Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

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State-of-the-Art Recycling Technology for Liquid Crystal Displays

STRIVE

Environmental Protection Agency Programme

2007-2013

SSTI Strategy for Science, Technology and Innovation

Comhshaol, Pobal agus Rialtas Áitiúil
Environment, Community and Local Government

Environmental Protection Agency

The Environmental Protection Agency (EPA) is a statutory body responsible for protecting the environment in Ireland. We regulate and police activities that might otherwise cause pollution. We ensure there is solid information on environmental trends so that necessary actions are taken. Our priorities are protecting the Irish environment and ensuring that development is sustainable.

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EPA STRIVE Programme 2007-2013

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Synthesis Report

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The EPA STRIVE Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Executive Summary

Liquid Crystal Display (LCD) technology has evolved and developed over the past two decades to replace Cathode Ray Tube (CRT) display technology as the market leader. This is evident, with predicted global market figures for liquid crystal displays surpassing $73 billion in 2010[1]. In turn, this will result in the increasing levels of used LCDs entering into the disposal / recycling stream. Under the European WEEE Directive[2], released in January 2003, LCD waste must achieve a rate of recovery of 75% by an average weight per appliance. Also, a direct requirement exists of the complete removal of the Cold Cathode Fluorescent Lamps (CCFL) within LCD televisions. These tubes provide the backlighting to the screen. Their removal is a prerequisite, as by their design they contain mercury for their successful operation. Mercury is classified as a hazardous material and therefore must be isolated from the LCD waste components during disassembly.

While the recycling methods for CRTs are well established, those of LCDs are as yet in their infancy. This project aims to address the challenges facing EoL (End-of-Life) treatment of LCD units by analysing LCD build types, structures and component material, to establish traits which may make EoL treatment less of a challenge. Analysing this data will lay the foundation to developing a balanced recovery system meeting the needs of economic viability and environmental conservation in future work.

This project culminated in the design, development, and successful testing of an automated method for the safe removal of the hazardous materials found within LCDs. Its fully automated nature allows a recovery through-put of on average 36 LCDs per hour. This is seen to be approximately ten times higher than manual disassembly methods. However, it is envisaged that through a series of further design reviews, the automated LCD machine, when constructed to an industrial specification, can exceed a through-put of 80 LCDs per hour. The obvious economic advantage, along with the intrinsic safety of an automated process, is seen to be a highly desirable technology

Annex II of the European WEEE Directive 2002/96/EC and Annex VII of the recast 2012/19/EU details regulations governing the recycling of Liquid Crystal Displays (LCDs). The Annex V of the recast states that 75% shall be recovered, while Annex VII states that components containing hazardous substances such as mercury and liquid crystals must be removed. This STRIVE research project has contributed to these policies in the following manner:

- Engaging with policy makers and advisors on the Steering Board of the project (EPA and DOE).
- Generating Irish statistical data on the amount of LCDs at End-of-Life in Ireland and comparison with EU.
- Ascertained the state-of-the-art LCD recycling available in Ireland through interviews, plant visits, surveys and cold calling.
- Identified a major problem facing Ireland in complying with the legislation: Unable to efficiently recycle LCDs due to lack of technology and currently waste LCDs are being stockpiled.
- Provide a solution to this problem which allows Ireland to meet the requirements of the legislation using a patent-pending automated technology.

[1] **Voorhees, S.**, Worldwide TV Forecasts, Display search, Editor. 2009.

[2] European Parliament and Council Directive on Waste Electrical and Electronic Equipment, 2002/96/EC.

The LCD recycling technology developed at the University of Limerick is a high through-put process designed with the aim to meet the WEEE directive requirements, remove the hazardous materials from the LCD display and provide fast recycling rates for LCD displays. The recycling technology is capable of processing approximately 80 LCDs per hour and separates the liquid crystal glass panel and the mercury containing CCLF tubes from the LCD display. The benefits are as follows:

- Instant removal of **hazardous substances/components**, in an environmentally-friendly process, which focuses on meeting the requirements of the WEEE directive.
- This recycling system is focused on processing **any type of LCD Television** regardless of size, make, model or shape.
- The removal of hazardous substances, which allows the possibility of a **shred process** for large scale operations. >**51%** of remaining material is ferrous metal-making magnetic separation viable.
- The time saving and costs saving for the recycler is great, as the process is capable of achieving processing rates of over **80 LCDs per/hour**.
- This technology focuses on achieving the safe recovery of these materials uncontaminated by mercury.

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1.0 Introduction

WEEE Legislation

Annex VII of the **Recast of European Waste Electrical and Electronic Equipment Directive** (2012/19/EU) details regulations governing the recycling of Liquid Crystal Displays (LCDs). Here, such items are contained under the headings of 'IT and Telecommunications Equipment' and 'Consumer Equipment.' The Annex V of the recast states that 75% recovery shall be required.

The **Recast of the RoHS Directive** (2011/65/EU) on the Restriction of Hazardous Substances in electrical and electronic equipment came into effect in 2011. It restricts the use of hazardous substances including lead, mercury, cadmium, hexavalent chromium and the flame retardants Polybrominated biphenyls (PBB) and Polybrominated diphenyl ethers (PBDE). The previous RoHS Directive covered several categories of electrical and electronic equipment including household appliances, IT and consumer equipment, but it has now been extended to all electronic equipment, cables and spare parts. The restricted use of mercury is of particular interest in LCD products, where the cold cathode fluorescent tubes contain mercury. Annex III of the Directive stipulates the mercury amounts per lamp length and type that is allowable in these products.

On 19 January 2013, the negotiations on a future global legally binding instrument on mercury concluded with 147 governments agreeing to the draft convention text for the **Minamata Convention on Mercury**. The objective of this Convention is to protect the human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds. The draft Minamata Convention was adopted and opened for signature at a Conference of Plenipotentiaries (Diplomatic Conference) in Kumamoto and Minamata, Japan which took place from 10 to 11 October 2013. Article 4 of the Convention states that parties shall not allow the manufacture, import or export of mercury-added products by the year 2020. Of particular relevance to LCDs, cold cathode fluorescent tubes for electronic displays are not exempt once a feasible mercury-free alternative is available for these devices (Annex A). With regard to the recycling of LCDs, Articles 8 and 9 stipulate the prevention of emissions to air from relevant point sources including waste incineration facilities, and the prevention of emissions to land and water from relevant points sources not addressed elsewhere. In addition, the convention required that developed country parties assist developing country parties with environmentally-sound alternative technologies where relevant, to strengthen the developing countries capacity to effectively implement the Convention.

With regard to the above legislation, the development of the LCD recycling technology achieves the following regarding the relevant legislation:

- Designed to achieve the Annex VII hazardous components removal (CCFL and liquid crystal display component) and the Annex V recovery rates of the Recast of the WEEE Directive.
- Designed to prevent the emission of Mercury to air, land or water.

WEEE Landscape in Ireland

The key players in the Irish WEEE recycling sector are the producers of EEE (Electrical and Electronic Equipment), the compliance schemes and the treatment facilities. Figure 1 outlines the relationship between these entities. All producers and importers of EEE must register with the WEEE Register Society (http://www.weeeregister.ie).

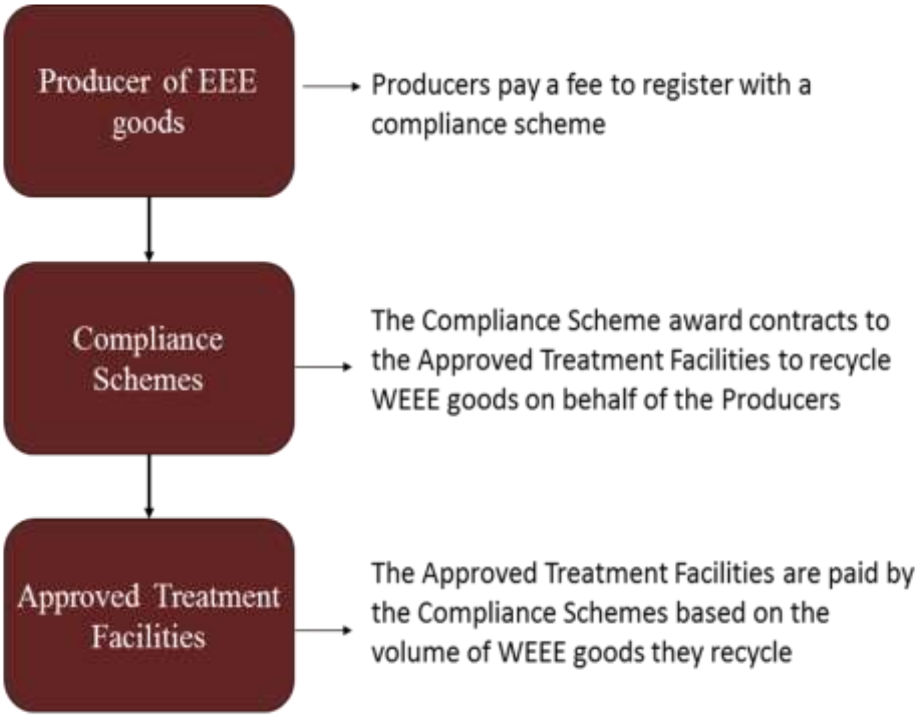


Figure 1 Key players in the Irish WEEE recycling sector

Figure 2 outlines the typical recycling system in Ireland, where WEEE waste is collected from civic amenity sites and take-back schemes, and the compliance schemes organise and engage the treatment facilities to process the WEEE waste on behalf of the producers. Two compliance schemes operate in Ireland; WEEE Ireland and European Recycling Platform.

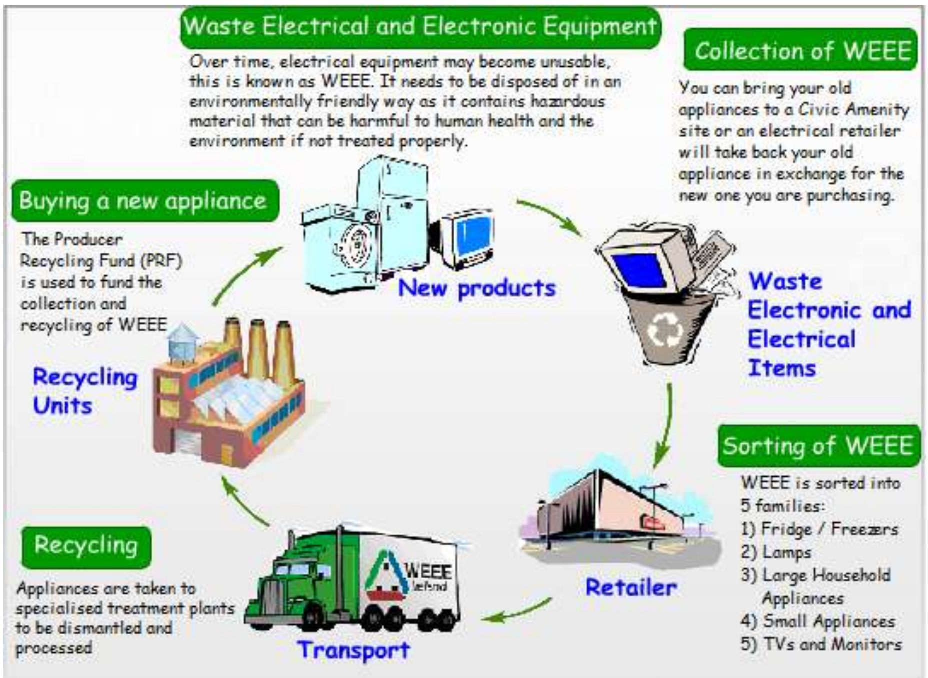


Figure 2 The Recycling System in Ireland. (Source: WEEE Ireland Website http://www.recyclefree.ie/howdoesitwork.html accessed on 28 June 2013)

Within Ireland, the Environmental Protection Agency (EPA) reported that the total amount of WEEE collected in 2011 was 41,092 metric tonnes [Environmental Protection Agency, National Waste Report, 2011]. The amount of TVs and monitors collected accounted for 6,651 metric tonnes of the total WEEE figure. This represents a substantial 16.2% of all electrical waste collected. The average amount of household WEEE collected from each person living in the Republic of Ireland was 7.6 kg in 2011, and this is nearly double the target of 4 kg per person specified by the original WEEE Directive in that year. A detailed breakdown of the proportions of LCDs, CRTs and Plasma screen televisions constituting the collected 6,651 metric tonnes was unavailable within the report. However, from meetings with operations managers of the WEEE Compliance Schemes in Ireland, a suggested figure of 95% by weight accounted for CRTs and 5% by weight accounted for the combination of LCDs and Plasma screen televisions. Hence, the current primary waste stream of television type devices within Ireland is based on CRT technologies.

State-of-the-Art

WEEE Ireland, one of the two approved WEEE Compliance Schemes, conducted a case study on CRT recycling and reported a recovery rate of 96.7% was being achieved [WEEE Ireland Annual Report, 2007]. The CRT recycling process is typically conducted with use of a semi-automated machine which assists in the separation process. The breakdown of material recovery from the CRT recycling was as follows:

Table 1.1-Recovered and Recycled Materials in a CRT Screen [WEEE Ireland Annual Report 2007]

Material	Percentage (%)
Ferrous Metal	4.02
Non-Ferrous Metal	13.05
Plastics	15.60
Glass	64.04
Total Recovery Rate	96.7

As a comparison, a disassembly study of LCDs was undertaken within this body of research and the breakdown by weight of materials found within LCDs is presented in Table 1.2 below.

