg/Nm^3
Hydrogen sulphide	Any trade, industry or process	7.6 mg/Nm^3
Lead and its compounds	Any trade, industry or process	5 mg/Nm^3 expressed as lead
Mercury and its compounds	Any trade, industry or process	3 mg/Nm^3 expressed as mercury

Oxides of nitrogen	Any trade, industry or process or fuel burning equipment	700 mg/Nm^3 expressed as nitrogen dioxide
Particulate substances including smoke, soot, dust, fly-ash, cinders, cement, lime, alumina, grit other solid particles of any kind	Any trade, industry, process, fuel burning equipment or industrial plant (except for any cold blast foundry and cupolas)	100 mg/Nm^3; or where there is more than one flue, duct or chimney in any scheduled premises, the total mass of the particulate emissions from all of such flue, duct or chimney divide by the total volume of such emissions shall not exceed 100 mg/Nm^3 and the particulate emissions from each of such flue, duct or chimney shall not exceed 200 mg/Nm^3 at any point in time.
Smoke	All stationary fuel-burning sources	Ringelmann No. 1 or equivalent opacity (not to exceed more than 5 minutes in any period of one hour)
Styrene monomer	Any trade, industry or process	100 mg/Nm^3
Sulphur dioxide (non-combustion sources)	Any trade, industry or process	500 mg/Nm^3
Sulphur trioxide and other acid gases	The manufacture of sulphuric acid	500 mg/Nm^3 expressed as sulphur trioxide. Effluent gases shall be free from persistent mist
Sulphur trioxide or sulphuric acid mist	Any trade, industry or process, other than any combustion process and any plant involving the manufacture of sulphuric acid	100 mg/Nm^3 expressed as sulphur trioxide
Vinyl chloride monomer	Any trade, industry or process	20 mg/Nm^3

The concentration of any specified substance (1st column) emitted from any specified operation in any trade, industry, process, fuel burning equipment or industrial plant (2nd column) shall not at any point before mixture with air, smoke or other gases, exceed the specified limits (3rd column).

"dioxins and furans'' means polychlorinated dibenzo-p-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF), being tricyclic and aromatic compounds formed by 2 benzene rings which are connected by 2 oxygen atoms in PCDD and by one oxygen atom in PCDF and the hydrogen atoms of which may be replaced by up to 8 chlorine atoms;

"mg'' means milligram;
"ng'' means nanogram;

"Nm^3" means normal cubic meter, being that amount of gas which when dry, occupies a cubic meter at a temperature of 0 degree Centigrade and at an absolute pressure of 760 millimeters of mercury;

"TEF'' means Toxic Equivalency Factor.

(Source: Singapore National Environment Agency 2004.)

Appendix E – Hazardous Substances Listed In The 2nd Schedule Of The Environmental Pollution Control Act In Singapore

Hazardous Substances	
Substance	**Exclusion**
Acetic acid	• Substances containing not more than 80%, weight in weight, of acetic acid; • Preparations and solutions for photographic use.
Acrolein	
Alkali metal bifluorides; Ammonium bifluoride; Potassium fluoride; Sodium fluoride; Potassium silicofluoride; Sodium silicofluoride; Silicofluoric acid	• Preparations containing not more than 0.3%, weight in weight, of potassium fluoride in radiator protectors; • Preparations containing not more than 0.96%, weight in weight, of potassium fluoride in photographic chemicals; • Substances containing not more than 3%, weight in weight, of sodium fluoride or sodium silicofluoride as a preservative; • Substances containing sodium fluoride intended for the treatment of human ailments.
Ammonia	• Preparations and solutions of ammonia containing not more than 10%, weight in weight, of ammonia; • Refrigeration equipment; • Photographic and plan developers; • Hair color dyes; • Perm lotions; • Smelling bottles.
Ammonium chlorate	
Ammonium perchlorate	
Acetic acid	• Substances containing not more than 80%, weight in weight, of acetic acid; • Preparations and solutions for photographic use.
Acrolein	
Anionic surface active agents	• Preparations containing less than 5% by weight of anionic surface active agents; • Preparations containing anionic surface active agents which are not less than 90% biodegradable under a test carried out in accordance with that part of the OECD • method which is referred to as "Confirmatory Test Procedure" in European Communities Council Directive No. 73/405/EEC (C) or other equivalent test methods acceptable to the Director.
Antimony pentachloride	Polishes
Carbamates	• Benomyl;Carbendazim;Chlorpropham;Propham;Thiophanate-methyl; • Preparations containing not more than 1%, weight in weight, of propoxur and not containing any other carbamate; • Preparations containing not more than 1%, weight in weight, of methomyl and not containing any other carbamate.
Carbon disulphide	

