Contents

Chapter 1 Introduction and Overview

Martin Goosey

1	Introduction	1			
2	WEEE - The Scale of the Problem				
3	Legislative Influences on Electronics				
	Recycling	4			
	3.1 Producer Responsibility Legislation	4			
	3.2 The WEEE Directive	6			
	3.3 The RoHS Directive	7			
	3.4 Other Examples of Legislation	8			
4	Treatment Options for WEEE	10			
5	Material Composition of WEEE	11			
6	Socio-economic Factors	13			
7	Logistics of WEEE	15			
8	WEEE - the International Perspective	18			
	8.1 European Perspective	18			
	8.2 Japan	20			
9	Barriers to Recycling of WEEE	24			
10	The Recycling Hierarchy and Markets				
	for Recyclate	25			
11	WEEE Health and Safety Implications	30			
12	Future Factors That May Influence Electronic				
	Waste Management	35			
13	Summary and Conclusions	37			
	eferences and Further Reading	37			

[©] Royal Society of Chemistry 2009

viii Contents

VIII		mienis					
Chapter 2	Materials Used in Manufacturing Electrical and Electronic Products Gary C. Stevens and Martin Goosey						
	1 Perspective	40					
	2 Impact of Legislation on Materials Used in Electronics	40					
	2.1 Overview	40					
	2.2 The RoHS Directive and Proscribed Materials	42					
	3 Where do RoHS Proscribed Materials Occur?	44					
	3.1 Lead	44					
	3.2 Brominated Flame Retardants	44					
	3.3 Cadmium, Mercury and Hexavalent Chromium	45					
	4 Soldering and the Move to Lead-free Assembly	46					
	4.1 Introduction 4.2 Lead-free Solder Choices	46					
	5 Printed Circuit Board Materials	46 47					
	5.1 Introduction	47					
	5.2 PCB Materials	48					
	5.3 Provision of Flame Retardancy in PCBs	50					
	5.4 Non-ferrous and Precious Metals	52					
	6 Encapsulants of Electronic Components	53					
	7 Indium Tin Oxide and LCD Screens	54					
	8 Polymeric Materials in Enclòsures, Casings and Panels	55					
	8.1 Product-related Plastic Content	55					
	9 WEEE Engineering Thermoplastics	59					
	9.1 Polycarbonate (PC)	59					
	9.2 ABS (Acrylonitrile-Butadiene-Styrene)	61					
	9.3 High Impact Polystyrene (HIPS)	62					
	9.4 Polyphenyleneoxide (PPO)	62					
	9.5 PC/ABS Blends	62					
	9.6 Flame Retardants in Engineering Thermoplastics	63					
	10 Materials Composition of WEEE	65					
	10.1 Introduction	65					
	10.2 Mobile Phones	66					
	10.3 Televisions	68					
	10.4 Washing Machines 11 Conclusions	71					
	References	72 73					
Chapter 3	Dumping, Burning and Landfill						
	Ian Holmes						
	1 Introduction	75					

1.1 England: Site Inputs 2002-2003

Contents

		1.2 Waste Inputs to Different Management Options	
		in 2005	77
	2	Landfill	77
		2.1 Historical	77
		2.2 Pollution from Landfills	79
		2.3 Landfill Gas	79
		2.4 Leachate	79
		2.5 Landfill-site Construction	80
	3	Burning	82
		3.1 Historical	82
		3.2 Incineration	82
		3.3 Mass Burn	82
		3.4 Energy Recovery/Energy from	0.3
		Waste (EFW)	83
		3.5 Advanced Thermal Processing	84
		3.6 Pollution from Incineration	85
	4	Legislation Summary	88
	n	4.1 Current UK Legislation	88 89
	K	eferences	09
Chapter 4		ecycling and Recovery	
	D	arren Kell	
	1	Introduction	91
	2	Separation and Sorting	92
	3	Treatment	92
		3.1 Mixed WEEE	93
		3.2 Refrigeration Equipment	95
		3.3 Cathode Ray Tubes	96
		3.4 Individual Processes	97
	4	Outputs and Markets	102
		4.1 Metals	103
		4.2 Glass	103
	_	4.3 Plastics	103
	5	Emerging Technologies	104
		5.1 Separation	104
		5.2 Thermal Treatments	105
		5.3 Hydrometallurgical Extraction	106
		5.4 Sensing Technologies	106
		5.5 Plastics to Liquid Fuel	107
		5.6 Plastics Containing Brominated Flame	
		Retardents	107
	6	Acknowledgements	108
	R	eferences	108