Table 1.2 LCD Constituent Material Breakdown by Weight

Material	Percentage (%)
Ferrous Metal	44
Non-Ferrous Metal	28
Plastics	27
Glass	8
Others	18

Manual disassembly represents the current state of the art for LCD recycling in Ireland. While there exists a proven recycling technology for that of CRTs, a review of this technology was seen as a starting point and reference for the development of LCD recycling technology.

1.1 CRT Recycling Technology

Irish recycling companies reported that the CRT recycling process takes approximately 7-8 minutes to disassemble a CRT unit from start to finish. The essential automated process includes separation of the panel and funnel sections. A diagrammatic view of these parts is represented in Figure **1.1**. As shown, the CRT is composed of the neck, funnel and panel sections.

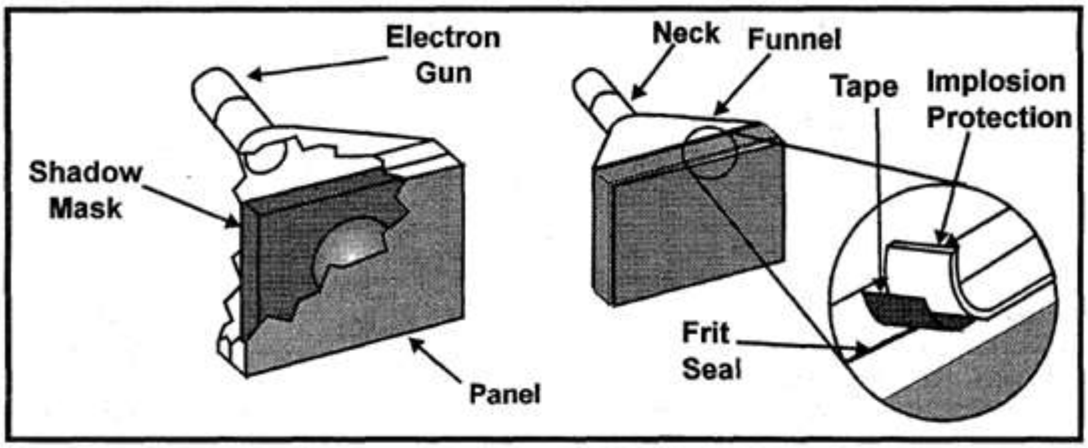


Figure 1.1 Construction of a Typical Cathode Ray Tube [Aanstoos et al., 1997]

The funnel and panel are soldered together with a glass solder known as frit. Each section of the CRT contains varying amounts of lead, as shown in Table 1.3. This high percentage lead content highlights the necessity for CRT recycling.

Table 1.3 CRT Lead Content by Part

CRT Part	Percentage Lead Content
Panel	0–3
Funnel	24
Neck	30
Frit	70

The first automated step involved in CRTs is the separation of the panel and funnel sections. This is achieved by various means, including: nitric acid, diamond cutting, thermal shock, hot wire splitting, LASER cutting and water jet. The second automated step involves removal of coatings from the funnel. This is achieved by processes including: soda blasting, caustic, waterjet and plastic media blasting. The machines which undertake CRT recycling are typically custom-built and sourced outside of Ireland.

1.2 LCD RECYCLING PROCESSES WORLDWIDE

Recycling technology for LCD displays originate from recycling plants, recycling equipment manufacturers, research groups, specialised facilities, patents and international journals and publications.

1.2.1 RECYCLING PLANTS

These facilities utilise several techniques to achieve material separation. The most basic technique includes manual separation, which involves physical labour to breakdown the LCD devices into their individual components. This technique is mainly employed within Small- to Medium-sized Enterprises (SMEs), and it is also found to dominate in countries with low labour costs.

A prime example of this includes the UK-based Recycling Lives manual disassembly plant. This €280,000 project was implemented with the guidance of the University of Central Lancashire. The company states its "groundbreaking" centre for LCDs is the first of its kind in England and that the Lancashire University is "at the forefront" of flat panel display research for the last four years [Lets Recycle, March 2011].

This investment in this most basic of LCD material separation techniques, clearly demonstrates both the viability and requirement for high through-put, automated LCD recycling solutions.

Other techniques for the disassembly of products within the WEEE waste stream include automated shredding, pyrometallurgy and energy from waste methods. The viability of these techniques depends on a sustained high through-put of waste material to overshadow the high setup and operational costs. The application of such techniques to recycling LCDs incurs other problems. The primary one includes the successful removal of the hazardous materials in their entirety. As shredding invariably mixes the waste material, this renders cross-contamination unavoidable. This is a definite issue for the processing of entire LCDs by shredding techniques.

1.2.2. Manufacturers of Recycling Equipment

Equipment available on the market takes the form of either shredding or CRT recycling equipment. No dedicated manufacturer was identified which specialised in the recycling of LCDs. This highlights a niche in the market for automated recycling technology.

1.2.3. Research Groups

There are a number of research groups who have previously researched or are actively researching LCD recycling technology. These include groups from Sweden, Europe and the United Kingdom. The Swedish LCD Centre is working with Hans Andersson Metal to develop a unique process for recycling LCDs. However, no information is available on the technology being used [Swedish LCD Centre, 2009]. Also the WEEE Forum, which is a European association of 39 electrical and electronic waste collection and recovery members, is actively involved in LCD recycling. Its most current project, investigating LCDs, looked at their disposal and existing treatment technologies. This project ran from 2009 to the end of 2010 at a cost of €532,300 [WEEE Annual Report, 2008]. Another project at the UK-based University of York is mainly focusing on recycling and recovery of individual materials post-dismantling of LCDs.

1.2.4 Specialised Facilities

Three main specialised facilities have been identified worldwide, which focus primarily on recycling LCD displays. These are detailed in Table 1.4 below.

Table 1.4 Specialised Facilities for Recycling LCD Displays

Company	Country	Technology
Kansai Recycling Systems Corporation http://sharp-world.com/corporate/eco/technology/lcd.html	Japan	Disassembly and Recycling
Hans Anderson Metal http://www.haindustri.com/index.aspx	Sweden	Disassembly and Recycling
Vicor Pilot plant http://www.vicor-berlin.de/	Germany	Disassembly and Recycling

The Kansai Recycling Systems Corporation is co-owned by the Sharp Corporation, Mitsubishi Corp., Sanyo Electric Co. Ltd., Hitachi Appliances Inc., Fujitsu General Ltd. and Mitsubishi Electric Corp. The corporation disclosed its recycling line for flat-panel TVs on March 18, 2009 and involved manual disassembly technology. The investment in this new line was reported to be €220,000 [Takata and Monozukuri, 2009].

Hans Anderson Metal reported a unique process for recycling LCD displays in collaboration with the Swedish LCD Center. The company stated the new technology had relatively low energy consumption and produced a high yield from the material for both small-scale and large-scale production. The technology was put into operation in early 2011; however no detailed information is available regarding the process [Recycling Bizz Website, 2009]

The German-based company VICOR has a pilot LCD recycling plant in operation, which manually separates the LCD components into its individual parts; the casing, electronic parts and polarisation films. It incorporates a distillation method to separate the liquid crystals and these are then passed to final storage in an underground landfill site. The other material fractions arising, namely glass, plastics and circuit boards, as well as structural elements, are processed further by conventional recycling methods. Disadvantages of the process include the technical complexity of the process, cost, and especially the subsequent landfilling of liquid crystals.

1.2.5 PATENTS

A comprehensive patent search was undertaken to identify technologies which dealt specifically with disassembly of LCDs into their individual components. All patents reviewed were generally concerned with techniques for recovery of specific LCD components, glass, liquid crystals and plastic.

The recycling of LCD glass for the production of new LCDs is described in the following patents; JP 2001/305501 A, JP 2001/305502 A, JP 2000/024613 A and JP 2001/337305 A. These patents detail techniques to recover the glass from LCDs; however the processes are complex and expensive since, in general, different glasses are employed for different LCD applications.

Thermal cycling to recover LCD plastics such as the cast parts, are generally separated off and either subjected to heat recovery or used for other products. Thermal recycling of such plastics is described, for example, in patent JP 2002/159955 A.

Processes for the removal of polarisation films, by mechanical removal, incineration or gasification, with subsequent comminution of the glasses are described in JP 2001/296508 A and JP 2001/296509 A. The disadvantage of these processes is that the glass obtained is highly contaminated and differ greatly in composition. They can therefore only be employed for low-value applications. While patent US 7553390 describes a process to cut the LCD glass and mechanically remove polarisation films, it does provide a holistic approach to the recycling of the entire LCD unit. Patent JP 2000/084531 describes a process for the recycling of LCDs, in which the LCDs are firstly shredded to particle sizes of less than 10 mm. The particles shredded in this way are subsequently employed in smelting furnaces at 1200° C for the removal of iron. Disadvantages in this process are, in particular, the complex comminution of the LCDs to particle sizes of less than 10 mm and the restricted use for the removal of iron.

No patented technology was found which infringed on the work undertaken within this body of work. No automation technology was identified which dealt with the removal of hazardous materials from LCDs.

1.2.6 INTERNATIONAL JOURNALS AND PUBLICATIONS

There are a number of publications referring to the treatment of general WEEE but few concentrating specifically on LCDs. These publications more specifically review techniques for precious material recovery. However, there are review journals which detail disassembly processes, and the most relevant of these to this body of work was researched by Shih and Lee [2007]. They reported on optimisation of recycling processes for LCD treatment. The researchers categorise the individual disassembly steps into 51 subassemblies and analyse the cost and environmental impact of each. Their results showed that maximum profit is achieved when manual disassembly is used to conduct the first 18 process steps, involving removal of hazardous substances and LCD panel modules. However, they also showed that minimum environmental impact is achieved when all 51 steps are carried out manually, as opposed to automated shredding processes. It must be noted that these results are based on current commercially available shredding technology and not state-of-the-art separation techniques, as developed within this body of work.

1.3 REGIONAL ANALYSIS OF RECYCLING TECHNOLOGY BY GEOGRAPHICAL AREA

Table 1.5 below details technology utilised within the recycling industry on a geographical basis.

Table 1.5 LCD Recycling Technologies by Geographical Region

Zone	Dominant Recycling Technology
Europe	All technologies including disassembly techniques, thermal treatment and shredding
USA	Landfill 80% of e-waste (preferred term in the US and Australia)
Australia	Commercial e-waste via disassembly or shredding - other e-waste typically landfilled
Asia	Manual disassembly
Africa	Manual disassembly

1.3.1 EUROPE

This region is governed by the Recast of the WEEE Directive 2012/19/EU and must be transposed by member states by 14 February 2014. The directive includes the recovery, recycle and reuse of WEEE. The regulations are seen as significant drivers of the continuous development and growth of the European recycling industry. This has led to the promotion of LCD recycling technology development with companies and groups such as: Hans Anderson Metal, Sweden; Vicor GmbH, Germany; The Swedish LCD Center, The WEEE Forum, France; York Liquid Crystal Research Group, UK; and the ReLCD Group in Austria. Hence Europe is now considered the hub of 'state-of-the-art' LCD recycling globally.

1.3.2 USA

In 2005, the USA discarded 1.36 – 1.72 million metric tonnes of e-waste mainly into landfills, only 0.34 million metric tonnes were recycled. According to the US Environmental Protection Agency, in the years between 2003 and 2005, approximately 80 – 85% of e-waste suitable for End-of-Life management was diverted to landfills [Kahhat et. al., 2008]. The USA also has bilateral agreements in place with developing countries which allows America to export e-waste. The lack of recycling in America can be attributed to the lack of federal level policies and regulations to address e-waste.

1.3.3 AUSTRALIA

There is an absence of national regulatory framework to deal with the e-waste issue. However, there are several recyclers who are expanding into this region. Of notable interest is Sim Metal Management. This organisation is the world's, as well as Australia's and North America's, largest metal and electronic recycler. However, the cost of their services, which is acceptable to commercial organisations, is found prohibitive to local authorities. This is also the case with individual householders who can dispose of their electrical items for free if they fit into their domestic wheeled bin [Takata and Monozukuri, 2009].

1.3.4 ASIA

In under-developed countries, electronic waste processing is usually undertaken by hand. While this offers benefits in terms of the human ability to recognise and save working and repairable parts, the disadvantage is that the labour is often cheapest in countries with the lowest health and safety standards. A high percentage of e-waste generated in Asia is recycled in China, especially in the Guangdong Province. However improper recycling methods have caused serious pollution in Asia [Sharp Website, 2007].

Generally, Asia represents the lower end of the scale in recycling technology, with one exception being Japan. The Kansai Recycling Systems Co. Ltd. disclosed its recycling line for flat panel TVs in March 2009. This is a manual disassembly plant with specially designed work stations to aid in speeding up the disassembly process.

1.3.5 AFRICA

Nnorom and Osibanjo [2008] report of the existence of large volumes of waste streams of obsolete electrical and electronic devices in developing countries, like Africa. There are high levels of trans-boundary movement of these devices, as second-hand electronic equipment in developing countries is an attempt to bridge the 'digital divide'. The past decade has witnessed a phenomenal advancement in information and communication technology (ICT) in Nigeria, most of which rely on imported second-hand devices [Recycling Magazine, 2009].

The disadvantages of Africa's growing information technology sector are both evident at the Ikeja Computer Village, near Lagos, Nigeria. Up to 75% of the electronics shipped to the Computer Village are irreparable junk, according to the Computer and Allied Product Dealers Association of Nigeria, a local industry group. Nigeria has a thriving repair market, but no capacity to safely deal with electronic waste, most of which winds up in landfills and informal dumps [Recycling Magazine, 2009].