Carbon tetrafluoride	
Chlorinated hydrocarbons, the following: Aldrin;Benzene hexachloride (BHC); Bromocyclen; Camphechlor; Chlorbenside; Chlorbicyclen; Chlordane; Chlordecone; Chlorfenethol; Chlorfenson; Chlorfensulphide; Chlorobenzilate; Chloropropylate; Dicophane (DDT); pp'-DDT'; Dicofol; Dieldrin; Endosulfan; Endrin; Fenazaflor; Fenson; Fluorbenzide; Gamma benzene hexachloride ; (Gamma – BHC); HEOD [1,2,3,4,10,10-hexachloro-6, 7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1, 4; (exo): 5,8 (endo)-dimethano naphthalene]; HHDN [1,2,3,4,10,10-hexachloro-1,4,4a,5,8,8a-hexahydro-1,4 (exo): 5,8 (endo)-dimethano naphthalene]; Heptachlor; Isobenzan; Isodrin; Kelevan; Methoxychlor [1,1,1-trichloro-2,2-di-(p-methoxyphenyl) ethane]; Tetrachlordiphenylethane; [TDE; 1,1-dichloro-2,2-bis (p-chlorophenyl) ethane]; Tetradifon; Tetrasul; Toxaphene Allied chlorinated hydrocarbon compounds used as pesticides (insecticides, acaricides, etc.)	Paper impregnated with not more than 0.3%, weight in weight, of benzene hexachloride or gamma – BHC provided it is labelled with directions that no food, wrapped or unwrapped, or food utensils are to be placed on the treated paper, and that it is not to be used where food is prepared or served.
Chlorine	Chlorine used for chlorination of water in swimming pools.
Chlorine trifluoride	
Chlorobenzenes, the following: Monochlorobenzene; Meta-dichlorobenzene; Ortho-dichlorobenzene Trichlorobenzene; Tetrachlorobenzene Pentachlorobenzene; Hexachlorobenzene.	
Chlorophenols, the following: Monochlorophenol; Dichlorophenol; Trichlorophenol;	• Substances containing not more than 1%,weight in weight, of chlorophenols.

Tetrachlorophenol; Pentachlorophenol and their salts.	
Chlorophenoxyacids; their salts, esters, amines	
Chloropicrin	
Chlorosilanes	
Chlorosulphonic acid	
Chromic acid	• Substances containing not more than 9%, weight in weight, of chromic acid; • Photographic solutions containing chromic acid in individual containers containing not more than 15 kilograms each of such solutions and of aggregate weight of not more than 500 kilograms of such solutions.
Cyanides	Ferrocyanides; Ferricyanides.
Diborane	
Dibromochloropropane	
Diethyl sulphate	
Dinitrocresols (DNOC); their compounds with a metal or a base	
Dinosam; its compounds with a metal or a base	
Dinoseb; its compounds with a metal or a base	
Diquat; its salts	
Disilane	
Drazoxolon; its salts	• Dressings on seeds.
Endothal; its salts	
Epichlorohydrin	
Ethyl mercaptan	• Substances containing less than 1%, weight in weight, of ethyl mercaptan.
Ethylene dibromide	
Ethylene dichloride	
Ethylene imine	
Ethylene oxide	• Mixtures of inert gases and ethylene oxide comprising not more than 12%, weight in weight, of ethylene oxide contained in cylinders of water capacity less than 47 litres and for aggregate of not more than 3 numbers of such cylinders.
Ferric chloride	
Fluorine	
Fluoroacetamide	
Formaldehyde	• Substances containing not more than 5%, weight in weight, of formaldehyde; • Photographic glazing or hardening solutions.
Formic acid	• Substances containing not more than 5%, weight in weight, of formic acid.
Germane	
Hydrazine anhydrous; Hydrazine aqueous solutions	
Hydrochloric acid	• Substances containing not more than 9%, weight in weight, of hydrochloric acid.