X Contents

Chapter 5	Integrated Approach to e-Waste Recycling Rod Kellner						
	1	Introduction	111				
	2	Recycling and Recovery Technologies	113				
	-	2.1 Sorting/Disassembly	114				
		2.2 Crushing/Diminution	115				
		2.3 Separation	115				
	3	Emerging Recycling and Recovery Technologies	117				
		3.1 Automated Disassembly	117				
		3.2 Comminution	117				
		3.3 Separation	118				
		3.4 Thermal Treatments	119				
		3.5 Hydrometallurgical Extraction	119				
		3.6 Dry Capture Technologies	119				
		3.7 Biotechnological Capture	119				
		3.8 Sensing Technologies	120				
		3.9 Design for Recycling and Inverse					
		Manufacturing	120				
	4	Printed Circuit Boards	121				
		4.1 Overview	121				
		4.2 Recycling	124				
		4.3 Current Disposal Hierarchy	126				
		4.4 Economics of Recycling	127				
		4.5 Future Developments	128				
		4.6 Characteristics of PCB Scrap	129				
	-	4.7 Emerging Technologies	132				
	5	Sector-based Eco-design	141				
		5.1 Disassembly	142				
		5.2 Fasteners 5.2 PEIDs (Padio Fraguency Identification Tags)	143 145				
		5.3 RFIDs (Radio Frequency Identification Tags)	143				
		5.4 Active Disassembly 5.5 Design Methodology and Pescurce Efficiency	147				
		5.5 Design Methodology and Resource Efficiency5.6 Recycling	147				
		5.7 Constraints on Materials Selection	148				
		5.8 Eco-design Guidelines for Manufacturing	150				
	Re	ferences	160				
Chapter 6	European Recycling Platform (ERP): a Pan-European Solution to WEEE Compliance Scott Butler						
	1	Brief Introduction to WEEE	161				
	-	1.1 The WEEE Directive	161				
		1.2 Producer Responsibility	162				
		1.3 Household and Non-household WEEE	162				

Contents			

		1.4 Marking EEE Products	163
		1.5 WEEE Collection Points	164
		1.6 Product Categories and Waste Streams	164
		1.7 Producer Compliance Schemes	164
		1.8 Variations in National WEEE Laws	164
	2	Introduction to European Recycling Platform (ERP)	165
		2.1 European Recycling Platform	165
		2.2 Founder Members	165
		2.3 Timeline	165
		2.4 Founding Principles	166
		2.5 Structure	166
		2.6 Scope of services	168
		2.7 The Operational Model – General	
		Contractor Approach	168
		2.8 Euro PLUS	170
	3	ERP in Operation	170
		3.1 Country Summaries	170
		3.2 Key Performance Indicators	170
		3.3 Members	170
	4	ERP – Beyond Compliance	172
		4.1 Implementation of Individual Producer	172
		Responsibility (IPR)	172
	5	4.2 ERP UK WEEE Survey	173
	5	Summary	175
		5.1 Key Achievements 5.2 Final Thoughts: Intervious with Two	175
		5.2 Final Thoughts: Interviews with Two	177
	D	Founding Members eferences	177 179
	N	ETETETICES	1/9
Chapter 7	Li	quid Crystal Displays: from Devices to Recycling	
	A	vtar S. Matharu and Yanbing Wu	
	1	Introduction	180
	2	Overview of Liquid Crystals	183
		2.1 Definition and Classification of Liquid Crystals	184
		2.2 Molecular and Chemical Architecture of	
		Liquid Crystals	185
		2.3 The Mesophase: Types of Intermediate State	
		of Matter	186
		2.4 Physical Properties of Liquid Crystals and	2 202
	-	Material Requirements	188
	3	Overview of Liquid Crystal Displays Based on	
		Nematic Mesophase	190
		3.1 Basic LCD Operating Principles	190
	4	3.2 Types of Electro-optic LCD Devices	191
	4	LCD Manufacturing Process	195