1.3.6 SUMMARY

It can be seen that Europe represents the hub of state-of-the-art recycling technology, while regions like the USA and Australia are lagging in recycling technology development due to lack of national level recycling policies. Asia and Africa are on the receiving end of the WEEE waste, as they are importing large quantities of WEEE to dismantle manually as labour is cheap in these countries. Therefore, state-of-the-art LCD recycling technology is clearly being led from Europe, with the exception of Japan (Sharps Corp. and Kansai Recycling Systems plants). Ireland is obliged under the Recast of the WEEE directive to recycle all WEEE waste within its scope; hence, development of an LCD recycling process which replaces CRT recycling technology is essential.

1.4 STATISTICS ON DISPOSAL OF LCDS IN IRELAND

Table 1.6 shows that 50,626 tonnes of WEEE were collected in Ireland in 2007. This quantity is very similar to the figure reported for 2006. The tonnage of WEEE collected by waste equipment type has also remained largely unchanged. Of the total WEEE collected, 80% was treated in Ireland and 20% was exported to other EU countries [EPA National Waste Report, 2007].

The data on WEEE collected in Ireland in 2007 is based on information supplied by WEEE recovery operators, local authorities and the WEEE compliance schemes such as WEEE Ireland (www.weeeireland.ie) and the European Recycling Platform (www.erp-recycling.org) [EPA National Waste Report, 2007].

From the 1st December 2008, producers were responsible for meeting targets for percentage recovery, and percentage component, material and substance reuse and recycling by category of equipment, for WEEE sent for treatment. The recovery rates reported here indicate that, in 2007, Ireland exceeded the recovery targets, with the exception of the category 'Large household appliances' (77% vs. 80%).

Table 1.6 WEEE Collected, Sent for Recovery and put into Storage, 2011 [EPA National Waste Report, 2011]

Metric Tonnes	Fridges and Freezers	Large Household Appliances	TVs and Monitors	Lighting Equipment	Other WEEE	Total WEEE
Collected	5,971	13,604	6,6651	665	14,202	41,092
Of Which						
Sent for Treatment in ROI	0	8,412	5,842	552	6,653	21,460
Exported to EU	5,977	5.160	584	85	7,358	19,164
Recovered	5,190	10,989	5,708	560	34,759	34,759
Change in Storage	-6	32	225	28	386	386

As WEEE waste is not landfilled or incinerated in Ireland, it is either recycled or exported abroad. displays 7,404 tonnes of the WEEE collected in 2011 was treated as hazardous waste due to the presence of toxic substances. TV and Monitors are the typical category of WEEE which contains toxic substances.

Table 1.7 Location of Treatment of Reported Hazardous Waste, 2011 [EPA National Waste Report, 2011]

Category	On-site at Industry (Tonnes)	Off-site in Ireland (Tonnes)	Total (Tonnes)
Equipment (Electrical, electronic, mechanical)	0	7,404	7,404

The statistics available for the TV and monitor disposal in Ireland do not include a breakdown of the amount of CRTs and LCD displays. Statistical data is not reported on the recycling of LCD displays in Ireland. As part of this research, the WEEE compliances schemes were contacted and they reported that LCD statistical data is not collected, and the operations manager of WEEE Ireland estimate that less 5% of the TV and monitor category consists of LCD displays.

Three Irish recycling facilities were visited and also took part in a questionnaire. The results are shown in Table 1.8.

Table 1.8 Questionnaire Results of Three Recycling Facilities

Question	Recycling Facility 1	Recycling Facility 2	Recycling Facility 3
Estimate of LCDs received in 2008 (individual units)	200	1200	589
Estimate of LCDs received in 2008 (tonnes)	4	9+	4.3
Estimate of LCDs received in 2007 (tonnes)	1	3.5	Not recorded
Estimate of LCDs received in 2006 (tonnes)	1	1.5	Not recorded
What is the predominant size of screen being collected at the facility?	26-28”	14-24”	Not recorded

1.4.1 SUMMARY

It is clear that CRT disposal currently dominants the TV and monitor WEEE Irish recycling market. The majority of people are replacing their old CRT TV and monitors with new LCD technology. It can be seen that LCD disposal is on the increase from the above data. In 2006, two recycling facilities recorded 2.5 tonnes of LCDs were collected, which increased by 420% to 13 tonnes in 2008. The LCD recycling market is clearly on the horizon in Ireland; hence, within the next section, a literature review on the typical life cycle assessment of LCD displays is undertaken. This reviews how the manufacture, use and disposal of LCD displays impact the environment.

1.5 LCD LIFE CYCLE LITERATURE REVIEW

The goal of a Life Cycle Analysis (LCA) is to compare the full range of environmental and social damages assignable to LCDs. The term 'life cycle' refers to the notion that a fair, holistic assessment requires the assessment of raw material production, manufacture, distribution, use and disposal, including all intervening transportation steps necessary or caused by the LCD displays existence. The sum of all those steps or phases is the life cycle of the product. The assessment of a typical life cycle analysis is regulated under the ISO 14044 environmental management standards. The LCA system boundaries cover all materials from the point where electronic equipment become waste, until the point where the fractions from the various sorting, dismantling and recycling processes either become secondary raw materials or are disposed of by incineration or landfilling. An overview of the system is shown in Figure 1.2 below. Here Hischier et. al. in 2005 undertook a study of different WEEE treatment options in Switzerland, examining two Swiss take-back and recycling systems of SWICO (computers, consumer electronics and telecommunication equipment) and S.EN.S (household appliances).

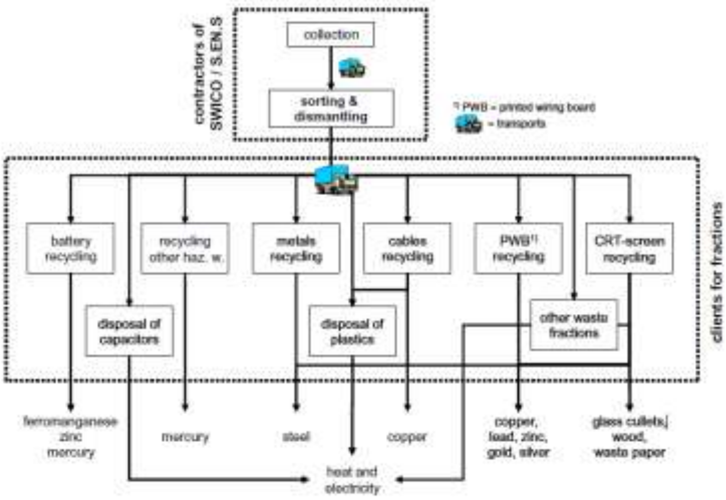


Figure 1.2 System Boundaries of the Modelled WEEE Take-Back and Recycling System [Hischier et. al., 2005]

Hischer et. al. (2005) reported that activities in the collection, sorting and dismantling phase of WEEE are only of minor importance in the entire secondary raw material production chain. An in-depth analysis of these phases shows that environmental impacts are dominated by the various transport activities within the collection phase. The sorting and dismantling activities contribute between 10% to the addition of unwanted substances and 40% to climate change phenomena in the total impact of this phase. From the results of this study, it could be concluded that a take-back and recycling system for WEEE, as established in Switzerland, has clear environmental advantages. However, it is not possible to recycle WEEE without causing any environmental impacts. In particular, the further treatment of products to produce secondary raw materials from them causes considerable environmental impact. However, the impact is much smaller than that from the respective primary production. This makes recycling of WEEE the preferred environmental disposal option.

Duan et. al. (2009) conducted a life cycle analysis of a Chinese desktop personal computer including the LCD display monitor. The following was found: The manufacture and use phases of LCDs generate significantly more impacts than the distribution and end of life disposal phases.

1.5.1 CONCLUSION

It is clear that there are positive environmental impacts of processing LCD waste for use as a raw material. In the Chinese study, it was found that LCD manufacture and use have higher environmental impacts then transportation and disposal. However, as LCD manufacture in Ireland is minimal, the LCD use phase, distribution and disposal are of main concern. As Ireland is a relatively small country, distribution would be envisioned to remain as one of the less significant impact factors. Therefore, environmentally-sound management of LCDs is critical to reduce the overall impact of LCD displays in Ireland. As LCDs in Ireland are dismantled and individual components sent abroad for further processing, Ireland currently has the advantage of minimal environmental impact of LCD disposal. As previously seen, the dismantling phase has minimal environmental impact [Hischier et. al., 2005]. Therefore, Ireland's continued investment in an efficient system for dismantling LCDs, would ensure continued minimal LCD impact on the environment in the future, as LCD disposal continues to increase.

2.0 Experimental Approach

A multi-disciplinary team of four researchers conducted research for this project. The work was divided into six stages or "Sections":

Section 1:	LCD Component Characterisation and Disassembly
Section 2:	Waste Management Technology
Section 3:	Prototype Design, Build and Operational Requirements
Section 4:	Identifying Applications for Materials Found in LCD Screens
Section 5:	Investigating the Potential of the Recycling Technology

Each researcher assessed LCDs from their own discipline. The primary researcher disciplines involved are: Material Science, Automation / Design Engineering, Mechanical Engineering and Automation Systems Engineering.

2.1 LCD Component Characterisation and Disassembly

A comprehensive review of LCD internal components, disassembly sequences / procedures, product variation, disassembly timings and disassembly technology was undertaken. This allowed the complexity / level of difficulty of automating the disassembly process to be realised.

2.2 Waste Management Technology

A review of companies and expertise specialising in waste sorting technology and companies vending destructive disassembly equipment were identified. This information gauged the commercial availability and the technical level of current recycling technology.

2.3 Prototype Design, Build and Operational Requirements

The prototype design was reviewed through the aid of drawings, an operational manual, health and safety manual, machine evaluation report, machine efficiency report, testing and debugging report, machine safety directives and Hg (mercury) containment and relevant machine guidelines review. These outlined the complete scope of the automated LCD disassembly machine and its processes. This section also addresses building and debugging of the prototype machine.

2.4 Identifying Applications for Materials Found in LCD Screens

A review of the materials recoverable from LCDs was undertaken and also a review of where these materials could be further processed was investigated.

2.5 Investigating the Potential of the recycling Technology

This section involves the review of feedback ascertained from a Steering Board which was initialised on day one of this project. It also looks at the WEEE market reports and trends and the impact these have on the commercial development of the technology put forward within this body of work.

3.0 Results and Discussion

What follows is a select review and discussion of the primary sections of the complete STRIVE report.

3.1 LCD COMPONENT CHARACTERISATION AND DISASSEMBLY

While the recycling methods for CRTs are well established, those of LCDs are as yet in their infancy. However, to reduce consumption of natural resources and reduce quantities of waste going to landfill, the recycling process must be encouraged and developed. This section highlights the challenges facing EoL (End-of-Life) treatment of LCD units by analysing LCD build types, structures and component material to establish traits which may make EoL treatment less of a challenge. Analysing this data will lay the foundation to developing a balanced recovery system, meeting the needs of economic viability and environmental conservation in future work.

3.1.1 LCD PHYSICAL STRUCTURE AND DISASSEMBLY PROCEDURE

From an analysis of LCD screens, it was established that the general structure of LCD units remains unchanged from supplier to supplier, however positional location of PCBs, screws, cables, speakers, etc., can differ radically from one manufacturer to the next and also within product families. It was established that the LCD unit consists primarily of the following components:

- Top Cover
- Lightbox Assembly
- PCB Mounting Frame
- PCBs
- Speakers
- Cables
- Back Cover

The lightbox assembly itself consists of a metal frame, LCD glass panel, plastic frame, a number of plastic diffuser sheets, Perspex sheet, Cold Cathode Fluorescent (CCFL) tubes, reflective foil and the lightbox support frame.

A comprehensive examination of 17 LCDs was undertaken within this body of work to ascertain the above components contribution by weight to the total LCD weight. This involved the segregation and weighing of the LCDs constituent parts, the data was then combined and is summarised in Figure 3.1 below. It is apparent that ferrous materials primarily contribute to the overall weight of an LCD screen.