Hydrofluoric acid	• Preparations or solutions containing not more than 2%, weight in weight, of hydrofluoric acid.
Hydrogen chloride	
Hydrogen cyanide; Hydrocyanic acid	• Preparations of wild cherry; • In reagent kits supplied for medical or veterinary purposes, substances containing less than the equivalent of 0.1%, weight in weight, of hydrocyanic acid.
Hydrogen fluoride	
Hydrogen peroxide	• Preparations and solutions containing not more than 20%, weight in weight, of hydrogen peroxide.
Hydrogen selenide	
Isocyanates	• Polyisocyanates containing less than 0.7%, weight in weight, of free monomeric diisocyanates; • Pre-polymerised isocyanates in polyurethane • paints and lacquers; • Hardeners and bonding agents for immediate • use in adhesives.
Lead compounds in paint	• Lead compounds in paint in which the lead content is not more than 0.06% by weight of the paint; • Lead compounds in paint in which the container is affixed with an appropriate label. • The labels to be used for paints containing lead compounds are in accordance with Part IV of the Second Schedule of the EPCA.
Lead tetra-ethyl and similar lead containing compounds	
Lead tetra-ethyl and similar lead containing compounds in petrol intended for use in Singapore as fuel for motor vehicles	
Mercuric chloride; Mercuric iodide; Organic compounds of mercury	• Dressings on seeds or bulbs; Toilet, cosmetic and therapeutic preparations containing not more than 0.01%, weight in weight, of phenyl mercuric salts as a • preservative; • Antiseptic dressings on toothbrushes; • Textiles containing not more than 0.01%, • weight in weight, of phenyl mercuric salts as • a bacteriostat and fungicide.
Mercury and its compounds in batteries	• Batteries other than mercury oxide batteries, zinc carbon batteries containing more than 0.001% by weight of mercury per cell and alkaline batteries, except those in button form, containing more than 0.025% by weight of mercury per cell.
Metanil yellow (sodium salt of metanilylazo-diphenylamine)	• Dye-indicators used in laboratories.
Methyl chloride	
Methyl mercaptan	• Substances containing less than 1%, weight in weight, of methyl mercaptan.
Monomethyltetrachloro diphenyl methane	
Monomethyl-dichloro-diphenyl	

methane	
Monomethyl-dibromodiphenyl methane	
Niclofolan	
Nicotine sulphate	
Nitric acid	• Substances containing not more than 9%, weight in weight, of nitric acid.
Nitric oxide	
Nitrobenzene	• Substances containing less than 0.1%, weight in weight, of nitrobenzene; • Soaps containing less than 1%, weight in weight, of nitrobenzene; • Polishes and cleansing agents.
Nitrogen trifluoride	
Ozone depleting substances, namely: Chlorofluorocarbons, the following: Chloroheptafluoropropane; Chloropentafluoroethane; Chlorotrifluoromethane; Dichlorodifluoromethane; Dichlorohexafluoropropane; Dichlorotetrafluoroethane; Heptachlorofluoropropane; Hexachlorodifluoropropane; Pentachlorofluoroethane; Pentachlorotrifluoropropane; Tetrachlorodifluoroethane; Tetrachlorotetrafluoropropane; Trichlorofluoromethane; Trichloropentafluoropropane; Trichlorotrifluoroethane. Halons, the following: Bromochlorodifluoromethane; Bromochloromethane; Bromotrifluoromethane; Dibromotetrafluoroethane; Hydrochlorofluorocarbons, the following: 1,1-dichloro-1-fluoro-ethane; 1,1-dichloro-2,2,3,3,3-pentafluoropropane; 1,3-dichloro-1,2,2,3,3-pentafluoropropane; 1-chloro-1,1-difluoro-ethane; Chlorodifluoroethane; Chlorodifluoromethane; Chlorodifluoropropane; Chlorofluoroethane; Chlorofluoromethane;	Products containing any ozone depleting substance other than the following products. (a) In the case of chlorofluorocarbons: • Air-conditioners in vehicles registered on or after 1st January 1995 or intended for such vehicles; • Equipment for domestic or commercial refrigeration or air-conditioning installed on or after 1st January 1993, or heat pump equipment, which contains any chlorofluorocarbon substance as a refrigerant or in any insulating material of such equipment; • Refrigerators that have a compressor rating which exceeds one horsepower; • Non-pharmaceutical aerosol products; • Insulation boards, panels or pipe covers; • Polystyrene sheets or finished products; (b) In the case of Halons, portable fire extinguishers; and • in the case of bromotrifluoromethane, fire protection systems with building plans approved after 17th June 1991 and installed after 31st December 1991.

