

Contents

List of Contributors ix

Preface xiii

1	Introduction	1
	<i>Hai Lei, Chao Zhu, Jiexiang Li, Hanyu Zhou, Xiangjin Lu, Xizhuo Chen, Yue Yang</i>	
1.1	Production Volume and Distribution of Spent LIBs	1
1.2	Strategic Significance of Spent LIBs Recycling	3
1.3	Global Industrialization Landscape of Spent LIBs Recycling	4
1.4	Full-chain Technological Process for High-value Recycling of Spent LIBs	5
1.5	Overview of Global Progress in LIBs Recycling	6
	References	8
2	Pretreatment	11
	<i>Shuaiqi Gong, Penghui Shi</i>	
2.1	Battery Structure and Classification	11
2.1.1	The Core Structure of Cell	11
2.1.2	Classified by Shape Structure: Cylindrical, Square, and Soft Bag (Polymer)	12
2.1.3	Factors Influencing the Selection of Shape Structure	18
2.1.4	Demands Analysis of Battery Assembly Process for Spent Battery Recycling	19
2.2	Detection and Evaluation	20
2.2.1	Physical Testing Methods	20
2.2.2	Chemical Testing Methods	22
2.2.3	Electrochemical Testing Methods	24
2.2.4	Comparison and Analysis of Detection Technologies	26
2.3	Safe Discharge	31
2.3.1	Physical Discharge Method	32
2.3.2	Chemical Discharge Method	33
2.4	Disassembly and Crushing	37

2.4.1	CMP Structure Battery Pack Disassembly	37
2.4.2	Battery Cell Collection	38
2.4.3	Fragmentation	39
2.5	Material Sorting	43
2.5.1	Screening and Pneumatic Separation	43
2.5.2	Electromagnetic Separation	45
2.5.3	Flotation	48
2.5.4	Other Sorting Methods	50
2.6	Summary	51
	References	52
3	Cascaded Utilization	57
	<i>Zeyu Dong, Gaoyun Tan, Zihao Lu, Yunpeng Wen, Runxuan Chen, Xizhuo Chen, Yue Yang</i>	
3.1	The Hub of Resource Recycling and Economic Benefits	57
3.2	Resource Efficiency and Low-carbon Transition Cornerstone	57
3.3	Safety Compliance and Systemic Necessity	58
3.4	Sorting of Retired LIBs	59
3.5	Sorting and Reconfiguration	60
3.6	Equalization Technology	64
3.7	Safety Management Technology	66
3.8	Safety Management Development Needs: Development of Highly Compatible BMS Systems	68
3.9	Application Scenarios for Cascading Use (Echelon Utilization)	68
3.10	Chapter Summary	70
	References	71
4	Metallurgical Extraction Techniques	75
	<i>Xuejing Qiu, Peixiang Gao, Yimeng Zhang, Lingling Xie, Limin Zhu, Xiaoyu Cao</i>	
4.1	Pyrometallurgical Extraction Techniques	75
4.1.1	Application of Pyrometallurgical Recycling in the Lithium Iron Phosphate (LiFePO ₄ , LFP)	75
4.1.2	Analysis of Pyrometallurgical Recovery Technology for LFP	76
4.1.3	Application of Pyrometallurgical Recycling in the Lithium Cobalt Oxide (LiCoO ₂ , LCO)	77
4.1.4	Analysis of Pyrometallurgical Recovery Technology for LCO	79
4.1.5	Application of Pyrometallurgical Recovery in Ternary Batteries	80
4.1.6	Analysis of Pyrometallurgical Recovery Technology for NCM	82
4.1.7	Application of Pyrometallurgical Recycling in Solid-state Batteries	82
4.1.8	Analysis of Pyrometallurgical Recovery for Solid-state Technology	84
4.1.9	Demand for Pyrometallurgical Recycling Technology Targeting Cathode Materials from Spent LIBs	85
4.2	Hydrometallurgical Extraction Technology	86
4.2.1	Application of Hydrometallurgical Recycling in the LFP	86

4.2.2	Analysis of Hydrometallurgical Recycling for LFP	94
4.2.3	Application of Hydrometallurgical Recycling for LCO	95
4.2.4	Technical Analysis of the Hydrometallurgical Process for LCO Recovery	98
4.2.5	Application of Hydrometallurgical Recycling for Ternary Battery	99
4.2.6	Analysis of Hydrometallurgical Recovery of Ternary Cathode Materials	110
4.2.7	Application of Hydrometallurgical Recovery for Solid-state Batteries	111
4.2.8	Analysis of Hydrometallurgical Recycling for Solid-state Batteries	112
4.2.9	Demand for Hydrometallurgical Recycling for Cathode Materials from Spent LIBs	114
4.3	Metallurgical Recycling Development Trends Across Different Battery Systems	116
4.3.1	LFP Batteries	116
4.3.2	Ternary LIB	118
4.3.3	LCO Batteries	119
4.3.4	Solid-state Battery	121
4.4	Chapter Summary	122
4.4.1	Demand for Pyrometallurgical Recycling Technology	122
4.4.2	Demand for Hydrometallurgical Recycling Technology	123
	References	123
5	Direct Regeneration Technologies	129
	<i>Binglei Jiao, Zhichao Yang, Tiyu Jiao, Mengqi Kong, Panpan Xu</i>	
5.1	Brief Introduction	129
5.1.1	Direct Regeneration of Spent Cathode Materials	129
5.2	Direct Regeneration of Spent Graphite Anode	158
5.2.1	Low-temperature Repair Technology	158
5.2.2	High-temperature Graphitization Repair Technology	164
5.3	Final Chapter Summary	168
	References	171
6	Pollution Prevention and Life Cycle Assessment of Degraded Lithium-ion Battery Recycling	177
	<i>Congrui Ouyang, Jin Wang, Wenhao Yu</i>	
6.1	Pollution Prevention	177
6.1.1	Current Status of Pollution and Prevention Strategies in Degraded Battery Recycling	178
6.1.2	Pollutants and Pollution Prevention Strategies of Different Recycling Processes	180
6.1.3	Comparative Analysis of Current Battery Recycling Technologies	189
6.1.4	Demands for Battery Recycling	189
6.2	Life Cycle Assessment	197
6.2.1	Current Status of LCA for LIBs	197

6.2.2	Comparison of Different LCA Methods	201
6.2.3	Development Trends of LCA Methods	204
6.3	Conclusions	206
	References	206
7	Prospects and Outlook	211
	<i>Zihao Zeng, Chao Zhu, Hai Lei, Run Ren, Quan Zhang, Jiale Zhang, Peng Ge</i>	
7.1	Pretreatment Technologies	211
7.2	Cascade Utilization	213
7.3	Metallurgical Recycling	214
7.3.1	Pyrometallurgical Recovery Technologies	214
7.3.2	Hydrometallurgical Recovery Technologies	216
7.4	Direct Regeneration	218
7.4.1	About the Regeneration of Spent LFP	218
7.4.2	About the Regeneration of Spent LCO	219
7.4.3	About the Regeneration of Spent NCM	220
7.5	About the Pollution Controlling and All-life Cycling Assessments	222
8	Conclusion	225
	<i>Chao Zhu, Hai Lei, Run Ren, Quan Zhang, Jiale Zhang, Zihao Zeng, Peng Ge</i>	
	Index	229