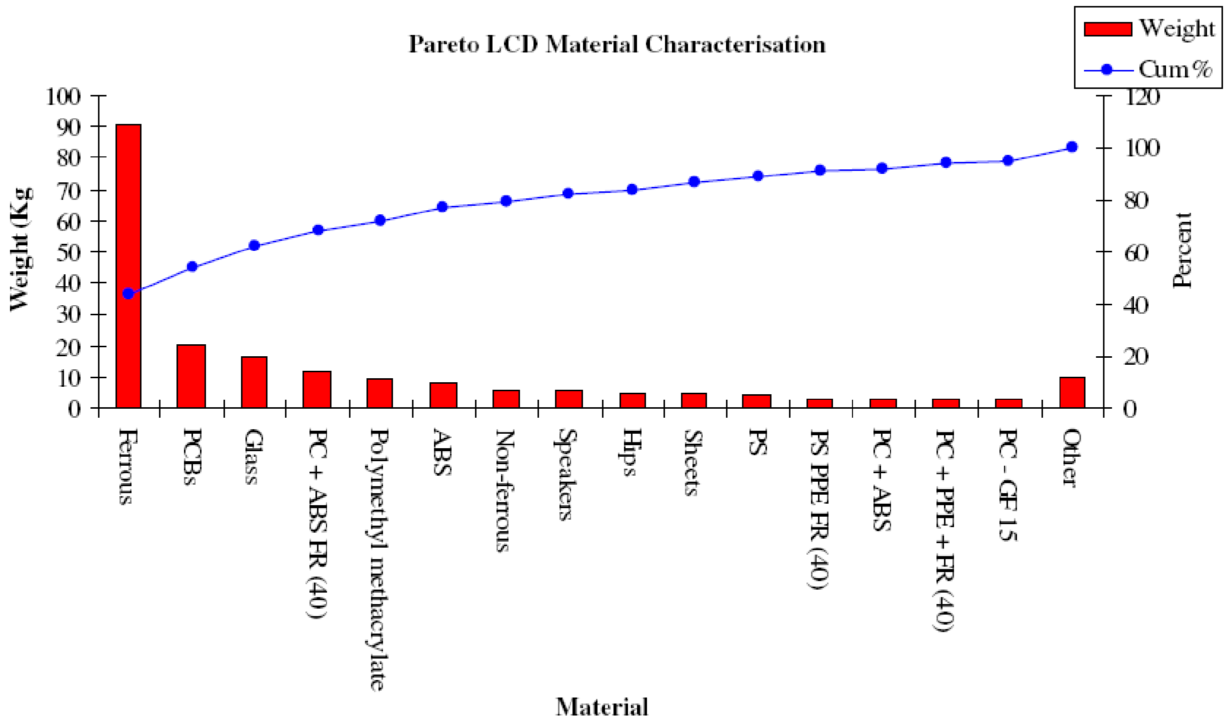


Figure 3.1 Pareto of LCD Material Type by Weight

On analysing the constituent parts of the LCD module, it should be noted that there are a number of potentially hazardous materials. CCFLs which contain small quantities of mercury require special treatment. CCFLs must be disassembled from the LCD module [Franke et al., 2006]. It was estimated that between 290 kg and 480 kg of mercury would ultimately have to be disposed of for all 80 million LCDs in use worldwide in 2010 [Displaysearch, 2007]. With LCD sales predicted to rise, the quantity of mercury to be disposed of as these LCDs reach their EoL (End-of-Life) is also increasing. It is essential, therefore, that any disassembly system / process developed is equipped to handle volumes of mercury and CCFL tubes.

The liquid crystal display glass is made up of a number of layers; these typically contain 25 or more components. These include glass, foil and liquid crystal compounds [Behrendt and Erdmann, 2004]. While the German Federal Environmental Agency has issued a statement stating the LCDs do not require special disposal due to the content of liquid crystals [Martin, 2005], and a report published by MERCK (liquid crystal manufacturer) claims that liquid crystals are “not acutely toxic, are not suspicious of carcinogenicity and are not toxic to aquatic organisms” [Martin et al., 2004], the European Union does not agree. In the WEEE Directive [Parliament, 2003], it is stated that liquid crystal displays (together with their casing where appropriate) of a surface greater than 100 square centimetres have to be removed from any separately collected WEEE. Accordingly, as the EU is of the view that the LCD glass panel represents an environmental risk, it is currently necessary to segregate and process the LCD glass aspect of the TV separately.

The EU WEEE Directive also states that PCBs greater than 10 cm^2 need to be removed from waste electrical and electronic equipment. Printed circuit boards are a constituent component of all electronic and electrical equipment and can contain various metals such as copper (Cu), iron (Fe), lead (Pb), zinc (Zn), gold (Au), silver (Ag) and platinum (Pt) [Becker et al., 2003].

It is apparent from different LCD manufacturers and of various sizes that there is significant variability within an LCD structure. This variation has considerable effect on disassembly. Design for disassembly and recovery is to the forefront of modern manufacture, however, as has been illustrated within the complete report, LCD manufacturing is a complex process with numerous fastening and joining technologies. This does not lend LCDs to be easily disassembled.

These variables ensure that disassembly is difficult and time consuming. Moving forward, LCDs should be designed with a view to End-of-Life material recovery, but this does not address the issue of millions of LCDs currently in production and in use worldwide. Key decisions such as the level of manual intervention required, the level of automation needed and the flexibility of the system need to be addressed, before a disassembly process to deal with these existing LCDs can be established.

While the layers of an LCD assembly are typically found to be a standard format from manufacturer to manufacturer, variation does occur in fastening technologies, position of components, types of material and orientation of components. This variation will have a significant impact on the ability to automate the disassembly process.

3.2 LCD DISASSEMBLY TIMINGS

Section 3.1 eluded to the fact that while LCD modules contain similar design features, there are numerous differences from manufacturer to manufacturer and within product families. This section aims to determine what effect these differences have on the time taken to disassemble an LCD unit. The same 17 LCD units as detailed in Section 3.1.1 and Figure 3.1 were used for this study, see Table 3.1 below.

Table 3.1 LCDs for Disassembly

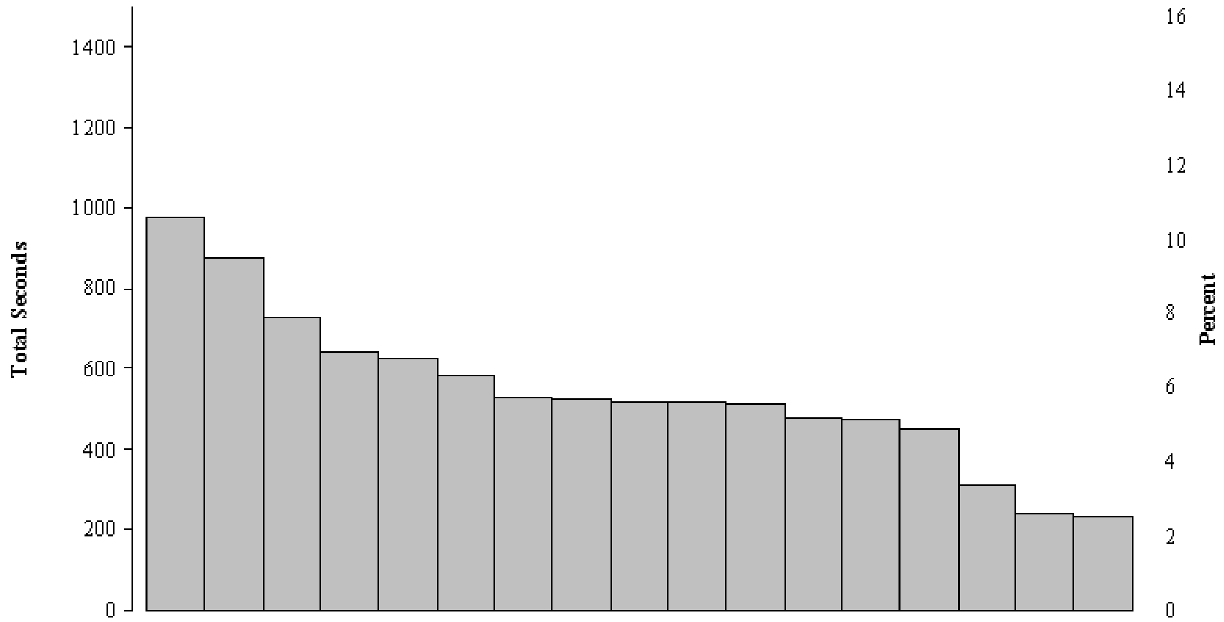
Screen ID	Manufacturer	Size	Screen ID	Manufacturer	Size
A	Sony Bravia	32”	J	Matsui	32”
B	Maxim	32”	K	Samsung	32”
C	Philips	32”	L	Advent	32”
D	Sony Bravia	40”	M	Sony	32”
E	Panasonic	32”	N	Maxima	32”
F	Philips	23”	O	Samsung	32”
G	Bush	27”	P	Bush	32”
H	Philips	27”	Q	Beko	20”
I	Sony	32”			

The objective of this disassembly evaluation was the non-destructive separation of modules and components to establish clean waste streams of potentially reusable or recyclable material free from contaminants. The data compiled from this manual disassembly process was then used as a datum against which the final developed automated disassembly system was measured. An automated disassembly system will need to be more efficient than current manual disassembly to justify investment and running costs.

This timing study highlighted the time consuming activities in manual disassembly and thus illustrated which processes would benefit most from automation.

Typical manual disassembly tools which are widely used in the recycling industry, e.g. electrical screwdrivers, manual screwdrivers and snips were used to perform the disassembly. The same approach was taken for each of the LCD screens, unscrew from the back cover, and work through the various layers to separate out the individual components.

Figure 3.2 illustrates the combined disassembly times for all 17 LCD units.



LCD	Q	A	J	E	G	D	H	C	B	M	F	K	I	P	O	L	N
Total	979	878	727	639	625	587	530	524	518	518	514	476	474	450	309	244	233
Percent	11	10	8	7	7	6	6	6	6	6	6	5	5	5	3	3	3
Cum %	11	20	28	35	42	48	54	60	65	71	76	81	87	91	95	97	100

Figure 3.2 Graphical Illustration of LCD Disassembly Timing

Clearly, from this graph, it is apparent that there is fluctuation in disassembly time between the LCD units. This primarily depends on the internal structure of the LCD unit, the number of screws, position of screws, clamping technology, etc.

Time consuming disassembly components within the LCDs will be identified below with a view to automating these processes and thereby improve the overall disassembly efficiency.

3.2.1. Time Consuming Disassembly Components within LCDs

Three specific disassembly operations for all LCD types consistently required a high manual disassembly time. These were:

- Removal of the LCD lightbox securing frame
- Unclipping of the CCFL tubes from the reflective backing panel
- Removal of the PCB boards.

Figure **3.3** shows a typical lightbox assembly. As can be seen, several securing screws hold the front surround fixture in place. This fixture effectively clamps the LCD screen, diffuser sheets and intermediate plastic sheets in place. Secondary securing of this fixture can take of the form of several metal / polymer press fit joints as shown in Figure 3.4; located on the outer vertical edges (vertical with reference to Figure **3.3**).

Figure 3.3 Fastening of LCD Glass in Lightbox Assembly

Alternatively, or in conjunction with the above two securing techniques, further securing screws can be found on some models. These lie on a horizontal plane relative to Figure **3.3**; along the outer vertical edge.

Figure 3.4 Metal and Polymer Press Fit Joint

This level of securing readily highlights the high investment in time required to manually disassemble the lightbox fixture, and in so doing, gain access to the CCFL tubes. If this procedure could be automated, disassembly time would be greatly reduced.

Figure **3.5** shows an opened lightbox with the LCD screen and related diffuser sheets removed. Direct access to the CCFL tubes is now possible. Several fixtures positively secure the tubes in place to the reflective backing panel; these include plastic tube supports, plastic tie clips, and in some cases, tie wrap systems.

Figure 3.5 CCFL Tubes Secured to Backing Frame

From a manual disassembly perspective, the successful removal of the tubes without breakage requires delicate handling. This then requires a high investment in time.

Figure 3.6 shows a typical layout of control PCB boards which are found on opening an LCD screen. The boards can vary in number and have several securing screws, clips and associated wiring. Even with the use of electric means to remove the screws, much time must be invested to remove these parts.

Figure 3.6 Typical PCB Layout

In conclusion, these potential bottlenecks in manual disassembly provide a logical starting point for the design of an automated disassembly system. If it is possible to reduce the time taken to disassemble these specific parts, then the recycling process becomes more economically viable and therefore more attractive to potential recyclers.

3.3 WASTE MANAGEMENT TECHNOLOGY

The recycling industry incorporate various technologies including: manual disassembly, shredding, smelting, crushing, semi-automated disassembly, magnetic / eddy current separation technology, incineration and energy recovery, cylonic disassembly, grinding, grading mechanisms, purification and compounding of polymers, flotation separation, smelter, foundry and electrolysis systems, distilling, granulation and gravity separation.

As applied to Ireland manual disassembly, shredding and sorting techniques dominate. These technologies, which are relatively basic, offer an adequate working solution to the country's current waste stream. However, manual disassembly is a slow process, allowing on average only 3 – 4 LCDs per hour per worker to be processed. Also LCDs cannot be shredded, as their hazardous material contents will contaminate the waste stream – which is the aim of Annex II of the WEEE Directive 2002/96/EC and the Recast Directive 2012/19/EU. With the predicted growth of LCD sales, investment must be forefront in recycling technology to engage Ireland's inevitable increase in LCD waste. In addition, the next generation of displays, including the Light Emitting Diode (LED) displays, are also governed by the WEEE legislation. An LED-backlit LCD display is a flat panel display which uses LED backlighting, instead of the cold cathode fluorescent (CCFL) backlighting used by most other LCDs. While not an LED display, a television using this display is called an "LED TV" by some manufacturers and suppliers. These displays still contain liquid crystal components and must be treated according to the WEEE directives.

Shredding forms a basic operation within the recycling industry. The reduction of the waste stream into a workable size allows more efficient and effective post-processing to take place. However, this destructive process is made viable through the implementation of post-sorting technology. Sorting can take many forms, including magnetic / eddy current technology and grading systems. More advanced flotation and electrolysis systems are also implemented.

Thus, in relation to LCD disposal, a system which isolates the primarily hazardous materials and removes these from the display is seen as complementary to the processing currently taking place within Ireland. Such a technology was developed within this body of work and is reviewed within the next section.

3.4 Prototype Design, Build and Operational Requirements

Full automation of the process involved the design and build of a prototype to carry out the entire process without any required manual intervention, see Figure 3.11. The prototype was manufactured and assembled in-house within a six month time period.

A method of disassembly would be to mechanically sever through the LCD display. This process would also provide direct access to the LCD CCFL tubes for removal, eliminating the number of steps required to present the tubes for recycling, thereby making the process more efficient (Figure 3.7 and Figure **3.8**).

