A Literature Review on the Environmental and Health Impacts of Waste Electrical and Electronic Equipment

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Preamble

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Executive Summary

Waste electrical and electronic equipment (WEEE) is a diverse waste category, and international opinions regarding the impacts of various substances contained within WEEE vary. This study considers the quality and weight of scientific evidence and reports on the state of knowledge regarding both consensus and diversity in scientific opinion pertaining to these impacts, both internationally, and as applicable to New Zealand.

The aim of the review is to assess the state of knowledge and consensus on the environmental and health impacts of post-consumer WEEE, within the context of New Zealand landfills and potential illegal dumping. The objectives which need to be met in order to achieve the aim are:

- Conduct a literature review of policy developments relative to WEEE internationally, focusing on known relevant case studies, and the underpinning reasons for the developments.
- Use review material to characterise WEEE in New Zealand, within a global context, including the volumes and sensitivities of component types within the definition.
- Conduct a literature review of the state of knowledge regarding the relevant dose-response relationships between WEEE substances, and human health and the environment.
- Collate and analyse evidence in order to draw relevant conclusions regarding the state of knowledge and consensus on the environmental and health impacts of post-consumer WEEE, within the context of New Zealand landfills and potential illegal dumping.

The scope of the review is limited to human and environmental impacts arising when post-consumer WEEE is disposed in landfills or illegally dumped. It does not include the environmental and health impacts from the manufacture/production and consumer use of the components and products, or during WEEE recycling. The scope of each main component of the review is as follows:

- International Policy and Regulation
- WEEE products
- WEEE componentry
- Dose-response.

There is a wide range of means and measures to influence WEEE generation, management and impacts, ranging from restricting its generation through better design, enhancing recycling and reuse schemes, introducing market forces into waste through product stewardship programmes, and more use of classic ‘end of pipe’ solutions such as technically engineered landfills.

Well established principles such as ‘polluter pays’, ‘prevention is better than cure’ and the ‘precautionary principle’ have been applied to such initiatives by various Governments internationally, in the effort to strike a balance between maintaining the benefits of electrical and electronic equipment (EEE) while minimising the environmental and human health costs of WEEE. Such initiatives can be loosely termed ‘policy and regulation’, and range from sponsorship of voluntary schemes to legislation mandating particular courses of action.

In considering the impacts of WEEE and the case for policy and regulation in New Zealand, it is relevant to review initiatives to date. For the purposes of this literature review several countries and regions have been used to describe the connection between policy, WEEE impacts and resulting legislation, directives, regulations and bans. These include: European Union (EU), United States of America (USA), Canada, Japan, and Australia.

While not conclusive, the following jurisdictional overview helps to highlight the breadth of activity in response to WEEE related impacts and issues. In policy terms, the WEEE and Restriction on the use of certain Hazardous Substances (RoHS) Directives place the EU at the forefront of legislative developments.

Through present WEEE management systems, valuable materials are disposed of and lost to future generations through the present methods of waste management of discarded electrical products. Along with the loss of resources, environmental degradation from mining is of concern. It is not possible to give exact figures on the environmental impact of the extraction of all the materials contained in electrical and electronic equipment. This depends very much on the site and region where the materials are extracted.

As indicated in the literature (European Commission, 2000), the risks relating to placing discarded electrical equipment in landfill are due to the variety of substances they contain. Due to the range of different substances in WEEE, unpredictable toxic hazards are potentially created by landfilling. Co-disposal with municipal waste adds to the unpredictability, and spreads the problem. While licensed, controlled landfills with liners do not eliminate risks of pollution, the potential amounts and concentrations – and resulting environmental impacts – are considerably higher when WEEE is put in uncontrolled landfills.

While some studies are several years old, they remain relevant until new evidence is developed, and significantly more research is needed into the toxicity potential of WEEE. Until then, it is prudent to take a precautionary approach; indeed, three well-established principles can be drawn upon to guide policy development in WEEE management:

- **Precautionary principle**; where theory or circumstantial evidence suggests damage potential exists, in the absence of fuller evidence, it is prudent to assume the worst case and legislate accordingly;[1]
- **Prevention is better than cure**; it is cheaper in the long run to prevent risks and impacts from occurring rather than to concentrate entirely on cleaning up problems, so eco-design mechanisms to minimise WEEE generation is a logical approach;
- **Polluter pays principle**; those who create the risks should incorporate the costs of dealing with them into their operating costs, for example, through operating product stewardship programmes.

A major issue for policy formulation in New Zealand is the effect of policies and regulations elsewhere. The EU WEEE and RoHS Directives are already creating considerable industry transformation, and will bring new materials to the market, as well as new industries and techniques for effectively managing the product stewardship and end-of-life implications of the Directives.

[1] Based on overseas risk assessment work due to the absence of a detailed risk analysis specific to New Zealand.

They can also be expected to have effects outside Europe, with more toxic EEE being ‘dumped’ onto markets in countries with less developed policy and regulations.

1. Introduction

1.1 Background and Context

The New Zealand Waste Strategy, published in March 2002, is a long term strategy to help reduce waste, recover resources and better manage residual waste in New Zealand. It covers solid, liquid, gaseous and hazardous waste. The context of this study is policy development designed to deliver the strategy. Specifically, in order to ensure that efforts are directed to wastes where the most benefits can be obtained, and are directed in a manner that best achieves those benefits, it is important that the current state of knowledge regarding the environmental and health impacts of wastes is considered and collated.

Waste electrical and electronic equipment (WEEE) is a diverse waste category, and international opinions regarding the impacts of various substances contained within WEEE vary. This study considers the quality and weight of scientific evidence and reports on the state of knowledge regarding both consensus and diversity in scientific opinion pertaining to these impacts, both internationally, and as applicable to New Zealand.

1.2 Aims and Objectives

1.2.1 Aim

The aim of the review is to assess the state of knowledge and consensus on the environmental and health impacts of post-consumer WEEE, within the context of New Zealand landfills and potential illegal dumping. The objectives and methods are contained in Appendix 1.

1.2.2 Objectives

The objectives which need to be met in order to achieve the aim are:

- Conduct a literature review of policy developments relative to WEEE internationally, focusing on known relevant case studies, and the underpinning reasons for the developments.

- Use review material to characterise WEEE in New Zealand, within a global context, including the volumes and sensitivities of component types within the definition.

- Conduct a literature review of the state of knowledge regarding the relevant dose-response relationships between WEEE substances, and human health and the environment.

- Collate and analyse evidence in order to draw relevant conclusions regarding the state of knowledge and consensus on the environmental and health impacts of post-consumer WEEE, within the context of New Zealand landfills and potential illegal dumping.

The scope of each research component is presented in section 1.3.

1.3 Research Methods and Scope

Literature review is a well-recognised and valid research method. In order to review the state of knowledge, due cognisance should be given to the quality of sources.

There is a recognised hierarchy of such sources, with peer-reviewed international journals and other scholarly publications being placed at the top of this hierarchy. Government policy processes often refer significantly to such sources, and so publications linked to such processes can also form a valid secondary source of evidence, provided the peer-reviewed sources referred to are valid. Likewise, other secondary sources and reviews of peer-reviewed literature can form useful indirect evidence which, cross-checked with original peer-reviewed sources, assist in providing a picture of the weight of scientific evidence and consensus. Where there is a paucity of peer-review material, non-peer reviewed information can be cited, but only with full notation in the report, and with the weight of evidence as analysed being adjusted accordingly. This approach summarises the method used in this study.

The scope of the review is limited to human and environmental impacts arising when post-consumer WEEE is disposed in landfills or illegally dumped. It does not include the environmental and health impacts from the manufacture/production and consumer use of the components and products, or during WEEE recycling. The scope of each main component of the review is as follows:

- **International Policy and Regulation –** Policy developments are summarised internationally, although the authors have selected case study regions and countries based on prior knowledge, in order to focus the effort within the time available.

- **WEEE products –** The study focuses on television sets (plasma, CRT and LCD), desktop PC's (incl peripherals), computer monitors (CRT, flatscreen), lap tops/notebooks, cell phones, fluorescent lightbulbs and shredder floc from WEEE including large domestic appliances.

- **WEEE componentry –** The study focuses on post-consumer printed circuit boards (including componentry and soldering), cathode ray tubes (including the glass), corrosion resistant metal parts, cabling and wires, plastic casing and batteries (including rechargeable).

- **Dose-response –** The study is restricted to review of the environmental and health impact of the following substances within WEEE: lead, mercury, cadmium, barium, hexavalent chromium, beryllium, brominated flame retardants, PVC (polyvinyl chloride), PBDE's (polybrominated diphenylethers), phosphorus.

1.4 Outline and Structure

The review is documented in the following order.

- Section 2 – Past, present and future developments in WEEE related policy and regulation is reviewed across the chosen international case studies.
- Section 3 – The WEEE products and componentry which are the focus of the review , within the New Zealand context.
- Section 4 – the state of knowledge regarding the dose-response relationships of the substances included in the review is documented.
- Section 5 – a brief analysis of the implications of changing practices and technologies in terms of health and environmental impacts and benefits. Conclusions of the review.

2. International Policy and Regulation

There is a wide range of means and measures to influence WEEE generation, management and impacts, ranging from restricting its generation through better design, enhancing recycling and reuse schemes, introducing market forces into waste through product stewardship programmes, and more use of classic 'end of pipe' solutions such as technically engineered landfills. Well established principles such as 'polluter pays', 'prevention is better than cure' and the 'precautionary principle' have been applied to such initiatives by various Governments internationally, in the effort to strike a balance between maintaining the benefits of EEE while minimising the environmental and human health costs of WEEE. Such initiatives can be loosely termed 'policy and regulation', and range from sponsorship of voluntary schemes to legislation mandating particular courses of action.