Chlorofluoropropane; Chlorohexafluoropropane; Chloropentafluoropropane; Chlorotetrafluoroethane; Chlorotetrafluoropropane; Chlorotrifluoroethane; Chlorotrifluoropropane; Dichlorodifluoroethane; Dichlorodifluoropropane; Dichlorofluoroethane; Dichlorofluoromethane; Dichlorofluoropropane; Dichloropentafluoropropane; Dichlorotetrafluoropropane; Dichlorotrifluoroethane; Dichlorotrifluoropropane; Hexachlorofluoropropane; Pentachlorodifluoropropane; Pentachlorofluoropropane; Tetrachlorodifluoropropane; Tetrachlorofluoroethane; Tetrachlorofluoropropane; Tetrachlorotrifluoropropane; Trichlorodifluoroethane; Trichlorodifluoropropane; Trichlorofluoroethane; Trichlorofluoropropane; Trichlorotetrafluoropropane; Trichlorotrifluoropropane. Hydrobromofluorocarbons, the following: Bromodifluoroethane; Bromodifluoromethane; Bromodifluoropropane; Bromofluoroethane; Bromofluoropropane; Bromohexafluoropropane; Bromopentafluoropropane; Bromotetrafluoroethane; Bromotetrafluoropropane; Bromotrifluoroethane; Bromotrifluoropropane; Dibromodifluoroethane; Dibromodifluoropropane; Dibromofluoroethane; Dibromofluoromethane; Dibromofluoropropane; Dibromopentafluoropropane; Dibromotetrafluoropropane; Dibromotrifluoroethane; Dibromotrifluoropropane; Hexabromofluoropropane; Pentabromodifluoropropane;	

Pentabromofluoropropane; Tetrabromodifluoropropane; Tetrabromofluoroethane; Tetrabromofluoropropane; Tetrabromotrifluoropropane; Tribromodifluoroethane; Tribromodifluoropropane; Tribromofluoroethane; Tribromofluoropropane; Tribromotetrafluoropropane; Tribromotrifluoropropane; Carbon tetrachloride; 1,1,1-trichloroethane (methyl chloroform); Methyl bromide;	
Oleum	
Orange II [sodium salt of p-(2-hydroxy-1-naphthylazo) benzenesulphonic acid]	• Dye-indicators used in laboratories.
Organic peroxides	• Car puttys; • Substances and preparations containing not more than 3%, weight in weight, of organic peroxides; • Solutions of not more than 60%, weight in weight, of methyl ethyl ketone peroxides and total aggregate weight of less than 50 kilograms of such solutions.
Organo-tin compounds, the following: Compounds of fentin; Cyhexatin.	
Paraquat; its salts	• Preparation in pellet form containing not more than 5%, weight in weight, of salts of paraquation.
Perchloromethyl mercaptan	• Substances containing less than 1%, weight in weight, of perchloromethyl mercaptan.
Phenols, the following: Catechol; Cresol; ydroquinone; Octyl phenol; Phenol; Resorcinol.	• Preparations containing less than 1%, weight in weight, of phenols; • Phenols which are intended for the treatment of human ailments and other medical purposes; • Soaps for washing; • Tar (coal or wood), crude or refined; • Photographic solutions containing hydroquinone in individual containers containing not more than 15 kilograms each of such solutions and of aggregate weight of not more than 500 kilograms of such solutions.
Phosgene	
Phosphides	
Phosphine	
Phosphoric acid	• Substances containing not more than 50%, weight in weight, of phosphoric acid.
Phosphorus compounds used as pesticides (insecticides, acaricides, etc.)	• Acephate; Bromophos; Iodofenphos; Malathion; Pirimiphos-methyl; Temephos; Tetrachlorvinphos; Trichlorfon; • Preparations containing not more than 0.5%, weight in weight, of chlorpyrifos and not containing any other phosphorus compound;