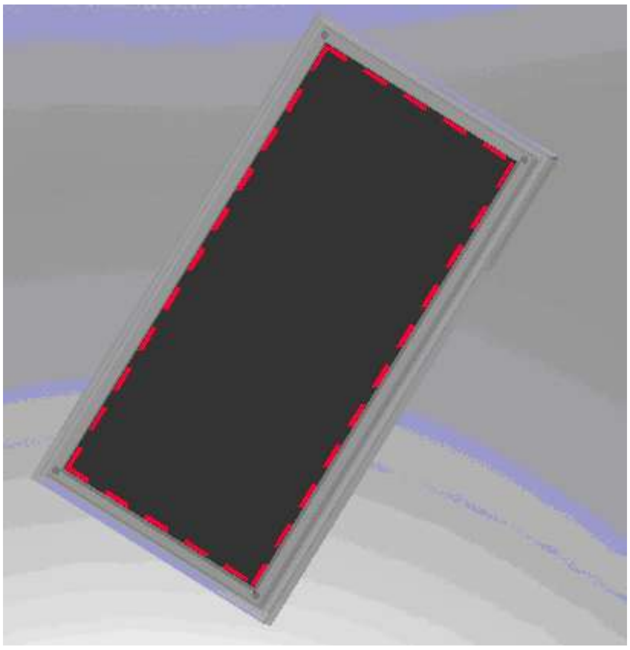


Figure 3.7 Mechanically sever through LCD

Figure 3.8 CCFL Tubes Exposed for Removal

Figure **3.9** illustrates the process flowchart for the vertical cut through the panel. It is apparent from this flowchart that the hazardous materials are removed within 4 process steps; this represents a clear advantage over the manual disassembly process which took 7 process steps to achieve CCFL tube removal.

Quick access to the hazardous materials ensures that the potential to contaminate future waste streams is reduced and also ensures that the potential impact to employees handling the waste units is reduced.

Figure **3.9** details the overall process flow for a mechanical sever through the LCD screen, while Figure **3.10** indicates the materials flow through the process.

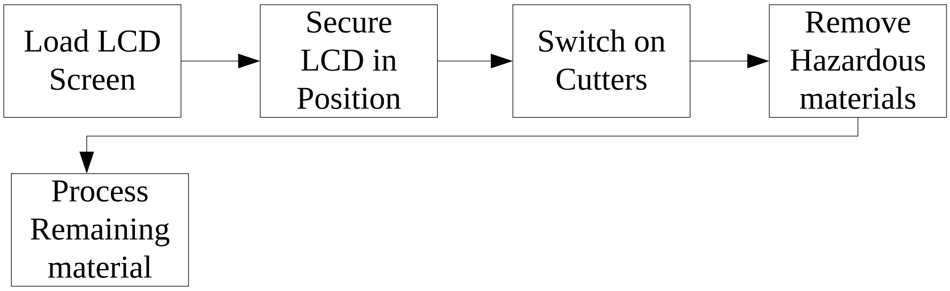


Figure 3.9 Mechanical sever through LCD Screen Process Flowchart

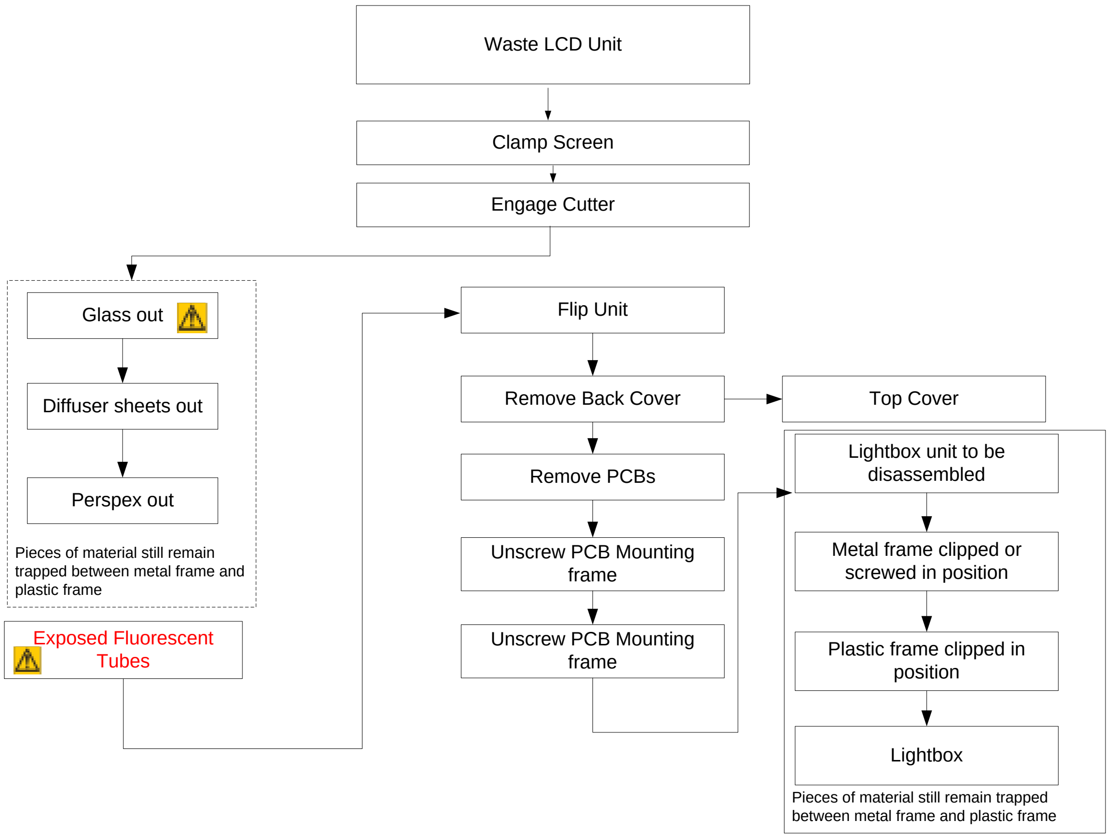


Figure 3.10 Mechanical sever through LCD Materials Flow Diagram

Figure 3.11 Picture of the Prototype

Machine Specification:

Dimensions: ≈ 3.5 X 3 metres

Technical aspects:

Motors X3, gear box X2, lead screw carriage X2, 4 specially adapted grinders, a pivoting weighting system, PLC automation control, overload electrical cutout, guarding system, transfer system, datum block for positioning, pneumatic cylinders X3, automated slide arms, sealed evacuation chamber, shaft with rotable chains and an extraction system.

After extensive testing of the prototype / process (including >450 different LCD models and dimensions), it has been concluded that the process is a success in the following aspects:

- Removal of the liquid crystal panel successfully.
- Removal of the mercury containing CCFLs successfully.
- Process was applicable to all make / models and variations of LCDs.
- Prototype process throughput ≈ 36 LCDs / Hr.

The machine can be divided into three distinct phases, with Sections one and two carrying out severing operations on the LCD, and Section three undertaking CCFL removal. A 3D representation of Sections one and two is shown in Figure **3.12** below. Refer to the EPA STRIVE Report 2008-WRM-MS-5-S1 entitled "State-of-the-Art Recycling Technology for Liquid Crystal Displays" for a complete description of the prototype. A brief description of the three sections follows below.

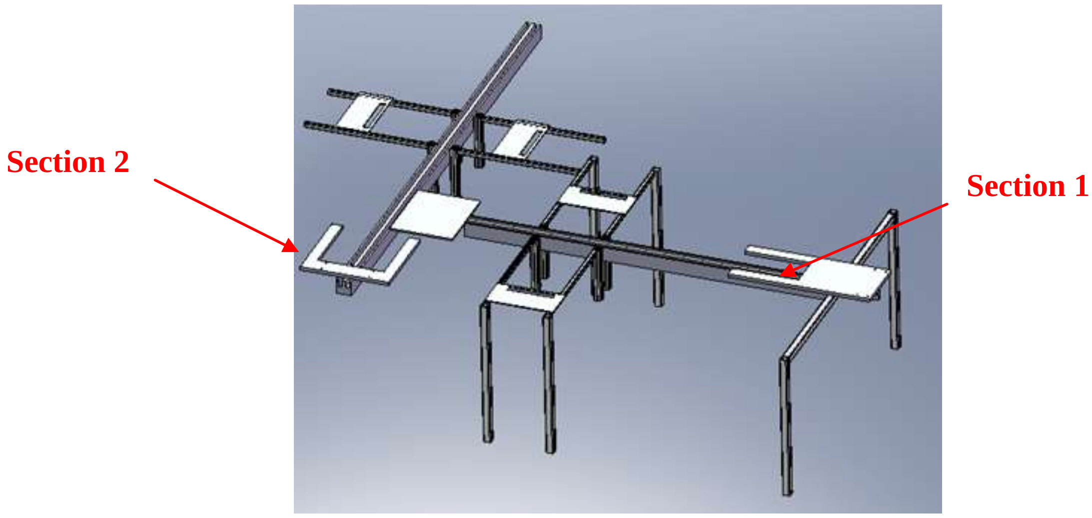


Figure 3.12 LCD Recycling Machine

3.4.1. LIQUID CRYSTAL PANEL REMOVAL STATION 1

This section begins the initial processing of the LCD by the application of an incision along the LCD body. The LCD to be recycled is loaded onto Section one of the machine. The operator begins the cycle by pressing the start button and the fully automated sequence now initiates. Once the machine is loaded and the cycle has started, no further operator input will be required, unless the cycle is disrupted by an emergency stop or equipment fault.

3.4.2 LIQUID CRYSTAL PANEL REMOVAL STATION 2

This section applies a second sever to the LCD body and in so doing allows the CCFLs to be accessed directly. As in Section one, no operator input is required, unless there is a disruption to the normal cycle of operation. The process is fully automated and the indication of process progression, status and faults will be displayed to the operator on the Human Machine Interface (HMI).

3.4.3 FLUORESCENT TUBE REMOVAL STATION 3

Here, material severed during Sections one and two are removed and direct access to the CCFLs is attained. Due to inspection requirements within Section three, the operational sequence is semi–automatic in nature. Requirements are placed upon the operator to visually inspect and confirm the correct removal of severed material. A push button mounted locally on Section three is required to be depressed such that the operation continues. Once depressed, the LCD is moved into a sealed unit for automated removal of the CCFLs.

3.4.4 OPERATIONAL REQUIREMENTS

To meet the safety requirement and to manufacture safe products, it is essential that the manufacturer understands the principles of safety. The requirements of safety standards are, in general, intended to prevent injury or damage caused by the following hazards:

- Electric shock
- Fire

- Energy
- Heat
- Mechanical
- Radiation
- Chemical
- Material

In order to design a machine to meet the above requirements, it is necessary to take the following into account:

- Component safety and reliability
- Component selection and conformity verification
- Constructional data forms
- Equipment classification
- Power consumption
- Rating label
- Markings and indicators
- Input, wirings, terminations and identifications
- Insulation and separation of circuits
- Grounding
- Power disconnect
- Circuit and thermal protection
- Stability and mechanical hazards
- Warnings, instructions and languages
- Flammability of materials
- Electrical safety testing
- Production tests

Additional requirements for machinery:

- Protective measures
- Mains disconnection switches
- Emergency stop switches
- Fault tolerant components
- Safety circuits
- Transformers
- Motors
- Wiring
- Protective earth
- Access areas
- Enclosures
- Functional markings
- Item designations
- Warning symbols
- Manuals
- Technical documents

3.4.5. Mercury Containment and Relevant Regulations

The term ‘containment’ is used to describe equipment or systems that prevent release of hazardous materials into the environment, in our case mercury (Hg) from LCD displays, during the recycling process. Containment is defined as utilisation of engineering controls, as follows:

- To prevent the escape of materials hazardous to health into the surrounding workplace.

The containment of hazardous substance is regulated by the EN 626-1 standard on:

- Safety of machinery - Reduction of risks to health from hazardous substances emitted by machinery - Part 1: Principles and specifications for machinery manufacturers.

This standard has been produced to assist designers, manufacturers and other interested bodies to interpret the essential safety requirements in order to achieve conformity with European Legislation on machinery safety. According to the standard, hazardous materials include any chemical or biological agent which is hazardous to health:

- Very toxic
- Toxic
- Harmful
- Corrosive

- Irritant
- Sensitising
- Carcinogenic
- Mutagenic
- Teratogenic
- Pathogenic
- Asphyxiants

The hazardous substances may arise from:

- Any part of a machine
- Substances present in the machine
- Material arising directly or indirectly from articles and / or substances processed by the machine or used on the machine. (This is seen to be the most relevant to that of CCFL removal).

Type of emission of hazardous materials as listed in the standard, indicate airborne emissions may arise from various sources, the most relevant include:

- Evaporation
- Hot metal processes e.g. cutting
- Material handling
- Leaks
- Maintenance
- Dismantling processes

The dismantling processes is the source that is most relevant to that of recycling LCD displays, where the substance mercury is present in the screens and the risk of inhalation of mercury is high. Mercury affects the nervous system and the kidneys and therefore represents a high risk.

Airborne emissions may be subject to techniques of evaluation based on the measurement of concentrations of substances in the breathing zone of the persons involved. The National Council for Occupational Safety and Welfare: 2002 Code of Practice (Ireland) for the Safety, Health and Welfare at Work (Chemical Agents) Regulations, 2001 (S.I. No. 619 of 2001) sets the maximum concentration of a chemical agent (mercury) in the air in a workplace to which workers may be exposed, in relation to an 8 hour reference period and at a temperature of 25^{o}c, to be < 0.025 mg / m^3.