Internationally, the main regulation is the Basel Convention on the control of Transboundary Movement of Hazardous Wastes and Disposal, and ratification obliges countries to address the problem of transboundary movement and disposal of dangerous hazardous wastes through international cooperation. Hazardous wastes listed in Annex VIII of the Convention cannot be passed between countries that have ratified the ban agreement. However, the agreement does not restrict the import of such wastes from countries that have not ratified the Convention. The 1994 amendment calls for a ban of hazardous waste export from certain countries, including all member countries of the Organization of Economic Cooperation Development (OECD), which includes the United States and China.

In considering the impacts of WEEE and the case for policy and regulation in New Zealand, it is relevant to review initiatives to date. For the purposes of this literature review several countries and regions have been used to describe the connection between policy, WEEE impacts and resulting legislation, directives, regulations and bans. These include:

- European Union (EU)
- United States of America (USA)
- Canada
- Japan
- Australia.

While not conclusive, the following jurisdictional overview helps to highlight the breadth of activity in response to WEEE related impacts and issues.

2.1 European Union – Policy Context and Development

The European Union as well as individual member states and non-members have a relatively long history of research and policy development focused on WEEE. Concern about the consequences and impacts of landfilling and incineration of WEEE has resulted in the enactment of two key related EU Directives:

> i) Waste Electrical and Electronic Equipment (EU WEEE) imposes on producers and distributors "take-back" and recycling obligations, and related obligations to reduce waste from EEE.
> ii) Restriction of Hazardous Substances (EU RoHS) bans the use of six substances in EEE to agreed levels. From 1st July 2006, new EEE put on the market may not contain lead, mercury, cadmium, hexavalent chromium, PBBs or PBDEs.

These two Directives represent a mandatory approach to obliging industry and other stakeholders to play a more significant role in maximising the environmental performance of EEE while simultaneously reducing risk, toxicity and hazard impacts associated with WEEE.

The key European Commission (EC) document aimed at substantiating the WEEE and RoHS Directives is the *Proposal for a Directive of the European Parliament and of the Council on Waste Electrical and Electronic Equipment* (2000). While this document is not as exhaustive as it may have been, and therefore has its critics, it does elaborate on the essential rationale behind the need for the WEEE Directive, both in terms of environmental and human health reasons (see below).

2.2 USA – Policy Context and Development

The diversity of WEEE policy initiatives across the USA underscores the complexity of Federal – State relations. Several individual States are moving much faster with local legislation, bans and initiatives related to WEEE, from landfill bans on specified WEEE through to more elaborate producer responsibility and product stewardship schemes targeting IT equipment, TVs and major appliances.

States with legislation already in place include:

State	Activity – Outcome
Arkansas	Allows the Arkansas Department of Environmental Quality to implement regulations banning the disposal of all computer and electronic equipment in landfills, beginning January 1, 2008.
California	The Electronic Waste Recycling Act (2003) represents one of the most ambitious pieces of WEEE related legislation in the USA. Key elements of the Act include: ▪ Reduction in hazardous substances used in certain electronic products sold in California. ▪ Collection of an electronics recycling fee at point of sale of certain products. ▪ Distribution of recovery and recycling payments to qualified entities covering the cost of electronic waste collection and recycling. ▪ Directive to recommend environmentally preferred purchasing criteria for state agency purchases of certain electronic equipment.
Illinois	Creates the Computer Equipment Disposal and Recycling Commission; working towards a computer recovery and recycling scheme.
Louisiana	Developing a strategy for the proper management of electronic discards focused on the recovery of components from discarded computers and for the reduction of landfilling or incinerating discarded electronics.
Maine	Requires the Department of Environment Protection to report on the effectiveness of cellular telephone recycling collection programs in the state to the legislature.
Maryland	Requires computer manufacturers to submit environment compliance plans that describe an action plan proving that computers can be easily broken down into recyclable components and contains the least achievable amounts of hazardous materials; includes a state computer recycling fee to be collected by retailers at the point of purchase.
Minnesota	Has created a waste management task force that will address WEEE issues in the state including implementation of a CRT disposal ban scheduled to go into effect on July 1, 2006.
Washington	Requires manufacturers to register with the Department of Ecology by January 2007 and to implement and finance the collection, transportation and recycled if covered products by January 2009. Includes creation of a public entity to develop and implement a collection and recycling program for manufacturers participating in the standard plan. Cover TVs and IT equipment.

Source: Personal communication, Andrew Sweatman, WSP Environmental, 26 May 2006.

There is an extensive list of proposed, debated and in-progress bills on e-waste across numerous states, illustrating the generally high but disjointed level of WEEE related policy activity in the USA. Examples of other States that have or are continuing through this process include:

Colorado, Connecticut, Delaware, Hawaii, Iowa, Kentucky, Massachusetts, Michigan, Mississippi, Nebraska, Nevada, New Hampshire, New Jersey, New York, Oklahoma, Oregon, Pennsylvania, Puerto Rico, Rhode island, South Carolina, Tennessee, Texas, Vermont, Virginia and Wisconsin.

In terms of relevant research and reports on WEEE impacts and issues, two noteworthy studies deal respectively with desktop computer displays and cell phones:

- Life Cycle Assessment of Desktop Computer Displays: Summary of Results. 2002, prepared for the US EPA; prepared by the University of Tennessee Center for Clean Products and Clean technologies; and

- Waste in the Wireless World. 2002, written by Bette K. Fishbein, Inform, Inc., New York.

2.3 Canada – Policy Context and Development

The Canadian Council of Ministers of the Environment (CCME) is facilitating a cooperative approach to addressing WEEE related issues in order to achieve regional and national solutions. Earlier research studies by Environment Canada in 2000 and 2003 established the extent of the issue while also helping improve awareness and understanding. Two key reports provided some of the initial impetus for continuing policy development:

Information Technology and Telecommunication Waste in Canada (2000); and Baseline Study on End-of-Life Electrical and Electronic Equipment in Canada (2003).

More recently in April 2005, the CCME released *'Canada-Wide Principles for Electronics Product Stewardship: Recommended E-Waste Products'*. This document includes two important notes in terms of continuing policy priorities and actions:

- "In June 2004, the Canadian Council of Ministers of the Environment endorsed Canada-wide principles for electronics product stewards. The objective of these Canada-wide principles is to assist and support jurisdictions in the development of e-waste programs. While recognizing difference in the legislative/regulatory framework and existing programs among jurisdictions, CCME encourages regional or national cooperation in the development of e-waste programs."
- It is anticipated that the lists may be revised from time to time to reflect changing priorities, new information, the development of stewardship programs and the introduction of new electronic devices into the Canadian market, Specific measures undertaken by each jurisdiction and their timing will be at their discretion, with the goal of effective, efficient, and harmonized implementation."

The CCME have also developed a comprehensive list of recommended e-waste products to 'assist and support jurisdictions' in the creation of specific take back and recycling initiatives.

Additional information and source documents regarding e-waste policy development is available from the CCME website: http://www.ccme.ca/ourwork/waste.html#ewaste

At a Provincial level, several jurisdictions are actively working on WEEE related regulations, rules and programs. For example:

- Manitoba has proposed regulation whereby producers and retailers would be 'prohibited from selling products containing household hazardous waste including consumer electronics equipment and batteries, unless they provide or participate in an approved "stewardship" plan for managing such waste that meets certain financial, educational, operational and service criteria'.
- Ontario has enacted waste diversion law that is likely to designate electronics components and batteries for take-back or recycling.
- British Columbia, Alberta and Saskatchewan are also moving forward on WEEE related policies and regulations.

2.4 Japan – Policy Context and Development

The Government of Japan has moved relatively swiftly in the development and implementation of their WEEE related policies and legislation. This has been further accompanied by strong support from consumers, producers and retailers. The principal statute is the Law for the Recycling of Specified Kinds of Home Appliances (also referred to as the "Home Appliance Recycling Law") came into effect in April 2001. Since enactment various post-consumer product types have been designated for collection and recycling action, including air conditioners, television sets, refrigerators and washing machines and PCs (Government of Japan, 2006).

The Home Appliance Recycling Law has a strong focus on collection by retailers as well as collection by manufacturers and other designated collection points. The Law requires the use of a 'home appliance voucher system' and provides consumers with the means of tracking their specific post consumer appliance and its status in terms of collection and processing. For more information (in Japanese) about the home appliance voucher system and product tracking visit: http://www.rkc.aeha.or.jp). For more information about the Home Appliance Recycling Law refer to the Government of Japan website: http://www.env.go.jp/en/recycle

2.5 Australia – Policy Context and Development

Australian Governments operate primarily through the Environment Protection and Heritage Council (EPHC) as a means of developing national WEEE related policies and programs. The EPHC represents all Federal, State and Territory Environment Ministers and provides a national framework for identifying environmental priorities and actions across a range of areas and issues, including WEEE.