	• Preparations containing not more than 0.5%, weight in weight, of dichlorvos and not containing any other phosphorus compound; • Materials impregnated with dichlorvos and not containing any other phosphorus compound for slow release; • Preparations containing not more than 1%, weight in weight, of azamethiphos and not containing any other phosphorus compound.
Phosphorus oxychloride	
Phosphorus pentachloride	
Phosphorus pentafluoride	
Phosphorus trichloride	
Polybrominated biphenyls	
Polychlorinated biphenyls	
Polychlorinated terphenyls	
Potassium chlorate	
Potassium hydroxide	• Substances containing not more than 17%, weight in weight, of potassium hydroxide; Accumulators; Batteries.
Potassium perchlorate	
Prochloraz	
Propylene imine	
Propylene oxide	
Silane	
Sodium chlorate	
Sodium hydroxide	• Substances containing not more than 17%, weight in weight, of sodium hydroxide; • Made-up formulated preparations either liquid or solid for biochemical tests.
Sodium perchlorate	
Styrene monomer	
Sulphur in diesel intended for use in Singapore as fuel for motor vehicles or industrial plants	• Sulphur in diesel in which the sulphur content is 0.05% or less by weight.
Sulphur tetrafluoride	
Sulphur trioxide	
Sulphuric acid	• Substances containing not more than 9%, weight in weight, of sulphuric acid; • Accumulators; Batteries; Fire extinguishers; • Photographic developers containing not more than 20%, weight in weight, of sulphuric acid.
Thallium; its salts	
Titanium tetrachloride	
Tris (2, 3-dibromo-l-propyl) phosphate	
Vinyl bromide	
Vinyl chloride monomer	

(Source: Singapore National Environment Agency 2004.)

Appendix F – Hazardous Substances Quantities Exceeding Which Transport Approval Is Required In Singapore

Substance	Qty (Kg)	Substance	Qty (Kg)
Acetic Acid	1000	Acrolein	50
Ammonia	500	Antimony Pentachloride	50
Arsenical Substances	50	Boric Acid; Sodium Borate	5000
Boron Trichloride	50	Boron Trifluoride	50
Bromine, Bromine Solutions	50	Captafol	0
Carbamates Except Bendiocard, Bpmc (Fenobucarb), Mercaptodimethur (Methiocarb)	0	Carbon Disulphide	50
Carbon Tetrafluoride	500	Chlorine	500
Chlorine Trifluoride	0	Chlorinated Hydrocarbon Compounds Used As Pesticides	0
Chlorobenzenes	0	Chlorophenols	0
Chlorophenoxyacids	0	Chlorosilanes	50
Chlorosulphonic Acid	50	Chromic Acid	50
Cyanides	50	Diborane	50
Dibromochloropropane	50	Diethyl Sulphate	500
Disilane	50	Epichlorohydrin	50
Ethyl Mercaptan	50	Ethylene Dibromide	0
Ethylene Dichloride	0	Ethylene Imine	0
Ethylene Oxide	50	Ferric Chloride	1000
Fluorine	0	Fluoroacetamide	50
Formic Acid	1000	Germane	50
Hydrazine Anhydrous, Hydrazine Aqueous Solutions	50	Hydrochloric Acid	1000
Hydrocyanic Acid	0	Hydrofluoric Acid	500
Hydrogen Chloride, All Forms	500	Hydrogen Peroxide	1000
Hydrogen Selenide	50	Isocyanates	500
Lead Tetra-Ethyl And Similar Lead Containing Compounds	0	Metanil Yellow (Sodium Salt Of Metanilylazo-Diphenylamine)	5000
Methyl Bromide	50	Methyl Chloride	50
Methyl Mercaptan	50	Monomethyltetrachloro Diphenyl Methane	0
Monomethyl-Dichloro-Diphenyl Methane	0	Monomethyl- ibromodiphenyl Methane	0
Nitric Acid	1000	Nitric Oxide	50
Nitrogen Trifluoride	50	Oleum	50