3.4.6 SUMMARY

The automated removal of hazardous materials from LCD screens can be successfully implemented. Automated disassembly technology, as developed within this body of work, offers a high throughput processing solution to the growing stockpiles of LCD screens.

Operational requirements must be met as outlined in Section 3.5.4. European legislatory requirements ensure safety directives are enforced and that manufacturers must provide documentary conformance. The automated technology as presented in Section 3.4 is listed as a high risk machine and as an Annex IV machine in the European Machinery Safety Directive (MSD).

The CCFL automated LCD recycling machine removal section is governed under the The National Council for Occupational Safety and Welfare. This requires workers to be exposed to a maximum concentration of less than 0.025 mg / m^3 of mercury vapour in an 8 hour period. In order for this to be met, carbon filtration systems which absorb mercury along with a high rate of “air changes per hour” need to be implemented. Also, the CCFL removal section may be constructed such that it is within an isolated enclosure which is under negative air pressure.

3.5 Quality of Separated Materials

This section analyses the quality of the separated materials derived from the processing of LCDs on the LCD recycling machine. It focuses on potential damage to the structural integrity of these materials during the process.

The hazard-free materials derived from the recycling process can be categorised into three groups:

- Main LCD body with hazardous materials removed, i.e. LCD Screen and CCFL tubes removed.
- Diffuser panels: composed primarily of translucent plastic sheets.
- Liquid Crystal Display screen.

These separated materials are hazard-free and can be disposed of safely or continued for further processing to recover electrical components and other key materials.

3.5.1 Quality of the Main LCD Body Post Processing

The processing of the LCD during the first two sections of the LCD recycling machine process instils a certain degree of damage to be borne by the chassis of the LCD television as a whole. This, in turn, facilitates the separation of the diffuser sheets and liquid crystal display from the main chassis. And thus, in turn, exposes the backlight fluorescent tubes for further processing in stage three of the LCD recycling machine.

As a result of the recycling processes undertaken in Section 1 and Section 2 of the LCD recycling machine, sections of the LCD chassis main body, composed mainly of plastic from the housing, can become separated.

After completion of Section two, the separated materials of the LCDs main body are removed.

Figure 3.13 LCD Body

3.5.2. Quality of the Liquid Crystal Display and Diffuser Panels

On completion of Section two, the separated liquid crystal display and back light diffuser panels are ejected from the LCD recycling machine via gravity conveyor for inspection and disposal.

The separated liquid crystal display and back light diffuser panels suffer minimum damage during the separation stages and are detached from the LCD main body intact.

Figure 3.14 Liquid Crystal Panel

3.6 Identifying Applications for Materials Found in LCD Screens

A forecasted breakdown of materials recycled from Irish LCDs on a per annum basis is graphed in Figure 3.15 on the following page. The figures used to populate this graph were derived from a projected recycling through-put of 300,000 LCDs per annum. This is the case, as the current number of CRTs recycled in Ireland is approximately 300,000 per annum, and this is expected to be completely replaced by LCDs within 5–10 years.

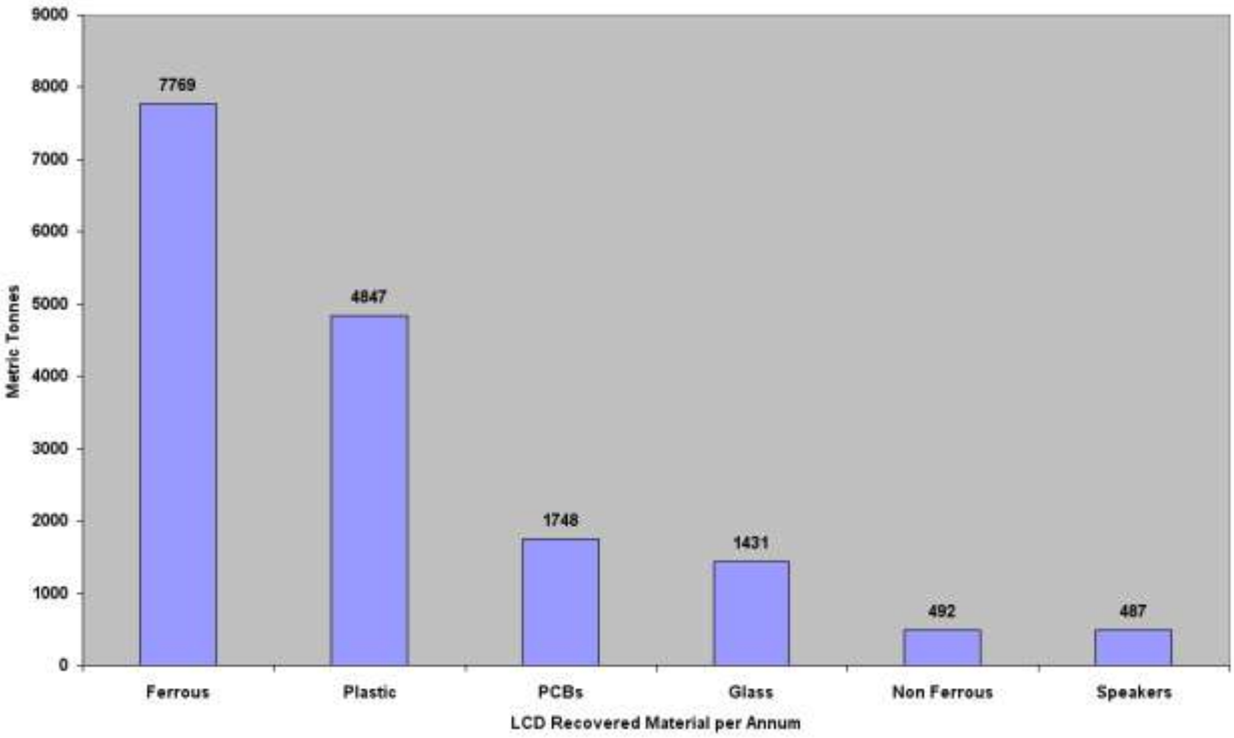


Figure 3.15 Projected Irish Material Recovery from LCD Recycling on a per Annum Basis assuming 300,000 waste LCDs per annum

3.6.1. FERROUS MATERIALS

In 2008, over 686 thousand metric tonnes of metal waste was recycled in Ireland, 8% of this was from packaging waste alone [Repak, 2008]. From Figure 3.15, recycling of steel from LCDs can potentially contribute to 1% of this figure, where a minimum recovery rate of 75% of materials from LCDs is achieved, according to the recast of the WEEE Directive. Within Ireland, several recyclers collect recycled steel scrap, however, re-processing is undertaken abroad.

3.6.2 PLASTICS MATERIALS

Plastic recycling is the process of recovering scrap or waste plastics and reprocessing the material into useful products, sometimes completely different in form from their original state. Typically, a plastic is not recycled into the same type of plastic, and products made from recycled plastics are often not recyclable.

When compared to other materials like glass and metal materials, plastic polymers require greater processing to be recycled. Heating alone is not enough to dissolve mixed plastics and hence, the plastics undergoing recycling must often be of nearly identical composition in order to mix efficiently.

When different types of plastics are melted together they tend to phase-separate, like oil and water, and set in these layers. The phase boundaries cause structural weakness in the resulting material, meaning that polymer blends are only useful in limited applications. Another barrier to recycling is the widespread use of dyes, fillers, and other additives in plastics.

Several plastics are present in different LCDs. These include:

- Polycarbonate (PC)
- Acrylonitrile Butadiene Styrene (ABS)

- High Impact Polystyrene (HIPS)
- Polystyrene. (PS)

However, they are generally mixed with various compounds, matrix materials and potentially flame retardants, such as:

- Flame Retardant - Halogen-Free Organic Phosphorus Compounds
- Polyphenyl Ethers
- Glass Fibre Reinforcement.

Within Ireland, several recycling companies collect plastics material and reduce it for recycling. These companies includes:

- Shabra Group (Monaghan)
- Greyhound Recycling & Recovery (Dublin)
- Polymer Recovery Ireland (Laois)
- FRS Farm Plastic Recycling (Tipperary)
- Mr. Binman (Limerick)
- Plastic Recycling Solutions (Derry)
- Envirogreen (Tyrone).

Companies within Ireland who actively reprocess recycled plastics materials include:

- Emerald Isle Recycle (Antrim).

3.6.3 PCB MATERIALS

One can recover all the metallic elements on a printed circuit board such as the copper, nickel, tin and lead from the solder. Also, small quantities of precious metals, such as gold, palladium and silver are recovered. Figure 3.15 indicates 1,748 metric tonnes of PCB recyclable material could be liberated from LCDs each year. Within Ireland, several recycling companies collect and reduce PCB waste material for further processing. These include:

- Electronic Recycling (Dublin)
- Greenstar (Dublin)
- Indaver Ireland (Dublin, Cork, Meath).

3.6.4 GLASS MATERIALS

Glass recycling is the process of turning waste glass into usable products. Glass waste should be separated by chemical composition, and then, depending on the end use and local processing capabilities, may also have to be separated into different colours. Many recyclers collect different colours of glass separately since glass retains its colour after recycling. Every metric ton of waste glass which is recycled saves 315 additional kilograms of carbon dioxide from being released into the atmosphere during the creation of new glass [Waste Online, 2006].

A report from the European Container Glass Federation has reported a rise in recycled container glass in Ireland from 19% in 1990 to 69% in 2004 [FEVE, 2001]. This shows the current market trend and growing demand for recycled glass raw material. As from Figure 3.15, 1,431 metric tonnes of glass is contained within 300,000 LCDs. Within Ireland, several recycling companies collect glass material and reduce it for further re-melting and reuse. Companies such as Quinn Glass, based in Fermanagh, is one example of a company which re-processes Irish waste glass.

3.6.5. NON-FERROUS MATERIALS

From Figure 3.15, approximately 492 metric tonnes of aluminium may be recovered from LCD recycling per annum. This metal can be recycled indefinitely without losing any of its properties.

Recycling aluminium requires only 5% of the energy and produces only 5% of the CO_2 emissions as compared with primary production and reduces the waste going to landfill. This makes aluminium one of the most cost-effective materials to recycle. Aluminium can be recycled indefinitely, as reprocessing does not damage its structure. For this reason, approximately 31% of all aluminium produced in the United States comes from recycled scrap [Mineral Resource Program, 2008].

Alupro, which is an Irish organisation funded by the European Aluminium Association, has identified the two primary companies which undertake Ireland's aluminium scrap collection and reprocessing as:

- Thorntons Recycling (Dublin, Meath, Kildare)
- Novelis Recycling (Cheshire, UK).

Thorntons Recycling is one of the most successful companies in Ireland's recycling industry, recovering over 80% of the 250,000 tonnes of material processed annually. The company operates a number of facilities in Dublin, Meath and Kildare. However, Thorntons acts as a collector of aluminium, bales it and sends it to a smelter for further processing.

Novelis Recycling is based in Warrington, Cheshire and produces aluminium ingots for the beverage can manufacturing industry. It has the capacity to recycle 130,000 tonnes of used aluminium per annum.

3.6.6. Magnet Recycling / Speakers

Rare earth materials are typically dispersed throughout the world and not often found in concentrated and economically exploitable forms. These materials include rare earth magnetic elements as used in the manufacture of LCD speaker devices. In order to become more self-sufficient in rare earths, Japanese manufacturer Hitachi has developed a more efficient system to recycle rare-earth magnets from discarded technology [Recycling International, 2011]. The company has devised innovative machinery which is said to be capable of extracting 100 magnets per hour, compared to the current manual approach which enjoys a typical extraction rate of around 12 magnets per hour.

Although rare-earth minerals are relatively common in the Earth's crust, few nations or companies have invested in sourcing these materials. However, as prices rise and with China looking to safeguard its own supplies, there is now a greater incentive to open up new sources. Celebrating its 100th anniversary, Hitachi's 'green' shift is being replicated among other Japanese companies: for example, Samsung made a US$4.3 billion commitment to green technologies in July last year (2010).

Clearly the push to recycle these rare-earth magnets is growing in pace within the global market. As shown in Figure 3.15, approximately 487 metric tonnes per annum of speakers could be directed towards rare-earth material extraction.

3.6.7. Summary

Clearly, Ireland is heavily reliant on the processing of its waste by its neighbouring countries. This is apparent due to the limited reprocessing facilities within Ireland. The large majority of Irish recyclers export sorted waste materials as volumes of materials are not sufficient to allow full-scale recycling in Ireland. This, however, has a beneficial effect on the environmental impact Ireland experiences due to waste materials. Recycling of Irish LCDs yields approximately 17 thousand metric tonnes of potentially reuseable materials. Hence, this more clearly highlights the elevated importance of implementing successful LCD automated disassembly technology on a commercial scale.

3.7 Investigating the Potential of the Recycling Technology

Survey of the Steering Board Evaluation of the Technology

A Steering Board from industry was involved from day one on this research. The Steering Board consisted of end users, trade bodies and relevant personnel from industry:

- KMK Metals - WEEE recycling company specialising in TVs
- WEEE Ireland - Irish compliance scheme for waste electronics
- Irish Lamps- Irish mercury lamps recycler
- EPA - Environmental Protective Agency
- DEHLG - Department of the Environment, Heritage and Local Government

To ensure that the research had a customer driven focus, the majority of the members of the Steering Board came from industry and government sectors. The objectives of the Steering Board were to:

- Give recommendations on the technical activities of the project
- Co-ordination of knowledge management and other innovation-related activities
- Provide the project with strategic management in line with current environmental policies
- Advise on the exploitation of results and common marketing strategies.