Within the context of WEEE, the EPHC has identified end-of-life IT equipment and televisions (TVs) as priority waste streams in need of industry action, particularly collection and processing. The consumer electronics industry is well advanced and has established a 'producer responsibility organisation' (PRO) called Product Stewardship Australia Ltd (PSA) to develop and implement a phased national collection, recycling and education scheme specifically focused on TVs. PSA's planning and scheme development activities are being developed on a collaborative basis with the EPHC and are significantly dependent on the formulation and enforcement of a National Environment Protection Measure (NEPM) that will specifically address free-riders and competitive disadvantage issues. A key element of how Australian Governments and the TV sector will cooperate and move forward will be guided by a 'product stewardship agreement' featuring specific targets and KPIs concerning collection, processing, recycling and community awareness and action. A draft product stewardship agreement for the TV industry is scheduled for release and discussion at the June 2006 EPHC meeting of Environment Ministers. This co-regulatory approach to addressing WEEE is likely to expand and be applied by the EPHC across a range of other WEEE categories. The IT equipment industry is also working through EPHC processes to develop a national response to end-of-life IT equipment. The Australian Information Industry Association (AIIA) is working closely with Ministers and policy makers at a State and Federal level to develop a roadmap for ongoing planning and scheme development. The AIIA's proposal for ongoing action will also be tabled and discussed at the June 2006 EPHC meeting.

At a State level, the New South Wales Government has the legislation in place to regulate industry to address WEEE related priorities. The EPR Priority Program in NSW has been explicit in aiming to encourage producer responsibility and product stewardship among manufacturers and importers of electrical and electronic equipment. While the NSW Government's approach has the potential to introduce WEEE related regulation, it is unlikely to take place if the EPHC process is effective.

For more information refer to:
Australian Government Department of the Environment and Heritage
http://www.deh.gov.au/settlements/waste/electricals/index.html
Environment Protection and Heritage Council
http://www.ephc.gov.au/nepms/product_stewardship/product_stewardship.htm
New South Wales Department of Environment and Conservation
http://www.environment.nsw.gov.au/education/spd_epr_prodsteward.htm

2.6 South America – Policy Context and Development

Several South American countries are moving forward with policy formulation related to WEEE and RoHS type issues.

It appears that Brazil has been one of the more proactive South American countries with a focus on WEEE related policies and programs. At national level batteries are the subject of take-back and recycling requirements. Take-back and recycling are also featuring in related product categories however the extent to which such measures are regulated and mandatory appears limited at this time.

Argentina is also moving towards take-back and recycling requirements that will impact on WEEE and the federal proposal has the potential to address particular categories such as batteries and specific chemicals/substances. Overall, batteries appear to be attracting the greatest attention in Argentina with proposed bills being considered by their senate; the focus being on producer responsibility and labelling.

While there does not seem to be any mandatory requirements or standards regarding product take-back for electronics in Chile, their National Environment Commission (CONAMA) released an Integral Solid Waste Management Policy in 2005 covering the principles and concept of Extended Producer Responsibility.

On a more collaborative basis, Mercosul (or the Common Market of the South comprised of Brazil, Argentina, Paraguay and Uruguay) is moving towards the creation of a detailed chemicals management program. Part of this activity includes the preparation of a regional plan to address all aspects of hazardous chemicals including their management and the role of EPR.

3. WEEE Related Concerns, Components and Substances

A wide variety of materials, compounds and components are found in WEEE. The state of knowledge regarding types, amounts and potential dangers associated with these has improved considerably over the past decade, yet remains well below 100%. As a result, research and studies emanating from Europe, the USA and Australia typically recommends caution and vigilance for policy makers and industry with a view to minimising potential environmental problems associated with WEEE (e.g. Nordic Council of Ministers, 1995; Swedish Environmental Protection Agency, 2001; Five Winds International, 2001; Environment Australia, 2001; Enproc, 2001). Many studies also highlight methodological limitations associated with the research to date.

3.1 Research on WEEE Related Impacts

The studies cited represent work conducted by or for government agencies, research institutions, universities and specialist consultants.

A report by the Swedish Environmental Protection Agency – *Electronic and Electrical Equipment: The Basis for Producer Responsibility* (1995) makes several observations and conclusions in relation to WEEE:

- Electronic and electrical products have a significant impact on the environment when they are manufactured, when they are used and when they reach the end of their life and are discarded.
- Hazardous substances can be found in all groups of products, although their presence and identity are difficult to ascertain owing to the frequent lack of environmental product information sheets.
- Sorting and disassembly are necessary in most cases to remove hazardous substances and materials for safe disposal and so other materials can be recycled or dealt with in an appropriate manner.
- It is important that recycling of WEEE leads to real environmental gains instead of merely changing the nature of the environmental problems faced. The EPA therefore considers that end-of-life EEE should be dismantled to remove hazardous components, which should then be disposed of in a secure manner.
- Stringent requirements should be set in respect of the design and location of sites for the disposal of cathode ray tubes.
- Production of raw materials consumes natural resources in the form of minerals, oil, etc. Extraction results in emissions to air, water and the creation of waste. If more material from end-of-life EEE could be recycled in an environmentally satisfactory manner, emissions associated with extraction of raw materials would decrease and natural resources would be saved.
- It is not clear how different processes at a landfill site affect metals and chemicals in landfilled EEE. However, it may be assumed that in time most of these substances will leach out.
- Particularly hazardous substances should not be allowed to enter the environment. The aim should be that materials and components containing printed circuit boards and other organic pollutants possessing similar properties should not be landfilled until these compounds have been destroyed.

- A fundamental aim should be to recycle metals to the greatest possible extent. Where metals are not recycled they should be landfilled. As far as possible metals should not be incinerated.
- A minimum precautionary measure is to sort out the most environmentally harmful components for safe disposal when end-of-life EEE is collected and sorted.
- Cathode ray tubes contain fairly large quantities of lead oxide in the cone glass and a multitude of other substances, which may be hazardous in the fluorescent layer. There is no reliable information on the rate at which this lead leaches.
- Stringent requirements should be made of the design and location of sites at which cathode ray tubes are to be landfilled in order to minimise the risk of leaching and dispersal of lead and other hazardous substances.

Two particularly relevant studies undertaken by the Nordic Council of Ministers focus a range of specific environment impacts, issues and concerns with WEEE. The first study – *Waste from Electrical and Electronic Products* – a survey of the contents of materials and hazardous substances in electric and electronic products (1995), concludes the following:

- The lead content of cathode ray tubes is of concern mainly because the material volumes are so large. It can be noted that glass is dissolved very quickly in bases, but very slowly in acids. This makes the currently used TCLP test to measure dissolution rate, where acids are used, of highly questionable value to assess leaching rates from CRTs in basic environments.

The second Nordic Council report – *Environmental Consequences of Incineration and Landfilling of Waste from Electr(on)ic Equipment* (1995b) is even more focused in its conclusions on WEEE impacts:

- Some materials in WEEE are hazardous to the environment. Other substances are not hazardous in the concentrations present. The amount of material has to be considered when discussing environmental impacts. Some substances in WEEE are in small quantities, but can be very poisonous.
- When WEEE is mixed with other types – especially organic waste – in landfills, the substances change their mobility and toxicity. Generally emissions will increase, but it is very difficult to estimate all the environmental impacts.
- The processes in landfills are very complicated and run over a wide time span. Therefore, it is impossible to quantify environmental consequences of WEEE in landfills.
- At present it is not possible to state negative environmental impacts from controlled landfills caused by WEEE. On the other hand, the processes are so complicated that it would be a mistake to neglect the possible risks.
- Degradation of CRT-glass in landfills is a very slow process, but eventually barium and lead will be leached from the glass. If CRT-glass contains cadmium as a pigment, the cadmium may also be leached.
- As a general rule, sorting waste from electric and electronic equipment and extracting of as many metals as possible especially copper, nickel, lead, and mercury before incinerating and landfilling should be recommended.

More recently a report by Five Winds International for the Canadian Government (Environment Canada) – *Toxic and Hazardous Materials in Electronics. An Environmental Scan of Toxic and Hazardous Materials in IT and Telecom Products* *and Waste* (2001), notes the following issues:

- Toxic and hazardous materials are present in IT and telecom products. The use of some toxic and hazardous materials in each unit is declining, but this is being offset by sales growth in these sectors and the introduction of new uses for toxic and hazardous materials (e.g. beryllium).
- There is a risk that toxic or hazardous materials present in IT and telecom products will be released to the environment during recycling, landfilling or incineration.
- The substances examined in this study are reported as not being released from IT and telecom equipment during manual disassembly.
- Many major OEMs are making progress in reducing and eliminating toxic or hazardous materials from their products. The key drivers are actual or anticipated regulations by governments and customers (especially in Europe and Japan), and their own environmental policies.
- The focus of OEM initiatives appears to be on eliminating lead solder and brominated flame-retardants from their products. This is driven, at least in part, by the EU WEEE Directive.
- Supply Chain Management is critical for OEMs to control and manage toxic and hazardous materials in their products. This has become even more important in recent years as the trend towards outsourcing electronics manufacturing continues.
- Japanese OEMs are leading in eliminating lead-containing solder from their products.

One of the more widely read documents directly influencing the need for increased policy and legislative attention to WEEE impacts is the European Commission's *Proposal for a Directive of the European Parliament and of the Council on Waste Electrical and Electronic Equipment* (2000). This document effectively provides the impetus for the EU WEEE and RoHS Directives and offers considerable information about WEEE impacts and issues:

- Today, more than 90% of WEEE is landfilled, incinerated or shredded without any pre-treatment. This leads to a considerable emission of the targeted substances into the environment. Usually small WEEE, which can be disposed of with the ordinary waste, goes directly to incineration or landfill.
- The risks relating to placing discarded electrical equipment in landfill are due to the variety of substances they contain. The main problem in this context is the leaching and evaporation of hazardous substances.
- Due to the variety of different substances contained in EEE, unknown toxic hazards are created during landfilling of WEEE. When co-disposed with municipal waste, there is the potential, particularly given rainwater and groundwater processes, of unknown toxic mixtures leaching out into the environment. The potential amounts and concentrations – and resulting environmental impacts – are considerably higher when WEEE is put in uncontrolled landfills, which still takes place to a significant extent in certain Member States.
- Leaching of mercury takes place when certain electronic devices, such as circuit breakers are destroyed. When brominated flame retarded plastic or cadmium containing plastics are landfilled, both PBDEs and cadmium may leach into the soil and groundwater. PBBs have been found to be 200 times more soluble in a landfill leachate than in distilled water. This may result in wider distribution in the environment.