Orange II (Sodium Salt Of P-(2-Ydroxy-1 Naphthylazo) Benzenesulphonic Acid)	5000	Organic Compounds Of Mercury	0
Organic Peroxides	500	Organo-Tin Compounds: Cyhexatin	0
Perchloro Methyl Mercaptan	50	Phenols	500
Phosgene	0	Phosphides	50
Phosphine	50	Phosphorous Compounds Except Dimethoate, Diazinon, Fenchlorphos, Fenitrothion, Phenthoate, Rofenophos, Prothiophos, Quinalphos	0
Phosphorus Oxychloride	50	Phosphorus Pentachloride	50
Phosphorus Pentafluoride	50	Phosphorus Trichloride	50
Polybrominated Biphenyls	0	Polychlorinated Biphenyls	0
Polychlorinated Terphenyls	0	Potassium Hydroxide	1000
Prochloraz	0	Propylene Imine	50
Propylene Oxide	500	Silane	50
Sodium Hydroxide	1000	Styrene Monomer	1000
#Sulphur In Diesel	-	Sulphur Tetrafluoride	0
Sulphur Trioxide	50	Sulphuric Acid	1000
Titanium Tetrachloride	1000	Tris(2,3-Dibomopropyl)Phosphate	0
Vinyl Bromide	0	Vinyl Chloride Monomer	0

(Source: Singapore National Environment Agency 2004.)

Appendix G – Toxic Industrial Wastes Controlled Under The Environmental Public Health (Toxic Industrial Waste) Regulations 1988 In Singapore

List of Toxic Industrial Wastes
Acids Spent inorganic acids e.g. hydrochloric acid, sulphuric acid, nitric acid, phosphoric acid, hydrofluoric acid, boric acid and pickling acid. Spent organic acids e.g. acetic acid, formic acid, benzoic acid and sulphuric acid.
Alkalis Spent alkaline solutions. Spent ammoniacal solutions. Metal hydroxide sludge and oxide sludge.
Antimony and its Compounds Spent antimony potassium tartrate.
Arsenic and its Compounds Timber preservative residues containing arsenic. Wastes containing gallium arsenide.
Asbestos Asbestos wastes from asbestos/cement manufacturing processes. Empty sacks/bags which have contained loose asbestos fiber.
Cadmium and its Compounds Plating effluents and residues containing cadmium. Wastes containing cadmium from Ni/Cd battery manufacturing.
Chromium Compounds Plating effluents and residues containing chromium. Timber preservative residues containing chromium. Spent and aqueous solutions containing chromium compounds. Tannery effluents and residues containing chromium.
Copper Compounds Plating effluents and residues containing copper. Spent etching solutions containing copper from PWB manufacturing. Timber preservative residues containing copper.
Cyanides Plating effluents and residues containing cyanides. Heat treatment residues containing cyanides. Spent quenching oils containing cyanides. Spent processing solutions containing cyanides from photographic processing.
Fluoride Compounds Timber preservative residues containing fluorides. Spent ammonium bi-fluoride.
Isocyanates Spent di-isocyanates e.g. toluene di-isocyanate and methylene di-isoc-yanate from polyurethane foam making process.
Laboratory Wastes Obsolete laboratory chemicals Toxic chemical wastes from chemical analysis

Lead Compounds
Sludge containing lead oxide/sulphate.
Spent organo-lead compounds e.g. tetraethyllead and tetramethyllead.
Waste lead-acid batteries, whole or crushed.