The Steering Board met twice a year at the University of Limerick. Individual meetings and plant visits were also held throughout the year. This was essential during the process design phase to ensure the process output was what the recyclers required.

Feedback Received

After the machine build was completed and tested, it was then demonstrated to the Steering Board. Following this, the Steering Board provided feedback in the form of a survey on the technical and commercial aspects of the machine. The conclusion from the feedback was as follows:

Summary of technical aspects:

- The technology 'supplies a much needed solution to the industry'
- Option to duplicate plants in other EU countries
- Easily separated recyclables
- Offers compliance with regulations
- Low manpower and high automation.

Summary of commercial aspects:

- Steering Board concluded that the lack of technology for recycling LCDs was a serious problem; especially as the industry faces an increased LCD waste stream.
- Steering Board believed that this is a serious problem facing both Ireland and the EU.

3.7.1 Engaging with the Recycling Sector

A number of relevant conferences and shows have been attended including:

- Recover, Irish Recycling and Waste Management Show, 24th March 2009, RDS, Dublin.

  What was learned/achieved by attendance: The research team met a number of prominent Irish recyclers including KMK metals; opportunity to talk with equipment manufacturers and distributors; confirmation that LCD recycling technology is not available nationally.

- UKDL Event – E-Waste Management and Manufacture for Recycling and Disassembly, 17th June 2009, Birmingham.

  What was learned/achieved by attendance: Event had a sub-session on LCD recycling; the research team met prominent recyclers in

Liquid Crystal from University of York who were researching LCD recycling technology in a EU project; learned they had no technology developed; conference was internationally attended, and confirmed that no technology had emerged in Europe.

- 'Reducing Costs through Environmental Improvement', Wednesday 20th May 2009, Radisson SAS Hotel, Limerick.

  What was learned/achieved by attendance: The research team member met local and regional environmental officers; learned about the national campaigns to increase environmental awareness, which included End-of-Life electronic products.

- Environment Ireland, 23rd-24th September 2009, Croke Park Conference Centre, Dublin.

  What was learned/achieved by attendance: Research team member met EPA officers; learned about updates to certain recycling legislation and relevant contacts.

- International Manufacturing Conference, 2009, Trinity College Dublin.

  What was learned/achieved by attendance: Increased awareness of state-of-the-art manufacturing technologies available; exposure to other automation and manufacturing systems; opportunity to speak with other machine manufacturing; list of contacts to assist or outsource machine test and debug operations.

- LCD Recycling Event, July 2010, York, UK, hosted by the co2 sense Yorkshire and Environmental Sustainability Knowledge Transfer Network https://ktn.innovateuk.org/web/sustainabilityktn.

  What was learned/achieved by attendance: This was an internationally attended event specifically focused on LCD recycling. A number of recyclers reported stockpiling LCD displays. Conference confirmed that no LCD recycling technology was available on the market a year on from the start of the project. Merck, a leading liquid crystal manufacturer, gave a presentation on aspects of liquid crystal recovery from LCD displays.

3.7.2. Review WEEE Market Reports

Currently in Europe, the majority of displays entering the waste stream are Cathode Ray Tube displays. Display recycling facilities in Ireland and Europe are mainly taking in and recycling CRT TVs. LCD TVs represent 5% of the waste displays in these recycling facilities [O'Donoghue, 2009]. CRT TVs dominate the disposal market, as many Europeans are replacing their old CRT TVs with new LCD and Plasma TVs. With further technology advances and more affordable prices, the trend is set to continue.
Off-the-shelf recycling equipment currently exists for CRT displays and it is an established and cost effective recycling method. CRT domination of the disposal market is, however, expected to peak within the next 5-10 years, after which LCD disposal will replace CRT disposal [Frost and Sullivan, 2009]. In 2010, predicted global sales for LCD displays was $73 billion, as can be seen in Figure **3.16** [Voorhees, 2009]. CRT display sales have dropped to $8 billion and are mainly traded in developing countries as a cheaper technology. In 2008, global LCD shipments reached 105 million units [Display Research, 2010]. In Europe alone, 25.6 million units of LCDs were sold in 2007. It is apparent that there is a large LCD waste stream on the horizon.

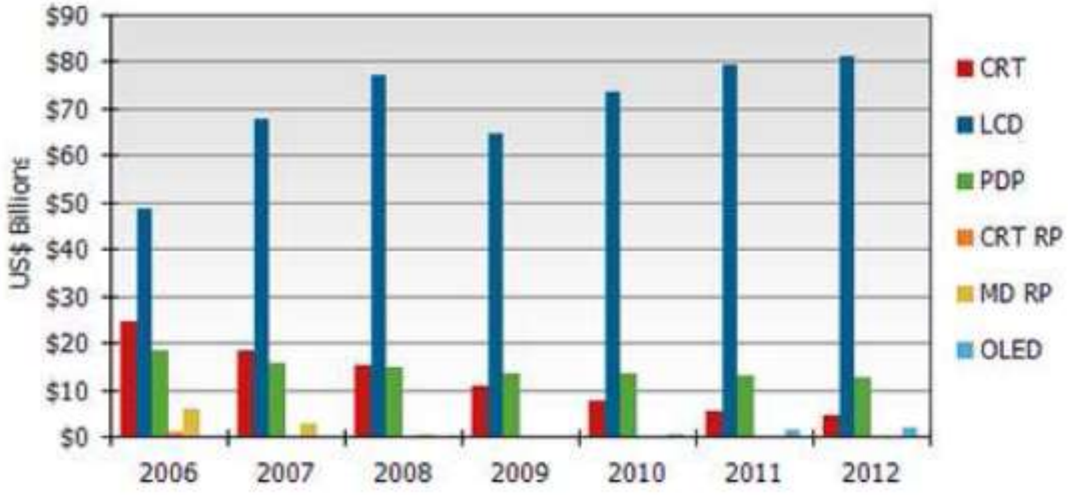


Figure 3.16 Worldwide Display Forecasts [Voorhees, 2009]

There are more than 150 recycling companies operating in this sector throughout Europe, with the top 3 companies having a combined market share of 22%. The LCD and WEEE recycling markets are driven by EU legislation. The target market ranges from small SME recyclers to large multinationals that operate shred and sort facilities.

Table 3.2 Size of the WEEE Recycling Market [Frost and Sullivan, 2009]

WEEE Recycling Markets	Size
European market (2008)	$1.14 billion
UK and ROI market (2008)	$260 million
European market - TV and Monitors only (2005)	1.97 million tonnes

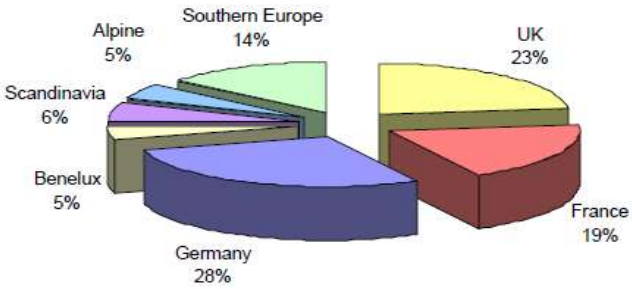


Figure 3.17 The WEEE Recycling Services Market (Potential Customers): Percentage Revenue Shares by Region [Frost and Sullivan, 2009]

There is currently no technology available for the automated removal of hazardous materials from LCDs. The nearest technologies are related to shredding and off-the-shelf CRT recycling equipment. Shredding technology has legislation compliance issues, while CRT recycling represents the state-of-the-art in automated hazardous materials removal. The LCD recycling technology developed at the University of Limerick is capable of creating a new *state-of-the-art* technology that offers an excellent solution to future recycling requirements. The advantages of the LCD recycling technology are as follows:

- No extensive manual pre-processing required for the LCD recycling process.
  (The CRT processing timings did not take into account the pre-process time).

- CRT process only separates the glass funnel, while the LCD recycling process separates glass panel, diffuser sheet, Perspex and fluorescent tubes.

- LCD recycling timings are based on 32" displays, while the CRT recycling timings are based on 20" displays. This results in lower through-put for the CRT recycling system for larger TVs (substantially <70 CRTs per hour).

- The CRT recycling process does not incorporate the removal of the phosphorous in the display. This requires an extra process, which is conducted manually and requires stringent health and safety monitoring.

- The LCD recycling process removes the hazardous substances without manual interaction.

4.0 Conclusions

The environmental impact of waste LCDs is significant as they contain many potentially hazardous substances including, mercury in the backlighting device, organic compounds in the form of liquid crystals, fire retardants within plastics materials and lead within printed circuit boards. Recycling LCDs is now compulsory within the EU member states and thus, disposal through landfill and incineration is no longer a viable or legal option to recyclers.

The volume of LCD screens entering the waste stream is increasing annually and this trend is imposing greater challenges onto recyclers to deal efficiently with the waste units. For example in 2007, Ireland collected in excess of 6,000 metric tonnes of waste displays. The predicted global LCD sales figure for 2009 was $64bn and this helps to demonstrate the level of growth in the use of LCD visual display technology. The cost and time to recycle waste LCDs is high, as manual disassembly is the only solution which is currently commercially available.

From the onset of this project, each stakeholder was consulted and involved as part of a steering committee. The group, which included Irish regulatory bodies, waste associations and recycler companies, helped to ensure that the project would result in the best solution which would meet their environmental, commercial and operating requirements.

The project utilised best practises from six engineering fields including, materials, design, manufacturing, process, environmental and sustainability engineering to develop a unique and innovative automated recycling technology. The developed process is currently patent-pending and unchallenged in the recycling field. The automated recycling machine allows fast, efficient recycling of LCDs in a safe and environmentally-friendly manner. It is capable of processing 80 LCDs / hour compared with 3 LCDs / hour for manual disassembly.

This project has not only set a benchmark in Ireland but also sets an engineering benchmark for the next generation of LCD recycling technologies worldwide by clearly surpassing the state-of-the-art.

An Original Solution

In Ireland, end of life LCDs are currently being stockpiled by Irish recyclers or disassembled manually by hand, which is an extremely labour intensive process. Currently, no automated technology in Ireland exists to recycle LCDs. The next nearest technology available in Ireland for recycling displays is the Cathode Ray Tube (CRT) semi-automated recycling processes. These processes are inadaptable for LCD recycling.

Worldwide, recycling technologies for LCD displays typically originate from the following sources: recycling plants, manufacturers of recycling equipment, research groups, specialised facilities, patents and international journals and publications. A comprehensive review of these sources revealed the main techniques currently employed worldwide to process LCD displays include manual disassembly, shred and sort, and thermal treatment technologies. All these methods are, however, found to have drawbacks. Manual disassembly is slow, shredding an LCD is a dangerous process due to the presence of mercury, and thermal treatment is a last resort incineration process. These generic options represent a threat to the environment and also reduce the profit derived from recycling LCDs to the recyclers. This is the case as the quality of recovered materials can be poor.

Actual and Potential Contribution of the Work to the Economy

As there is no optimised recycling process for LCDs currently available on the market to remove the hazardous materials, a significant recycling problem exists into the future. It is essential that an effective recycling capability for LCD TVs is in place prior to LCDs dominating the disposal market. The patented recycling equipment can aid Irish recyclers to become more competitive, reduce their manual labour costs and achieve a higher quality of recycled material. As recyclers sell the materials recovered from LCDs to scrap metal merchants, the higher the speed the LCDs can be processed and the greater the purity of the recovered materials, the more economical the recycling process is for the local recycler.

A major impact of this engineering project is the generation of this specialised recycling technology making Ireland a leader in this field. The development of this technology through the project augments Ireland's knowledge economy as laid out in national policies and detailed in government publications such as 'Building a Smart Economy' and 'Strategy for Science, Technology and Innovation'. The generation of this technology may help lead Ireland to become a hub for state-of-the-art recycling and other green technologies. With the current decline of the manufacturing industry in Ireland, generating expertise in both green technologies, research and development (R&D), and progressive process design will help drive Ireland into its new role, where these skills are key to a sustainable future.

Impact of the Work on the Quality of Life of the Relevant Communities

As the recycling technology developed within this body of work is a safe and environmentally-friendly solution, it protects the recycling workers from exposure to the hazardous materials contained within LCDs.

There is also an added advantage of developing a green technology for the people of Ireland, as is aims to decouple environmental degradation from economic growth. Instead of waste LCDs posing a threat to the environment, they are being utilised to foster a state-of-the-art global recycling industry within Ireland. Therefore, environmentally-friendly TV End-of-Life can lead to sustainable development and a green tech future for Ireland.

5.0 References

Aanstoos, Braith, House, Robinson and Nichols, 1997. "Disassembly Process for a Cathode Ray Tube" IEEE/CPMT International Electronics Manufacturing Technology Symposium, p 121-128.

Becker, W., Simon-Hettich, B., Honicke, P., 2003. "Toxicology and Ecotoxicology Investigations for Liquid Crystal and Disposal of LCDs".

Behrendt, S. and L. Erdmann, 2004. "Display-Märkte im Umbruch Neuorientierungen für Umweltschutzstrategien 2004", Institut für Zukunftsstudien und Technologiebewertung Berlin.

Display Research, *Global Flat Panel Revenue*, <http://www.displaysearch.com/cps/rde/xchg/displaysearch/hs.xsl/090218_global_flat_panel_tv_revenues_fall_for_first_time_ever%20.asp> assessed in March 2010.

Display Search, 2007. TV Supply Chain Conference, Displaysearch, Editor.

Duan, Eugster, Hischier, Streicher-Porte and Li, 2009. "Life cycle assessment study of a Chinese desktop personal computer." Science of the Total Environmental 407 (2009) 1755-1764.