- As regards mercury, both the leaching of elemental mercury and the vaporisation of metallic mercury and dimethylene mercury, both contained in WEEE, are of concern.
- Leachate collection and treatment of controlled landfills respecting current best practice technical standards, such as those set out in Directive 99/31/EC, does not completely eliminate exposure nor does it solve all the problems of WEEE. High standard landfills collect leachate in controlled and sealed systems. In these cases the leachate is collected and sent to treatment plants on site or to municipal sewage treatment plants, where it must be contained and further processed.
- Apart from the situation relating to the management of controlled landfills, it should be noted that a number of landfill sites do not apply best available technologies concerning emission controls. It is not likely that the majority of uncontrolled landfilled sites will be completely replaced, in the short and middle term, by high standard landfill sites in all parts of the Community.
- In the case of uncontrolled landfills contaminated leachate goes directly to the soil, groundwater and surface water. Leachate containing the above pollutants from uncontrolled landfills could contaminate water to an extent that its use as drinking water is impossible on the basis of the limits set out in Council Directive 80/778/EEC relating to the quality of water intended for human consumption.
- Through present WEEE management systems, valuable materials are disposed of and lost to future generations through the present methods of waste management of discarded electrical products. Along with the loss of resources, substantial pollution of the environment from mining is of concern. It is not possible to give exact figures on the environmental impact of the extraction of all the materials contained in electrical and electronic equipment. This depends very much on the site and region where the materials are extracted. However, the process leading to the extraction of these metals and their general impact on the environment is well known and documented.

In 2004 the UK Department for Environment, Food and Rural Affairs (DEFRA) commissioned AEA Technology to look specifically at identifying the products and components of present and historic waste from electrical and electronic equipment. The report – *WEEE and Hazardous Waste*, presents some noteworthy findings especially in relation to information availability and information gaps:

- An extensive review of published literature has been carried out to determine the range of typical components found in equipment and the composition of various types of equipment. This has been moderately successful in covering the more common types of WEEE (representing greater than 80% of this waste stream), however, there still remains a significant proportion of WEEE that falls in the ‘unknown’ area.
- Where information on a product/component is unknown, treatment facilities face difficulties in identifying what is and what is not hazardous. Although this issue will be resolved in time through the information provision requirements of Article 11 of the WEEE Directive, practical dismantling and analysis trials on historic WEEE are needed to address this knowledge gap.
- On the basis of our assessments, the results obtained confirmed that the removal and treatment requirements of Annex II of the WEEE Directive were generally in line with the HWD. It would appear that the ‘Precautionary Principle’ has been applied in requirements to remove circuit boards, plastics containing brominated flame retardants (BFRs) and electrolyte capacitors (>L/D 25mm) containing ‘substances of concern’ because threshold criteria for certain BFRs (which can be present in significant proportions) have not yet

been fully determined and 'substances of concern' have not been defined. Clarification is needed on the hazardousness and appropriate treatment of these items.
- The results also found that some other components that are not specified in Annex II may be hazardous, and may need to be removed to render the WEEE item non-hazardous. These include plastics and rubbers containing phthalate plasticizers or lead stabilisers, lithium batteries, and components containing mineral wools that come under the classification as a category 3 carcinogen.

Research from the University of Florida has also contributed to the discussion on WEEE related impacts with a particular focus on lead leachability in landfills. These studies – *Assessment of True Impacts of E-Waste Disposal in Florida (2003), and RCRA Toxicity Characterization of Computer CPUs and Other Discarded Electronic Devices* (2004) – offer the following observations:

- The US EPA has been examining the applicability of the TCLP (Toxicity Characteristic Leaching Procedure) and this research adds to this complicated issue. For those state and local government agencies wrestling with whether to ban discarded electronics from landfills, the results of this work suggest that lead leaching from PWBs and CRTs in one landfill studied may be less than might be estimated using TCLP results. It should be noted that this was a short term study and does not provide evidence of long term processes in landfills. It is also important to note that other factors affect the migration of leached lead from a disposed device to the leachate collection systems of a landfill (e.g. sorption, reduction, precipitation).
- The testing of entire colour computer monitors and colour televisions confirms previous experiments that show colour CRTs can leach lead above the toxicity characteristic concentration. Small electronic devices that contain a PWB with lead solder often leach above 5mg/L of lead using the standard TCLP. When larger devices were tested using the modified large-scale method, they often exceeded the TC limit for lead. The amount of ferrous metal present in some of these devices may result in less lead being leached if the standard TCLP were to be performed.
- Size-reduced computer CPUs leached less lead than the same model of CPU leached with the large-scale modified method (it should be noted that this particular model did not fail TCLP even for the large method, while many of the other CPU models tested did). On the other hand, in limited testing of laptops using the standard approach and modified approach, the TC limit was always exceeded for lead. The difference between leaching results for the two devices likely resulted from the greater ferrous metal content (68%) of the computer CPUs relative to the laptops (7%).

3.2 Substances in WEEE

The following tables provide an overview of post consumer electronics in terms of product types and componentry and reported concerns about toxic and/or hazardous substances.

Lead

Apart from in batteries, lead is used widely in solders, as an alloying element for machining metals, printed circuit boards, components, incandescent light bulbs, and weighting. Lead oxides occur in leaded glass in cathode ray tubes, light bulbs and photocopier plates, and in batteries. Lead-based solder (typically a 60:40 ratio of tin to lead), which is used to attach electrical components, represents the major solder type used in most EEE applications and typical motherboards have been reported to contain approximately 50 g/m^2 lead (Five Winds International, 2001). In CRTs, leaded glass provides shielding from X-rays generated during the picture projection process. Color CRTs contain 1.6 kg to 3.2 kg of lead on average (Microelectronics and Computer Technology Corporation, 1996). A TV set glass contains about 2 kg lead (European Commission, 2000). The lead oxide in CRTs tubes constitutes the largest share of lead in WEEE, where it is present in the form of silicates. A light bulb contains between 0.3 and 1.0 g of lead in lead-tin solder and 0.5 to 1.0 g of lead silicates in the glass (on average 1.5 g lead in solder and glass). In Sweden this application amounts to the use of about 100 t of lead annually.

Mercury
The global man-made release of mercury to the atmosphere is approximately 2000-3000 tonnes per year. It is estimated that of the yearly world consumption of mercury 22% is used in EEE (AEA, 2004). Mercury is basically used in thermostats, sensors, relays and switches (on printed circuit boards and in measuring equipment and discharge lamps). Furthermore, it is used in medical equipment, data transmission, telecommunications, and mobile phones. In the EU, 300 tonnes of mercury are used in position sensors alone.

Cadmium
It is known that in Printed Circuit Boards cadmium occurs in certain components, such as chip resistors, infrared detectors and semiconductors (European Commission, 2000). Older types of CRTs contain cadmium. Furthermore, cadmium has been used as a stabiliser in PVC. Cadmium metal or powder is still used as part of the negative electrode material in nickel-cadmium (NiCad) batteries, as an electrodeposited, vacuum deposited or mechanically deposited coating on iron, steel, aluminium-base materials, titanium-base alloys or other non-ferrous alloys, and as an alloying element in low-melting brazing, soldering and other specialty alloys (AEA (2004). Cadmium oxide forms part of the negative cadmium electrode in nickel-cadmium batteries, and cadmium sulphide is found widely in CRT and electronic devices.

Hexavalent chromium and barium compounds
Very little information on the uses of hexavalent chromium in IT and telecom equipment exists in the literature. Hexavalent chromium is used in the plastics of personal computers, cabling and packaging. Chromium VI is typically used as a hardener or stabilizer for plastic housings and as a colorant in pigments. References to quantities of chromium VI in these components are poor (Five Winds International, 2001). The use that is occurring seems to be in trace amounts, between 0.2 and 0.3 grams per component. As a colour pigment, the European Union is moving to restrict the use of chromium VI. Hexavalent chromium may also be present on the surface of metal parts that have been protected from corrosion with chromate conversion coatings – no references to quantities of Cr VI present in this application were found.

Beryllium
Beryllium metal offers a unique and incomparable combination of properties. It is one of the lightest structural materials available but is several times stronger than steel. It has excellent thermal conductivity, high electrical conductivity, good corrosion resistance, good fatigue resistance, high strength and good formability. Traditionally, copper-beryllium alloys were used in motherboards on personal computers. Beryllium is rarely used in this form anymore, but its use in combination with copper as an alloy is increasing (Five Winds International, 2001). Beryllium improves the properties of copper contact springs because of its high strength, high conductivity and high elastic quality. Between 2 – 4% of these copper alloys is beryllium metal. Beryllium metal is

sometimes overlooked as one of the components of concern in end-of-life electronic equipment. It is used amongst other things, in electrical insulators and resistors, microwave tubes, photographic equipment, rotating mirrors in laser printers, and both beryllium and beryllium oxide are used in heat sinks.