Mercury and its Compounds
Effluents, residues or sludge containing mercury from chlor-alkali industry.
Wastes containing mercury from equipment manufacturing involving the use of metal mercury.
Spent catalysts from chemical processes containing mercury.
Spent organo-mercury compounds.

Metal Catalysts
Spent metal catalysts from chemical processes and petroleum refining e.g. catalysts containing chromium and cobalt.

Nickel Compounds
Plating effluents and residues containing nickel.

Organic Compounds containing Halogen
Spent halogenated organic solvents e.g. trichloroethylene, 111-trichloroethane, perchloro-ethylene, methylene chloride, tetrachloromethane and 112-trichloro-122-trifluoroethane.
Residues from recovery of halogenated organic solvents.
Packaging materials or residues containing chloro- benzenes and/or chlorophenols and their salts.

Organic Compounds not containing Halogen
Spent non-halogenated organic solvents e.g. benzene, toluene, xylene, turpentine, petroleum, thinner, kerosene, methanol, ethanol, isobutanol, iso-propanol, methyl ethyl ketone, methyl isobutyl ketone, isopropyl ether, diethyl ether, hexane, dimethyl sulphide and dimethyl sulphoxide.
Residues from recovery of non-halogenated organic solvents.

Organic Compounds not containing Halogen
Spent non-halogenated organic solvents e.g. benzene, toluene, xylene, turpentine, petroleum, thinner, kerosene, methanol, ethanol, isobutanol, iso-propanol, methyl ethyl ketone, methyl isobutyl ketone, isopropyl ether, diethyl ether, hexane, dimethyl sulphide and dimethyl sulphoxide.
Residues from recovery of non-halogenated organic solvents.

Other Wastes
Obsolete/abandoned chemicals and pesticides from storage, manufacturing and trading activities
Used containers, bags and process equipment contaminated by chemicals and pesticides from storage, manufacturing and trading activities
Wastes/residues containing un-reacted monomers, i.e. vinyl chloride and styrene monomers, from polymer manufacturing processes
Tar residues from distilling and tarry materials from refining
Wastes from toxic waste treatment processes i.e. wastes and residues from solidification, fixation and incineration processes
Wastes from toxic chemical drums and tank cleaning activities
Chemical and oil slops from ship tankers
Wastes from the production, formulation and use of resins, latex, plasticisers, glues/adhesives containing solvents and other contaminants.
Obsolete/abandoned chemicals and pesticides from storage, manufacturing and trading activities

Pathogenic Wastes Pathogenic wastes from hospitals.
Phenolic Compounds Sludge/residue from paint stripping using chemicals containing phenols. Residues containing un-reacted phenol and formaldehyde from adhesive industry.
Polychlorinated Bi-phenyl (PCB) including Poly-chlorinated Ter-phenyl (PCT) Spent transformer oil containing PCB and/or PCT. Retrofilled transformer contaminated with PCB and/or PCT. Electrical equipment and parts containing or contaminated with PCB and/or PCT e.g. capacitors. and transformers. Containers and all waste materials contaminated with PCB and/or PCT.
Polyvinyl Chloride (PVC). All waste materials containing PVC e.g. PVC insulated wires, PVC pipes and trunking, PVC parts, PVC upholstery and PVC resins.
Silver Compounds Spent processing solutions containing silver from photographic processing.
Used, Contaminated Oil Used mineral, lubricating and hydraulic oil from machine cylinders, turbines, switch gears and transformers. Spent motor oils from petrol and diesel engines. Spent quenching oil from metal hardening. Oil recovered from solvent degreasers. Spent oil water emulsions e.g. Spent coolants from metal working industries. Oil water mixtures (mainly oil) e.g. Oily ballast water from ship tankers. Oil and sludge from oil interceptors. Tanker sludge and oil sludge/residue from storage tanks. Oil sludge containing acid from recovery and recycling of used oil.
Zinc Compounds Plating effluents and residues containing zinc.

(Source: Singapore National Environment Agency 2004.)