European Parliament and Council Directive on Waste Electrical and Electronic Equipment, 2002/96/EC.8

FEVE (European Container Glass Federation), Consumers in Europe: Facts and Figures. Eurostat. Theme 3: Population and Social Statistics. Luxembourg, 2001.

Franke, C., Kernbaum, S. and Seliger, G., 2006. "Remanufacturing of Flat Screen Monitors" in Innovation in Life Cycle Engineering and Sustainable Development, Springer, Netherlands.

Frost and Sullivan Technical Insight, 2009, E-Waste Recycling, D1C4.

Hischier, Wager and Gauglhofer, 2005. "Does WEEE recycling make sense from an environmental perspective? The environmental impacts of the Swiss take-back and recycling systems for waste electrical and electronic equipment (WEEE)." Environmental Impact Assessment Review 25 (2005) 525– 539.

Hunt, A.J., Budarin, V.L., Breeden, S.W., Matharu, A.S., and Clark, J. H., 2009. *Green Chem*.

Irish Environmental Protection Agency, National Waste Report 2007.

Kahhat, Kim, Xu, Allenby, Williams and Zhang, 2008. Exploring e-waste management systems in the United States, Resources, Conservation and Recycling 52 955–964.

Kawaguchi, Y., 2009. "Coming Full Circle" Recycling Magazine February 2009. Retrieved in June 2009. <http://www.recyclingmagazin.de/rmeng/news_detail.asp?ID=10640&MODE=202>

Let's Recycle website. Retrieved April 2011. <http://www.letsrecycle.com/news/latest-news/waste-management/201cengland2019s-first201d-flat-panel-recycling-centre-opens>

Martin, R., 2005. "New Industrial Recovery Processes for LCDs - An example for Sustainability," in International Electronics Recycling Congress. 2005, Merck: Basel.

Martin, R., Becker, W., B, S.-H., 2004. "Safe Recovery of Liquid Crystal Displays (LCDs)," in Compliance with WEEE in Electronics Goes Green (Berlin).

Mineral Resource Program, 2008. <http://minerals.usgs.gov/minerals/pubs/commodity/aluminum/mcs-2008-alumi.pdf>

Nnoroma and Osibanjob, 2009. "Toxicity characterization of waste mobile phone plastics." Journal of Hazardous Materials 161 (2009) 183–188.

O'Donoghue, L. Current Statistics Review of Disposal of LCDs in Ireland, 2009. EPA funding research project report, report code LCD-WP2-R1, University of Limerick, Ireland.

O'Donoghue, L., Ryan, A., 2009. LCD Structure and Disassembly Sequence, EPA funding research project report, report code LCD-WP2-R1, University of Limerick, Ireland.

Rare Earth Digest "Japan Forges Ahead with Magnet Recycling." Retrieved on 13th April 2011. <http://rareearthdigest.com/ree-news/news-global/65-news09122010greenasiamagnets.html>

Recycling Bizz website. Retrieved in June 2009. <http://www.recyclingbizz.com/politics_law/LA846662.html>

Recycling International, "Hitachi Technology to Recycle Rare-Earth Magnets." Retrived on 13th April 2011.<http://recyclinginternational.com/recycling-news/3441/non-ferrous-metals/japan/hitachi-technology-recycle-rare-earth-magnets>

Repak, Activity Report 2008. <http://www.repak.ie/files/PDFs/Repak%20Activity%20Report_1.pdf>

Ryan, A., O'Donoghue, L and Lewis, H, 2011. Characterising Components of Liquid Crystal Displays to Facilitate Disassembly. Journal of Cleaner Production, Volume 19, Issues 9-10, June - July 2011, Pages 1066-1071.

Sharp's website. Retrieved in June 2007. <http://sharp-world.com/corporate/eco/technology/lcd.html>

Takata, K., Monozukuri, N., June 2009. "Sharp, Others to Start Running Flat-panel TV Recycling Line," published March 19th 2009 and retrieved in June 2009. <http://techon.nikkeibp.co.jp/english/NEWS_EN/20090319/167425/>

The Swedish LCD Center website. Retrieved in June 2009. <http://www.lcdcenter.se/index.asp>

THE, T.E.P.A.T.C.O. and E. UNION, DIRECTIVE 2002/96/EC on waste electrical and electronic equipment (WEEE) 2003, EUROPEAN PARLIAMENT AND COUNCIL

United Nations University, 2008, *Review of Directive 2002/96 on Waste Electrical and Electronic Equipment (WEEE),* Contract No: 07010401/2006/442493/ETU/G4ENV.G.4/ETU/2006/0032, Germany.

Voorhees, S., Worldwide TV Forecasts, Display search, Editor. 2009.

Waste Online, "Glass Recycling Information Sheet." Retrieved on 26 November 2006. <http://dl.dropbox.com/u/21130258/resources/InformationSheets/Glass.htm>

WEEE Forum, 2008. Annual Report

Wikipedia, 2011, "Plastic Recycling." Retrieved on 13 April 2011 <http://en.wikipedia.org/wiki/Plastic_recycling>

5.1 GLOSSARY

ABS – Acrylonitrile Butadiene Styrene
Ag – Silver
Au – Gold
CRT – Cathode Ray Tube
CCFL – Cold Cathode Fluorescent Lamps
Cu – Copper
DEHLG – Department of the Environment, Heritage and Local Government
EEE – Electrical and Electronic Equipment
EPA – Environmental Protection Agency
EoL – End-of-Life
EU – European Union
Fe- Iron
Hg – Mercury
HIPS – High Impact Polystyrene
HMI – Human Machine Interface
ICT – Information and Communication Technology
LCA – Life Cycle Analysis
LED – Light Emitting Diode
LCD – Liquid Crystal Display
MSD – Machine Safety Directive
Pb – Lead
PBB – Polybrominated Biphenyls
PBDE – Polybrominated Diphenyl Ethers
PC - Polycarbonate
PCB – Printed Circuit Board
PS - Polystyrene
Pt- Platinum
RoHS – Restriction of Hazardous Substances
ROI – Republic of Ireland
SME – Small- to Medium-sized Enterprises
TV - Television
UK – United Kingdom
USA – United States of America
WEEE – Waste Electrical and Electronic Equipment
Zn - Zinc

An Ghníomhaireacht um Chaomhnú Comhshaoil

Is í an Gníomhaireacht um Chaomhnú Comhshaoil (EPA) comhlachta reachtúil a chosnaíonn an comhshaol do mhuintir na tíre go léir. Rialaímid agus déanaimid maoirsiú ar ghníomhaíochtaí a d'fhéadfadh truailliú a chruthú murach sin. Cinntímid go bhfuil eolas cruinn ann ar threochtaí comhshaoil ionas go nglactar aon chéim is gá. Is iad na príomh-nithe a bhfuilimid gníomhach leo ná comhshaol na hÉireann a chosaint agus cinntiú go bhfuil forbairt inbhuanaithe.

Is comhlacht poiblí neamhspleách í an Ghníomhaireacht um Chaomhnú Comhshaoil (EPA) a bunaíodh i mí Iúil 1993 faoin Acht fán nGníomhaireacht um Chaomhnú Comhshaoil 1992. Ó thaobh an Rialtais, is í an Roinn Comhshaoil, Pobal agus Rialtais Áitiúil.

ÁR bhFREAGRACHTAÍ

CEADÚNÚ

Bíonn ceadúnais á n-eisiúint againn i gcomhair na nithe seo a leanas chun a chinntiú nach mbíonn astuithe uathu ag cur sláinte an phobail ná an comhshaol i mbaol:

- áiseanna dramhaíola (m.sh., líonadh talún, loisceoirí, stáisiúin aistrithe dramhaíola);
- gníomhaíochtaí tionsclaíocha ar scála mór (m.sh., déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta);
- diantalmhaíocht;
- úsáid faoi shrian agus scaoileadh smachtaithe Orgánach Géinathraithe (GMO);
- mór-áiseanna stórais peitreail;
- scardadh dramhuisce;
- dumpáil mara.

FEIDHMIÚ COMHSHAOIL NÁISIÚNTA

- Stiúradh os cionn 2,000 iniúchadh agus cigireacht de áiseanna a fuair ceadúnas ón nGníomhaireacht gach bliain
- Maoirsiú freagrachtaí cosanta comhshaoil údarás áitiúla thar sé earnáil - aer, fuaim, dramhaíl, dramhuisce agus caighdeán uisce
- Obair le húdaráis áitiúla agus leis na Gardaí chun stop a chur le gníomhaíocht mhídhleathach dramhaíola trí comhordú a dhéanamh ar líonra forfheidhmithe náisiúnta, díriú isteach ar chiontóirí, stiúradh fiosrúcháin agus maoirsiú leigheas na bhfadhbanna.
- An dlí a chur orthu siúd a bhriseann dlí comhshaoil agus a dhéanann dochar don chomhshaol mar thoradh ar a ngníomhaíochtaí.

MONATÓIREACHT, ANAILÍS AGUS TUAIRISCIÚ AR AN GCOMHSHAOL

- Monatóireacht ar chaighdeán aeir agus caighdeáin aibhneacha, locha, uiscí taoide agus uiscí talaimh; leibhéil agus sruth aibhneacha a thomhas.
- Tuairisciú neamhspleách chun cabhrú le rialtais náisiúnta agus áitiúla cinntí a dhéanamh.

RIALÚ ASTUITHE GÁIS CEAPTHA TEASA NA HÉIREANN

- Cainníochtú astuithe gáis ceaptha teasa na hÉireann i gcomhthéacs ár dtiomantas Kyoto.
- Cur i bhfeidhm na Treorach um Thrádáil Astuithe, a bhfuil baint aige le hos cionn 100 cuideachta atá ina mór-ghineadóirí dé-ocsaíd charbóin in Éirinn.

TAIGHDE AGUS FORBAIRT COMHSHAOIL

- Taighde ar shaincheisteanna comhshaoil a chomhordú (cosúil le caighdéan aeir agus uisce, athrú aeráide, bithéagsúlacht, teicneolaíochtaí comhshaoil).

MEASÚNÚ STRAITÉISEACH COMHSHAOIL

- Ag déanamh measúnú ar thionchar phleananna agus chláracha ar chomhshaol na hÉireann (cosúil le pleananna bainistíochta dramhaíola agus forbartha).

PLEANÁIL, OIDEACHAS AGUS TREOIR CHOMHSHAOIL

- Treoir a thabhairt don phobal agus do thionscal ar cheisteanna comhshaoil éagsúla (m.sh., iarratais ar cheadúnais, seachaint dramhaíola agus rialacháin chomhshaoil).
- Eolas níos fearr ar an gcomhshaol a scaipeadh (trí cláracha teilifíse comhshaoil agus pacáistí acmhainne do bhunscoileanna agus do mheánscoileanna).

BAINISTÍOCHT DRAMHAÍOLA FHORGHNÍOMHACH

- Cur chun cinn seachaint agus laghdú dramhaíola trí chomhordú An Chláir Náisiúnta um Chosc Dramhaíola, lena n-áirítear cur i bhfeidhm na dTionscnamh Freagrachta Táirgeoirí.
- Cur i bhfeidhm Rialachán ar nós na treoracha maidir le Trealamh Leictreach agus Leictreonach Caite agus le Srianadh Substaintí Guaiseacha agus substaintí a dhéanann ídiú ar an gcrios ózóin.
- Plean Náisiúnta Bainistíochta um Dramhaíl Ghuaiseach a fhorbairt chun dramhaíl ghuaiseach a sheachaint agus a bhainistiú.

STRUCHTÚR NA GNÍOMHAIREACHTA

Bunaíodh an Ghníomhaireacht i 1993 chun comhshaol na hÉireann a chosaint. Tá an eagraíocht á bhainistiú ag Bord lánaimseartha, ar a bhfuil Príomhstiúrthóir agus ceithre Stiúrthóir.

Tá obair na Gníomhaireachta ar siúl trí ceithre Oifig:

- An Oifig Aeráide, Ceadúnaithe agus Úsáide Acmhainní
- An Oifig um Fhorfheidhmiúchán Comhshaoil
- An Oifig um Measúnacht Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáide

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag ball air agus tagann siad le chéile cúpla uair in aghaidh na bliana le plé a dhéanamh ar cheisteanna ar ábhar imní iad agus le comhairle a thabhairt don Bhord.

Science, Technology, Research and Innovation for the Environment (STRIVE) 2007-2013

The Science, Technology, Research and Innovation for the Environment (STRIVE) programme covers the period 2007 to 2013.

The programme comprises three key measures: Sustainable Development, Cleaner Production and Environmental Technologies, and A Healthy Environment; together with two supporting measures: EPA Environmental Research Centre (ERC) and Capacity & Capability Building. The seven principal thematic areas for the programme are Climate Change; Waste, Resource Management and Chemicals; Water Quality and the Aquatic Environment; Air Quality, Atmospheric Deposition and Noise; Impacts on Biodiversity; Soils and Land-use; and Socio-economic Considerations. In addition, other emerging issues will be addressed as the need arises.

The funding for the programme (approximately €100 million) comes from the Environmental Research Sub-Programme of the National Development Plan (NDP), the Inter-Departmental Committee for the Strategy for Science, Technology and Innovation (IDC-SSTI); and EPA core funding and co-funding by economic sectors.

The EPA has a statutory role to co-ordinate environmental research in Ireland and is organising and administering the STRIVE programme on behalf of the Department of the Environment, Heritage and Local Government.

Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

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SSTI Strategy for Science, Technology and Innovation

Comhshaol, Pobal agus Rialtas Áitiúil
Environment, Community and Local Government