Brominated flame retardants including PBDEs
Brominated flame retardants (BFRs) are today regularly designed into electronic products as a means for ensuring flammability protection, which constitutes the main use of these substances. The three main groups of PBDEs, which are currently commercially available, are penta-, octa- and decabromodiphenythether. BFRs are used in a wide range of products including plastics, white goods, car interiors, carpets and carpet underlay, polyurethane foams in furniture and bedding. They occur in EEE in mainly four applications; PCBs, components such as connectors, plastic covers, and cables, and their use has increased markedly over the past two decades, with worldwide production over 200,000 tonnes per year. According to a Danish estimation, WEEE represents about 78% of the total content of brominated flame retardants in waste (European Commission, 2000).

Tetrabromobisphenol-A (TBBPA) is the largest volume brominated flame retardant in production today. It is used as a reactive (primary use) or additive flame retardant in polymers, such as epoxy and poly-carbonate resins, high impact polystyrene, phenolic resins, adhesives, and others. Its main use in EEE is as a reactive flame retardant in printed circuit boards. Further commentary on the contemporary use and toxicity evidence of BFRs is provided in section 4.6.

PVC
Many different types of plastics are used in the manufacture of electronic equipment. PVC is ubiquitous in electronics, forming the structure of computer housings, keyboards and cables. Estimated quantities of PVC in different products range from 37.1 grams in a keyboard to a total of 314 grams in all of the cables connecting different component pieces together (for example, the cables connecting the monitor, mouse and keyboard to the CPU) (Five Winds International, 2001).

The predominant use of PVC plastic in electronics is as a structural feature in plastic computer housings, keyboards and cables. PVC has good chemical resistance that original electronic equipment manufactures look for when designing durable products.

Phosphors
Phosphors are found in all CRT screens as well as fluorescent lights. Many phosphors used in CRTs contain zinc, although only small quantities of phosphors are used in electrical and electronic products. Some phosphors can contain terbium. However, little is known of terbium’s toxicity. Some old monitors contain phosphors that include arsenic (Environment Australia, 2001).

3.3 Toxic and Hazardous Substances in EEE

At a product and substance specific level, work conducted by Five Winds International (2001) provides a relatively detailed overview of specified IT and telecommunications products (and components) and the presence of particular toxic and hazardous substances.

The Five Winds report describes substances across specific products and components including reference to various factors, for example:

Mercury in IT and Telecom Equipment				
Where Found	**Use**	**Quantity**	**Status**	**More Info**
Fluorescent lamps – flat screen laptop displays	Back light for LCD	Manufacturers must report any intentionally added mercury	Banned in all uses except lamps (EU)	EIA, 2001

The report provides this level of information across numerous relevant EEE products and components for the following substances:

- Mercury
- Lead
- Cadmium
- Beryllium
- Hexavalent Chromium
- Antimony
- Brominated Flame-Retardants
- Polyvinyl Chloride – PVC
- Polychlorinated Biphenyls.

The detailed tables relating to the above can be found under Section 2: Toxic and Hazardous Materials in IT and Telecom Products (pp7 – 24). The report is available to download from: http://www.fivewinds.com/publications/publications.cfm?pid=75.

4. Toxicity, Humans and the Environment

Any substance is potentially toxic if the dose and duration of exposure are sufficiently high. However, there are many ways in which chemicals might disrupt the functioning of an organism, including corrosive or irritant effects, acute and chronic toxicity, effects on the nervous system (neurotoxicity), impairment of the reproduction of cells or organisms (by carcinogens, mutagens or reproductive toxins), or damage to hormone systems, for example, the effects resulting from endocrine-disrupting chemicals (RCEP, 2003). Tests have been devised to assist in determining toxic doses – i.e. doses required to cause a specified impact on health of humans or other living organisms. The major sources of uncertainty in toxicity testing include the difficulty in envisaging all important possible impacts, and in modeling or otherwise determining the conditions under which the relevant doses are likely to be applied. Regarding the former, the relatively recent realisation that endocrine disruption is important is a reminder that there may still be impacts that have yet to be recognised, and for which tests have not yet been developed. Regarding the latter, in general, tests are devised which are intended to take a conservative approach in identifying 'worst case' scenarios of doses, accompanied by risk assessment based upon comparing the estimates of concentration in different conditions.

It is well-documented that toxicity is not solely a characteristic of synthetic chemicals (e.g. RCEP, 2003). Some of the most toxic substances known occur naturally in organisms, where they usually form part of a defence mechanism. For example, many plants, including common ones such as clovers, produce hydrogen cyanide when damaged, and a number of Australian plants produce fluoroacetate, a respiratory inhibitor which is highly toxic to sheep, but to which red kangaroos have adapted.

Therefore, in devising toxicity tests, and levels of exposure above which toxicity is deemed to cause an unacceptable impact, due cognisance must be paid both the natural and synthetic substances, and to the conditions of the receiving environment. Characterisation of the dose-response relationship is thus a process of identifying the concentration and time of exposure required to produce a specific impact outcome, or response. Hence, we can talk of the dose-response relationship between airborne lead from vehicle exhausts (assuming leaded petrol) and the response in terms of child brain development impact. Of course, the dose for another response, such as death of roadside vegetation, will be different.

In WEEE-relevant substances, it is important to note that the form of the waste and the conditions of its storage or burial will be important in determining both the dose and the response. As there are a wide variety of landfill conditions, not to mention illegal tipping conditions, the determination of dose-response across these varying conditions is not simple, and even if it could be determined, it would vary across the various conditions, and for different receptors, impacts and outcomes. A common approach is therefore to set 'guideline' levels of concentrations of known toxic substances, above which further investigation or treatment is required. Where dose-response relationships are unknown, it is appropriate to take a precautionary approach and set exposure levels to as low as reasonably practicable.

To provide a general overview of the 'toxicity' of the substances under review in this study in a New Zealand context, New Zealand Landfill Leachability Limits are included in Table 2, and a summary drawn from a recent review (Table 3) below, with further explanation in the following subsections.

Table 2. New Zealand Landfill Leachability Limits
All figures are sourced from the NZ Ministry for Environment Leachability Limits for Class A and Class B Landfills.

WEEE Substance	NZ Landfill Leachability Limits
Lead	Class A: 5mg/L. Class B: 0.5mg/L
Mercury	Class A: 0.2mg/L Class B: 0.02mg/L.
Cadmium	Class A: 1 mg/L Class B: 0.1mg/L.
Barium	Class A: 100 mg/L Class B: 10 mg/L.
Hexavalent chromium	Chromium VI Class A: 5 mg/L Class B: 0.5 mg/L.
Beryllium	Class A: 10 mg/L Class B: 1mg/L.
Brominated flame retardants	Not indicated.
PVC (polyvinyl chloride)	Vinyl chloride Monomer: Class A: 2 mg/L Class B: 0.2mg/L.
PBDE's (polybrominated diphenylethers)	Not indicated
Phosphorus	Not indicated

http://www.mfe.govt.nz/publications/waste/haz-waste-guide-module-2-may04/html/table-appendixa.html

Table 3. Environmental Impacts of Selected Materials Used in Computer Production – Australia (EV, 2005)

Material	% of Total (by weight)	Main Applications in Computer Production	Environmental/Health Impacts	Recycling Efficiency[a]	Annual Waste Volume (kg.)[b]
Plastics[c] including PVC	23%	Cabling, computer housings	Various cancers; endocrine system disruption PVC emits highly toxic dioxins and furans when manufactured and also if materials containing it are burnt	20%	8,150,000
Lead	6%	Soldering of printed circuit boards and other components; glass panels in CRT monitors	Significant amounts of lead ions are dissolved from broken lead containing glass, such as the cone glass of cathode ray tubes, when mixed with acid waters which commonly occur in landfills. Accumulates in environment and has high acute and toxic effects on plants, animals, and micro-organisms Damage to nervous system, blood system, and kidneys; serious effects on child brain development.	5%	2,126,000
Barium	0.03%	Vacuum tubes in CRT monitors	Short-term exposure to barium can lead to brain swelling, muscle weakness, damage to the heart, liver and spleen. Long-term effects of chronic exposure not yet known.	0%	10,500
Beryllium	0.02%	Used for thermal conductivity	Recently identified as human carcinogen. Exposure can cause lung cancer and skin diseases.	0%	7,000
Cadmium	0.01%	SMD chip resistors, infrared detectors, semiconductors, older models of CRTs; also used as plastic stabilizer	When plastics containing cadmium are landfilled, can leach into groundwater. Acute and chronic toxic compound which accumulates in human body, esp. in kidneys. Can be absorbed either through respiration or ingested through food.	0%	3,550
Hexavalent Chromium	0.006%	Mostly phased out, but still some limited use as corrosion protector and decorative or hardener for steel housings	Highly toxic material which can pass easily through cell membranes; causes strong allergic reactions (e.g. asthmatic bronchitis) even in small concentrations. May also cause DNA damage. Contaminated wastes can leach from landfills and also fly ash if chromium-containing wastes are incinerated.	0%	2,120
Selenium	0.002%	Used in rectifiers and printed wiring boards	Exposure to high concentrations of selenium compounds cause selenosis, the symptoms of which are hair loss, nail brittleness, and neurological abnormalities.	0%	710
Mercury	0.002%	Sensors and switches on printed circuit boards, batteries, switches/housing, printed wiring boards, tubes in flat panel screens	Mercury is released when electronic devices that contain it are destroyed – such as in, or on the way to, landfills. The vaporization of metallic mercury and dimethylene mercury is also a possibility. Both are highly toxic – methylated mercury causes chronic brain damage. Inorganic mercury is transformed into methylated mercury when introduced into natural water systems, where it concentrates in sediment. Easily accumulates in living organisms, especially fish.	0%	710
Arsenic	0.001%	'Doping' agents in transistors and printed wiring boards	Chronic exposure to arsenic can lead to various diseases of the skin and decrease nerve conduction velocity. It can also cause lung cancer and can often be fatal.	0%	350
PCBs (Poly-chlorinated biphenyls)	Only found in older equipment	Used in capacitors and transformers	PCBs affect the immune, hormone, nervous, and enzyme systems of the body and therefore have impacts on almost every organ. PCBs are considered by health agencies as a known carcinogen for animals and a probable carcinogen for humans.	0%	<500
TOTAL	29-30%			<20%	~10,300,000

a) Percentage of the material that can be recovered using current best recycling practices.
b) Estimated annual volume of each waste material requiring management, based on an annual average for Australia for 2005-2014 of 1.31 million PCs being available for recycling (Meinhart report), and an assumed average weight per computer of 27kg. Note that these figures do not include CRT monitors or notebook computers.
c) Plastics also contain polybrominated flame retardants and many compounds not listed separately.