хi

1.0	
X11	Contents

	5	Envi	ironmental Legislation and Lifecycle Analysis	197
		5.1	The WEEE Directive and LCDs	197
		5.2	RoHS and REACH	199
		5.3	Far East Environmental Measures	199
		5.4	Lifecycle Analysis	199
	6	Pote	ntially Hazardous Constituents: Toxicity	
		of L	CD Constituents	201
		6.1	Toxicity of Mercury and Backlighting	201
		6.2	Toxicity of Liquid-crystal Mixture	203
		6.3	Demanufacture and Recycling	204
	7	Futu	ire Outlook	208
		7.1	LCD Panels	208
		7.2	Smart Disassembly	209
		7.3	Legislation	209
	Re	feren	ces	209
Chapter 8			e of Collective versus Individual Producer	
			ibility in e-Waste Management: Key Learnings	
	58.5		ound the World	
	7 Refro	ark L	Dempsey and Kirstie McIntyre	
Chapter 8	1	Intro	oduction	212
		1.1	E-waste and Its Environmental Impacts	212
		1.2	Background to Producer Responsibility	213
		1.3	Defining Individual and Collective Producer	210
			Responsibility	215
	2	The	WEEE Directive in Europe	216
	_	2.1	The WEEE Directive's Approach to Individual	
		2.1	and Collective Producer Responsibility	216
		2.2	Implementation of Individual and Collective	
			Producer Responsibility in the EU	218
		2.3	YOUR ACID ON ACID OF	219
	3		aste Laws and Voluntary Agreements in Other	
			ntries	220
		3.1	Japanese Electronics Take-back Directive	220
		3.2	Product Take-back in the USA	221
		3.3	Product Stewardship in Australia	222
	4		ussion	223
		4.1	Competition in E-Waste Management	223
		4.2	Collective Producer Responsibility: Benefits and	225
		1.2	Disadvantages	225
		4.3	Individual Producer Responsibility: Benefits and	223
		1.5	Disadvantages	225
		4.4	Evaluating Collective <i>versus</i> Individual Producer	223
		7.7	Responsibility	227
			responsibility	221

Contents			xiii	
	5	Recommendations to Implement IPR	230	
		5.1 Recommendation #1: Ensure Article 8.2 of the		
		WEEE Directive is Fully Transposed	230	
		5.2 Recommendation #2: Adopt a Phased Approach		
		to IPR	231	
		5.3 Recommendation #3: Member States to		
		Implement IPR	232	
		Conclusions	233	
	Re	eferences	234	
Chapter 9	Ra	apid Assessment of Electronics Enclosure Plastics		
		trick J. Baird, Henryk Herman and Gary C. Stevens		
	1	Introduction	236	
	2	Instrumental Techniques	237	
	3	Visible-NIR Spectroscopy of Engineering	1000	
		Thermoplastics	239	
		3.1 Discrimination of Enclosure Materials	241	
		3.2 Base Polymer Identification	243	
		3.3 Selected Thermoplastics for Processing	244	
		3.4 Controlled Degradation Experiments	245	
		3.5 Analysis of Processed Thermoplastics	245	
	4	Analysis of Plastics Containing Flame-retardant		
		Additives	248	
		4.1 Visible-NIR Spectroscopy	249	
		4.2 X-Ray Fluorescence and Optical Emission		
		Spectroscopy	251	
		4.3 Infrared and Raman Spectroscopy	253	
	5	Conclusions	255 256	
	References			
Subject Ind	lex		258	