4.1 Lead

Lead has known toxic properties and is found in large amounts in many electronic devices (Nordic Council of Ministers, 1995). Indeed, electronic devices, along with batteries, are the major contributors of lead in the municipal solid waste stream (US EPA, 1989). The possible effects of lead on human health and the environment are well documented (e.g. Waldron, 1980; Gosselin et al., 1984). Indeed, all lead compounds are classified as dangerous substances, with particular dangers to children, unborn children, and a danger of cumulative effects.

Both adults and children can suffer from the effects of lead poisoning, but childhood lead poisoning is much more frequent. Over the many years since we have known about the hazards of lead, tens of millions of children have suffered its health effects. In 2004, it was reported that there were at minimum more than 400,000 children under the age of six who have elevated blood lead levels.

Young children under the age of six are especially vulnerable because their brains and central nervous system are still being formed, and even low exposure can result in reduced IQ, learning disabilities, attention deficit disorders, behavioral problems, stunted growth, impaired hearing, and kidney damage. As evidence on the harmful effects of lead in children at low levels has increased, the US Centers for Disease Control and Prevention (CDC) "level of concern" for children at 1 microgram per litre has become increasingly questioned, and there is now arguably no demonstrably safe level of exposure for children. In adults, lead can increase blood pressure and cause fertility problems, nerve disorders, muscle and joint pain, irritability, and memory or concentration problems. Most adult poisoning cases are occupational.

Regarding dose levels of lead associated with WEEE, in one recent study, 12 different types of electronic devices were tested using either the standard US toxicity test (TCLP) or modified versions of it. In many cases, lead concentrations in the leachates exceeded the 5 mg/L Toxicity Characteristic (TC) level and every device type leached lead above this level in at least one test (Townsend et al, 2004). To quote the authors**;** “The results provide sufficient evidence that discarded electronic devices that contain a color CRT or printer wiring boards with lead-bearing solder have a potential to be hazardous wastes for lead (unless otherwise excluded) and that generators should assume such devices are hazardous”.

While there is no compelling evidence that WEEE items consistently leach toxic quantities of heavy metals in landfills, it should be noted that there is a general lack of monitored evidence in this area, and certainly little opposing evidence. A one-year study in Florida, USA suggests that ‘heavy metal concentrations in leachate and landfill gas are generally far below the limits that have been established to protect human health and the environment’ (Jang and Townsend 2003), although this and other reports from the same authors also indicate that toxic leachate is produced and that our understanding of the factors that determine heavy metal concentrations in leachate is in its infancy.

It is also notable that alternatives to lead-free solder (such as tin and silver) may not be as reliable in the short term, pending technology improvements. In Japan, it has been alleged that the adoption of lead-free solder has lead to higher rates of equipment failure which in turn has lead to an increase in the amount of waste (AEEA, nd). Notwithstanding, tin and silver are much more benign to humans and the environment than lead.

4.2 Mercury

Mercury comes in various forms. Metallic, or elemental mercury, is an inorganic form of mercury that is used in WEEE. It is a liquid at room temperature, and like any liquid it evaporates into the air as a gas. It is toxic by inhalation with danger of cumulative effects, very toxic to aquatic organisms, and damaging to the human central nervous system and kidney.

Mercury bioaccumulates in the environment and is a potent neurotoxin that can affect the brain, liver and kidneys, and cause developmental disorders in children. Young children and developing foetuses are especially at risk. Mercury contained in WEEE can also evaporate into the air or leach into the groundwater from landfills. When products containing elemental mercury break in the waste stream, the mercury is released and begins to evaporate. Gaseous mercury can then be emitted as air pollution at various stages of the solid waste disposal process, although some studies suggest there are two main pathways; the working face and landfill gas vents (e.g. Lindberg and Price, 1999).

Once buried, some of the inorganic mercury in the landfill is converted by bacteria living there into a more toxic form, called organic or methylated mercury. Organic mercury can be released into the atmosphere from landfills in the same way that inorganic mercury is released. Researchers have measured one organic mercury compound, dimethyl mercury, from gas destined for landfill venting at levels 1,000 times higher than what has been measured in open air (Lindberg, 2001). Organic mercury is primarily a local pollution concern because it probably deposits quickly after being emitted.

Mercury in groundwater can exceed drinking water standards from older, unlined landfills, but is less likely to leach into groundwater from landfills that are lined and use leachate collection systems. Depending on how the leachate is treated, however, mercury collected in leachate systems may re-enter the environment through typical practices of land-filling or applying the residue to land as fertilizer. Lindberg and Price (1999) reported that leachate contained highly elevated concentrations of methyl mercury at one Florida landfill. In 1999 the US EPA Office of Solid Waste conducted a review of 39 Superfund sites on the National Priority List that involved mercury contamination. Ten of these were municipal landfills, eight of which had mercury in soil or groundwater at levels exceeding federal guidelines (Dynamac Corporation, 1999).

4.3 Cadmium

In the 1950s and 1960s industrial exposure to cadmium was high. But as the toxic effects of cadmium became apparent, industrial limits on cadmium exposure have been reduced in most industrialized nations and many policy makers agree on the need to reduce exposure further. The American Electronic Industry Association (EIA) considers cadmium a substance of concern and the WEEE Directive requires a substitute for cadmium in all uses by 2008.

Cadmium is classified as toxic by inhalation, carcinogenic and eco-toxic in aquatic environments. Cadmium oxide is classified as ‘harmful’ if swallowed and potentially carcinogenic if inhaled as dust, while cadmium sulphide has similar although less toxic effects to cadmium and cadmium oxide. Serious toxicity problems have resulted from long-term exposure to cadmium plating baths. Environmental exposure to cadmium has been particularly problematic in Japan where many people have consumed rice that was grown in cadmium contaminated irrigation water. Build up of cadmium levels in the water, air, and soil has been occurring particularly in industrial areas. Food is another source of cadmium, and fertilisers have been shown to increase cadmium concentrations in soil (Taylor, 1997).

Acute exposure to cadmium fumes may cause flu like symptoms including chills, fever and muscle ache. Symptoms may resolve after a week if there is no respiratory damage. More severe exposures can cause tracheo-bronchitis, pneumonitis, and pulmonary edema. Symptoms of inflammation may start hours after the exposure and include cough, dryness and irritation of the nose and throat, headache, dizziness, weakness, fever, chills, and chest pain. Inhaling cadmium-laden dust quickly leads to respiratory tract and kidney problems which can be fatal (often from renal failure). Ingestion of any significant amount of cadmium causes immediate poisoning and damage to the liver and the kidneys. The kidney damage afflicted by cadmium poisoning is irreversible and does not heal over time. Compounds containing cadmium are also carcinogenic, the bone tissue becomes soft, loses bone mass and become weaker (*osteoporosis*).[2] This can cause pain in the joints and the back, and can also increase the risk of fractures (Taylor 1997). Regarding other organisms, "No data are available on the short-term effects, or long term effects of cadmium on plants, birds, or land animals, excepting test animals, which did develop lung and testicle cancers. Cadmium is highly persistent in the environment and will concentrate or bioaccumulate in aquatic animals" (NPI, 2006), however, its occurrence and toxicity is landfill leachate is less studied than lead, and further research is required.

4.4 Hexavalent chromium and barium compounds

Hexavalent chromium is an oxidated state of chromium and barium chromate is a hexavalent chromium compound. Studies show hexavalent chromium (Cr VI) is transferred to incineration residues. In landfills, chromium VI leaches from incineration residues and directly from products, hence contributing to the chromium VI that is released to air, soil and water from incineration and landfill reactions.

The need to replace chromates based upon hexavalent chromium is gathering momentum in response to its environmentally and toxicologically hazardous properties. Calcium chromate, chromium trioxide, lead chromate, strontium chromate, and zinc chromate are all known human carcinogens. Hexavalent chromium is considered a potential lung carcinogen. Studies of workers in the chromate production, plating, and pigment industries consistently show increased rates of lung cancer. Hexavalent chromium can irritate the nose, throat and lungs. Repeated or prolonged exposure can damage the mucous membranes of the nasal passages and result in ulcers. Prolonged skin contact can result in dermatitis and skin ulcers. Some workers develop an allergic sensitization to chromium. In sensitized workers, contact with even small amounts can cause a serious skin rash. Kidney damage has been linked to high dermal exposures.

4.5 Beryllium

Exposure risk for beryllium and beryllium oxide generally arises from airborne dust or fumes generated from the material. By inhalation it is classified as very toxic and carcinogenic (AEA, 2004). Beryllium metal component scrap is classified as non-hazardous in the OECD, Basel and EU Waste Control Systems. However, it is recommended that beryllium metal components should be segregated from equipment at end-of-life and returned to the supplier for recycling.

The lung is the main target organ of beryllium toxicity in humans. Beryllium lung disease can persist up to a year, and chronic beryllium disease can be fatal. Indications include fever, anorexia, nausea, vomiting, palpitation, convulsions, and renal, eye and blood complications. As indicated in the literature (Hooper, 1981, Jones Williams 1993, Kriebel et al, 1988) most cases are occupational, and beryllium compounds may also cause contact dermatitis, and beryllium ulcers occur where a beryllium crystal penetrates the skin at a site of previous trauma. Beryllium chloride, fluoride, nitrate or sulphate are acute eye irritants.

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2 Note – this report does not make claims about the relative prevalence of different causes of osteoporosis. Swedish studies have concluded that there is a "dose-response relation between cadmium dose and osteoporosis. Cadmium may be a risk factor for the development of osteoporosis in lower doses than previously anticipated." Jarup L et al, (1998) Occup Environ Med Jul; 55 (7): 435-9. This study does not report on the source of the cadmium exposure.

In summary, the quantities and forms of beryllium in EEE have not led to their identification as a major issue during landfill and waste management, although it should be noted that occupational exposure is a possibility during recycling and reclamation. Since beryllium is not known to be particularly toxic in the environment and because it has only recently been identified as a health hazard in IT and telecom equipment due to trends for recycling, it is a reasonable assumption that it is most hazardous when inhaled as a dust or fume released when components are shredded, and from copper-beryllium alloys when metals are heated. If an organization is aware of the risks of beryllium and manages or controls those risks appropriately, the risk to human health is small.

4.6 Brominated flame retardants including PBDEs and phosphorous

The most important PBDEs are the penta-BDEs, octa-BDEs and deca-BDEs. These are used in EEE, textiles and plastics in vehicles, building materials, paints and insulation foam, in order to reduce fire risk. PDBEs are applied as additives, and can migrate into the environment, where they bioaccumulate. Penta- and octa-BDEs are persistent and lipophilic compounds; these physical properties encourage long-range transport and bioaccumulation. Deca-BDEs are characterized as semi-persistent, and bioaccumulate to a lesser extent.

The whole substance group of BFRs is listed in general on the Danish list of unwanted substances. Reasons for this concern include the potential for TBBPA to form brominated dioxins/furans in thermal processes and for endocrine modulating effects (hormone disruption). TBBPA has a proposed classification of ‘very toxic to aquatic organisms’ and may cause long term adverse effects in these environments, based on toxic effects seen in recent acute toxicity studies (AEA, 2004). As a result of their similarity in chemical properties (extremely stable, accumulate in the food chains and in sediments and degrade very slowly), high volume production, and widespread use, comparisons are often drawn between polybrominated diphenyl ether flame retardants (PBDEs) and polychlorinated biphenols (PCBs).

The December 2003 study conducted by the University of Florida (Townsend et al, 2003) into the impact of e-waste on landfills found unexpectedly high levels of organo-bromine compounds in landfill leachate samples, indicating not only the propensity for brominated flame retardants to migrate from landfills through leaching but also their ability to break down into products with higher abilities to bioaccumulate. PBDEs have also been found to contaminate human breast milk in Sweden (Darnerud et al., 2001). Swedish research has found that PBDEs were present in the blood of office workers who use computers, and also in hospital cleaners and workers at an electronics-dismantling plant. The highest levels were in the latter, demonstrating the role of electrical goods in the contamination.   PBDEs have been shown to mimic oestrogen, and are linked with cancer and reproductive damage. These have been found in the dust of homes and offices (http://www.oztoxics.org/ntn/pbts_kids.html). Low level exposure of young mice to PBDEs causes permanent disturbances in behaviour, memory and learning. PBDEs have also been shown to disrupt the thyroid hormone system in rats and mice; these systems are a crucial part of the development of the brain and body. Typical values of PBDEs (mainly BDE 47 and BDE 99) in plasma are in the range 5 to 40 ng/L (about 0.5% of levels of PCBs) (Darnerud et al, 2001). Blood levels in Canada, however, are up to 10 times higher than those found in Europe, and in the USA up to 10-100 times higher (with levels over 500 ng/g lw reported). Levels of PBDEs in breast milk are also reported to be 5-10 times higher in the USA (up to 200 ng/g lw) than in Europe. [3]

As a result of such evidence, the EU ROHS Directive bans PBBs, Penta-BDE, and Octa-BDE, from the production of new E&E equipment from 1 July 2006. This reflects existing industry practice and European legislation; industry voluntarily ceased production of PBBs in 2000 and Penta-BDE and Octa-BDE have been banned in the European Union since August 2004. However, following mixed evidence and lobbying from industry, Deca-BDE (DBDE) was exempted from the RoHS Directive on 15th October 2005, on the basis of the life-saving fire resistance of the devices it is used in compared to a situation where none were used, and the lack of commercially viable suitable alternatives.

In January 2006 the European Parliament and Denmark both launched legal procedures against the European Commission regarding the exemption of Deca-BDE from the RoHS Directive. However, until any European Court of Justice ruling, the European Commission Decision to exempt Deca-BDE form the RoHS Directive remains valid.

Gattuso (2005) finds that studies by the US National Academy of Sciences, World Health Organization and US Consumer Product Safety Commission corroborate the 10-year EU study in finding limited justification for applying the precautionary principle to ban the use of Deca-BDE. A major factor in limiting use of such flame retardants is consequent increased fire danger, which itself leads to fires and higher emissions of toxic products such as dioxins, furans and polycyclic hydrocarbons (Gattuso 2005, Simonson and Stripple 2000). A recent review concludes; “Overall, the toxicology database is very limited; the current literature is incomplete and often conflicting. Available data, however, raise concern over the use of certain classes of brominated flame retardants”. (Birnbaum and Staskal, 2004)

Note: Phosphate ester flame retardants (PEFRs) are a group of phosphorus compounds which are currently attracting interest as replacement fire retardants for polymeric materials. No toxicity information is currently available to this study. The commercially available 9,10-dihydro-9-oxa-10-phosphaphenanthrene-10-oxide (DOPO) is an effective flame retardant for some polymers. However, it is not suitable for polyamides and polyester because it affects the mechanical properties of these materials by acidic cracking of the amide or ester bonds at higher temperatures. Nevertheless, as nonhalogenated flame retardants that provide equivalent performance and costs are developed, such compounds will gain market share. Brominated flame retardants are also losing ground because of the growing use of polycarbonate/acrylonitrile-butadiene-styrene blends, which can use either halogenated or phosphate ester flame retardants. In response, some brominated flame-retardant makers are diversifying their portfolios.

4.7 PVC (polyvinyl chloride)

PVC doesn’t bioaccumulate, however, it appears to draw the most attention in literature focusing on potentially hazardous materials in electronics. This is probably because of the well-documented risks of dioxin formation during the incineration of PVC material, as with any material containing chlorine. Both chlorine and flame-retardants are often additives in the plastic manufacturing process and are added to cables and housings. This creates considerable difficulty when attempting to manage

[3] Note – brominated flame retardants do occur in other products, but they are ubiquitous in WEEE.

WEEE and disassembly can generate dusts and fumes hazardous to workers when heated and shredded. Hence, very little PVC is recycled due to poor labeling of the plastics. In certain applications, PVC will contain chloro-paraffins, poly-chlorinated biphenyl and other phthalates that are released during shredding and heating and pose potential hazards to recycling workers and the environment (Five Winds International, 2001).

Recent health/environmental concerns have been raised about some additives used in PVC processing i.e. heavy metals used as stabilisers and the aforementioned phthalate plasticizers. The UK PVC industry has voluntarily committed to replace lead stabilizers to achieve a 50 % reduction on 2000 levels by 2010, will complete phase-out by 2015. Until then, lead remains a major concern, and irrespective, phthalates are an issue as yet unaddressed. Indeed, PVC stabilisers and plasticizers have known health and environmental effects e.g. phthalate plasticizer is a known carcinogen, moderately bio-accumulative and moderately persistent in the environment (http://www.healthybuilding.net/pvc/terms.html). There is a large and growing body of literature relating to the environmental performance and toxicity of PVC, and this amounts to mixed evidence relating to the fate of phthalates from PVC cabling after their deposition in landfills; some studies posit that migration will occur, others are less certain. It would therefore be prudent and precautionary to assume that the potential for leaching of phthalates is possible.

4.8 Phosphors

The zinc contained in many phosphors can be harmful in large amounts. However, due to the quantities of phosphors used in electrical and electronic products, zinc contamination of groundwater from phosphors in landfill is of little concern. Another possible component is terbium, however, little is known of terbium’s toxicity. A further component is arsenic, which can accumulate in fish, but only in the non-toxic organic form. Arsenic is a human poison in its inorganic form. The small quantities of phosphors used in electrical and electronic products mean that arsenic contamination of groundwater from phosphors in landfills is of little concern (Environment Australia, 2001).

5. Discussion and Conclusions

The reviews of policy developments, WEEE components and substances, and the environmental and health effects of these substances upon landfilling or illegal dumping demonstrates a rapidly developing and mixed picture. In some areas, there is clear consensus and parallel directions in policy and action, while in others, there is less certainty and even some controversy.

In policy terms, the WEEE and RoHS Directives place the EU at the forefront of legislative developments. The US provides a range of local legislation, bans and initiatives across different states. This is not the intention of either the manufacturers and retailers, or the public or government, it simply reflects the progress different states have made so far in managing the real and potential hazards and risks of WEEE. While the systems vary, Europe and the US are indicative of the moves across the developed world to tackle the rapidly growing problem of WEEE. In the developing world, anecdotal evidence suggests the uptake of WEEE management systems is less advanced, although manufacturing companies in these countries are aware of the developments and the implications for them in supplying products into European markets.

As a result, market transformation is happening, especially driven by the WEEE and RoHS Directives, and it can be expected that countries which do not implement appropriate systems will be increasingly subject to imports which are non-compliant with these Directives; in other words, they will become a dumping ground for the more toxic EEE.

The detractors of the European approach cite implementation costs and uncertainties over some toxicity information (see below). Other potential problems occur when the costs of end-of-life are borne by consumers rather than manufacturers. Rising landfill costs, where they are passed on directly to consumers, can increase the incidence of illegal dumping. However, evidence is mixed; a Tidy Britain group report, "Effects of the Landfill Tax on Flytipping" (published in 1998), did not establish a clear link between the tax and increased fly tipping. Also in the UK, DEFRA (2006) has developed Flycapture to help get a better picture of the problem facing authorities and to track the future impact of fly-tipping. Flycapture is showing that around 50% of fly-tipping incidents involve household waste even though householders are not subject to landfill tax at civic amenity sites in the UK.

Through present WEEE management systems, valuable materials are disposed of and lost to future generations through the present methods of waste management of discarded electrical products. Along with the loss of resources, substantial pollution of the environment from mining is of concern. It is not possible to give exact figures on the environmental impact of the extraction of all the materials contained in electrical and electronic equipment. This depends very much on the site and region where the materials are extracted. However, the process leading to the extraction of these metals and their general impact on the environment are well known and documented. This itself adds to the case for reduction of WEEE at source, through application and development of eco-design in EEE.

5.1 Risks and Toxicity

As indicated in the literature (European Commission, 2000), the risks relating to placing discarded electrical equipment in landfill are due to the variety of substances they contain. Due to the range of different substances in WEEE, unpredictable toxic hazards are potentially created by landfilling. Co-disposal with municipal waste adds to the unpredictability, and spreads the problem. While licensed, controlled landfills with liners do not eliminate risks of pollution, the potential amounts and concentrations – and resulting environmental impacts – are considerably higher when WEEE is put in uncontrolled landfills.

In the EU, the ‘Precautionary Principle’ has been applied in requirements to remove ‘substances of concern’, pending clarification on their hazardousness and appropriate treatment. Furthermore, some other components that are not specified in Annex II may be hazardous, and may need to be removed to render the WEEE item non-hazardous, for example, substances containing phthalate plasticizers or lead stabilisers, lithium batteries, and components containing mineral wools that are classified as category 3 carcinogens (AEA, 2004).

Notwithstanding, there is good (although not perfect) information about the toxicity of many WEEE components and the likelihood of damage to human health and the environment. Lead has well-known toxicity and is used widely in soldering, CRT screens and other EEE components. While the literature is less conclusive about the rate of leaching of lead from landfills, and further monitoring is required, it is well-established that lead leaches from landfill and evidence indicates that even low concentrations of lead can cause serious developmental effects on the brains of children. Mercury is used in smaller amounts in EEE, however, leaching of elemental mercury and the vaporisation of metallic mercury and dimethylene mercury, both contained in WEEE, are of concern. While leaching of mercury in large concentrations from well-managed landfills is unlikely, mercury is highly persistent in the environment and so causes long-term effects.

Cadmium is also highly persistent in the environment, although in the quantities it occurs in WEEE, it is most likely to be of concern to humans in the case of assembly and recycling/reprocessing workers. Chromium VI (hexavalent chromium) is of increasing concern because of its toxicity and leaching potential, while beryllium is less likely to cause a problem to humans and the environment, apart from assembly workers associated with assembly and disassembly of EEE. When BFR PVC plastic or cadmium containing plastics are landfilled, both PBDEs and cadmium may leach into the soil and groundwater, along with other components of these compounds and mixtures. BFRs are a major problem facing risk assessment, as they offer health benefits in reducing the risk of EEE catching fire during use, yet they are also toxic to both humans and the environment. Different BFRs provide different toxicity but the whole substance group of BFRs is listed on the Danish list of unwanted substances. Of the main groups, PBBs, Penta-BDE and Octa-BDE are banned under the RoHS Directive from July 2006, and, while Deca-BDE has been exempted from this ban, it is currently the subject of legal challenges from both the European Parliament and Denmark. With the current literature incomplete, there is enough evidence to warrant consideration of a precautionary ban on these BFRs, pending the development of alternatives which are already appearing on the market.

PVC is mainly a concern due to the risk of the release of chlorine, heavy metals used as stabilisers and phthalate plasticizers. The PVC industry is committed to tackling lead stabilisers within a decade, but this leaves other issues unresolved. A precautionary approach would therefore be to assume that the potential for leaching of chlorine, heavy metals and phthalates is possible. Similarly with phosphors, additives such zinc, terbium and arsenic are the main areas of concern regarding toxicity and pollution risk, although less-publicised and less well understood than PVC.

5.2 Conclusions

A major issue for policy formulation in New Zealand is the effect of policies and regulations elsewhere. The EU WEEE and RoHS Directives are already creating considerable industry transformation, and will bring new materials to the market, as well as new industries and techniques for effectively managing the product stewardship and end-of-life implications of the Directives. They can also be expected to have effects outside Europe, with more toxic EEE being 'dumped' onto markets in countries with less developed policy and regulations.

Of the substances reviewed in this study, lead poses major risks because of the amounts occurring in WEEE and the toxicity potential. Mercury, cadmium and chromium VI (hexavalent chromium) are also of concern both because of their toxicity and leaching potential, and their persistence in the environment. BFRs are a complex issue, with proven potential human health effects associated with some compounds, and documented suspicions associated with most current major commercial substances. Similarly, PVC is a major concern, as well as being a contaminant in recycling streams.

The state of knowledge regarding the toxicity of WEEE components is developing, with still some way to go before confident and accurate predictions of effects on humans and the environment for all WEEE substances can be made. While some studies are several years old, they remain relevant until new evidence is developed, and significantly more research is needed into the toxicity potential of WEEE. Until then, it is prudent to take a precautionary approach; indeed, three well-established principles can be drawn upon to guide policy development in WEEE management:

- **Precautionary principle**; where theory or circumstantial evidence suggests damage potential exists, in the absence of fuller evidence, it is prudent to assume the worst case and legislate accordingly;
- **Prevention is better than cure**; it is cheaper in the long run to prevent risks and impacts from occurring rather than to concentrate entirely on cleaning up problems, so eco-design mechanisms to minimise WEEE generation is a logical approach;
- **Polluter pays principle**; those who create the risks should incorporate the costs of dealing with them into their operating costs, for example, through operating product stewardship programmes.

Special Acknowledgements – Sources

This report is a collation of literature. Accordingly, acknowledgements are due in particular to a range of key current literature on WEEE, which are quoted from and referred to throughout this report. These sources include; Five Winds International. 2001; Environment Australia. 2001; European Commission. 2000; AEA. 2004; RCEP. 2003; and Townsend et al, 2003, 2004.

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Appendix: Definitions and Acronyms

The following definitions and acronyms have been used in this study:

CRT – Cathode Ray Tube, as in TVs and computer monitors.

EEE – Electrical and electronic equipment.

Hazard – property or situation in which particular circumstances can lead to harm.

Hazard Identification – determines what can go wrong by identifying a set of circumstances.

PCBs – Printed circuit boards (not Polychlorinated Bi-Phenols).

Probability – mathematical expression of chance (e.g., 0.2 is a 20% or one in five chance). Often not calculable and can only be expressed qualitatively (e.g., possible/likely).

PWB – Printed wiring board.

Regulation – The term 'regulation' is used in its broadest sense, being voluntary or mandatory mechanisms, legislation or formal initiatives of government or peak industry bodies.

Risk – a combination of the probability, or frequency, of occurrence of a defined hazard and the magnitude of the consequences of the occurrence.

Risk Assessment – consists of risk estimation and risk evaluation.

Risk Estimation – is concerned with the outcome or consequences of an intention taking account of the probability of occurrence. It includes predicting how likely it is that a set of circumstances will occur.

Risk Evaluation – is concerned with determining the significance of the estimated risks or tolerable level of risk for those affected: it therefore includes the element of risk perception.

RoHS – European Union Directive on the Restriction on the use of certain Hazardous Substances.

TCLP – Toxicity Characteristic Leaching Procedure, US precautionary-based test to assess maximum leachate. If the leachate produced using the TCLP contains certain elements at concentrations above a regulatory threshold, the solid waste is a TC hazardous waste (unless otherwise excluded). The TCLP analysis simulates landfill conditions. Over time, water and other liquids percolate through landfills. The percolating liquid often reacts with the solid waste in the landfill, and may pose public and environmental health risks because of the contaminants it absorbs. The TCLP, or Toxicity Characteristic Leaching (not Leachate) Procedure is designed to determine the mobility of both organic and inorganic analytes present in liquid, solid, and multiphase wastes.

US EPA – Environmental Protection Agency, USA.

WEEE – Waste electrical and electronic equipment.