

Index

a

acrylonitrile butadiene styrene (ABS)
77, 81, 88, 109, 155, 236
advanced recycling fees (ARFs) 44
air current separation 138
air tables 113–114
Alcaligenes eutrophus 284
amphiphilic siderophores 198
anaerobic bacteria 279
anaerobic sulfur-reducing bacteria 200
9,10-anthraquinones (9,10-AQ) 262
approximation 2 method 63
arsenic (III)-binding peptides 195
Australian Battery Recycling Initiative
51

b

Bacillus weihenstephanensis 284
Basel Action Network 35, 39
Basel Convention 34–35, 49
BATENUS process 176–177
batteries 176
 hybrid cars batteries 180
 lithium-ion batteries (LIBs) 7
 primary batteries 176
 rechargeable batteries 176
1,4-benzoquinone (1,4-BQ) 264
bio-ceramics (biocers) 193, 196
bio-electro-hydrometallurgical process
191
bio-Pd 200–201
bioaccumulation 189, 199–201
biodegradable electronic systems
258–260, 272, 283, 285
biodegradation 270, 276
 half-lives 275
 principle 285

bioflotation 189, 197–199
 of pyrite and chalcopyrite 197
biogenic cyanide 190
biohydrometallurgy 189–202
bioleaching 189–191, 197
biological half-life 275
biomass 191–192, 201, 222, 258, 270,
279, 283
biopolymers 192, 196, 197, 260, 265, 268,
270
bioreactor design 271
bioreduction 189, 199–201
biosorption
 challenges 192
 chelators derived from nature
 196–197
 defined 191
 via metal selective peptides 194–196
 REE recovery 192
biosurfactants 197
Brazilian Policy of Solid Waste (BPSW)
47
brominated flame retardants (BFRs)
136, 155
Burkholderia fungorum 284

c

CadR 193
Canadian WEEE management systems
46
carbon-neutral circular economy 311
Carnegie Mellon method 64, 65
Cartridges 4 Planet Ark 51
cathode ray tube TV and monitor units
79–80
cellphone devices
 gold and silver in 6

- cellulose 192, 194, 196, 213–214, 260, 268, 270, 275, 281
 - centrifugal classifier 104–105
 - China WEEE regulation 48
 - chip bonding process 260
 - circular economy
 - barriers 300
 - challenges for e-waste recycling 304–306
 - demand for recyclable products 309–310
 - digitalization 301–302
 - drivers for change 306–309
 - recycling 302–304
 - classical microbiology 276–277
 - classification process 104
 - CLEANLEAD process 177
 - climate change 300, 311
 - closed-circuit comminution circuit 102
 - column flotation cells 118
 - composting biodegradation process 282
 - composting kinetics modeling 274
 - composting of organic waste 255, 271, 275, 279
 - composting process 271
 - materials half-life 274–275
 - compost's quality and eco-safety assessment 274
 - microbiome 272
 - schematic illustration 271
 - specific endpoint parameters, monitoring of 274
 - computers and notebooks 78–79
 - consumption and use/leaching/
 - approximation 1 method 62–63
 - copper matte smelting 138
 - copper recovery from e-waste 150
 - copper smelting processes
 - secondary smelters 142
 - sulfide route 138–142
 - copper-rich scrap 142
 - copper-rich slag 139
 - corona electrostatic separation 108–109, 138
 - COVID pandemic 41
 - COVID-19 pandemic 302
 - cradle-to-cradle flow concept 300
 - criticality-based impact assessment (CIAM) method 236
 - cryogrinding technology 100
 - crystalline silicon PV modules 85
 - c-Si modules, recycling process of 174–176
 - Cu nanoparticle synthesis, via bioreduction 201
 - CuFeS-SiO₂-O₂ system 138
- d**
- degradation 155–156, 166, 200, 221, 259, 262, 269–275, 280–285
 - of green PLA-based composites 275
 - demand for recyclable products 305, 309–310
 - density-based float-sink separation 219
 - DHI-melanin 267–268
 - DHICA-melanin 267
 - diamagnetic particles 106
 - digitalization 301–302, 311
 - direct-to-copper smelting 139–140
 - direction smelting 143–144
 - dismantling process 96, 241, 244, 247–248, 250
 - distillation 153–155
 - distribution delay method 63–64, 67
 - DNA metagenomic techniques 276–277
 - domestic e-waste recyclers 22
 - dopamine (DA) 265–266
- e**
- e-glass analysis 215
 - e-waste 2, 255, 302
 - average metal content 5
 - collection and recycling 3
 - definition 2, 15
 - developed economies 21
 - estimated value of materials present 4
 - generation pattern 15
 - imports/exports, permissions/bans for known routes 35, 40
 - legislations and regulations 35–39
 - international legislation 34–41
 - international management and transboundary movement 18–19
 - management
 - in Australia 22
 - in Brazil 23
 - community awareness 17
 - cost of 20
 - in developed countries 21–22
 - developing countries 23–26
 - extended producer responsibility 41
 - flowchart 16

- goal of 20
 - in India 23–24
 - in Japan 22
 - in Nigeria 25
 - in South Africa 24
 - in Switzerland 21–22
 - in Taiwan 21, 25–26
 - management programs 8
 - recycling, multidisciplinary aspects of 8, 9
 - take-back systems 17
 - total generation 3
 - total raw material value 34
 - transboundary movement 40
 - utilization as secondary raw material 165
 - yearly generation 34
 - e-waste collection rate 69
 - e-waste for repair 36
 - e-waste generation 33, 95
 - consumption and use/leaching/ approximation 1 method 62
 - econometric analysis 61–62
 - estimation methods 65
 - global estimation 66
 - and gross domestic product (GDP) 61, 62
 - market supply method 63–64
 - and purchasing power parity 61, 62
 - sales/approximation 2 method 63
 - time step method 64–65
 - e-waste generation statistics 61
 - e-waste landfill 45, 135
 - e-waste recycling 20, 141, 304
 - advantages 165
 - challenge 165
 - e-waste regulations 41
 - in Asia
 - in China 48
 - India 49
 - in Japan 47–48
 - in Taiwan 49
 - in Australia 50–51
 - Brazil 47
 - in Canada 46–47
 - in Europe
 - France 43
 - Germany 43
 - Norway 44
 - Switzerland 44
 - in Nigeria 50
 - in South Africa 49–50
 - in United States of America 45–46
 - e-waste trafficking 36
 - eco-design 90, 255, 257, 304, 311
 - eco-friendliness 257
 - eco-organizations 43
 - econometric analysis 61–62
 - eddy current separation 108, 110–111, 138
 - electrical and electronic equipment 1–2, 15, 18, 33, 48, 62, 73–74, 135–157, 166, 231, 301–302
 - electrical separation 108–111, 220
 - electrochemical energy storage
 - dopamine 265
 - lignin 269
 - melanins 265–268
 - quinones 264–265
 - tannins 268
 - electrochemical processes 147–148
 - high-temperature electrolysis 148–149
 - low-temperature electrolysis 149–152
 - review 147
 - electroflotation process 198
 - electronic products, lifespan of 65–66
 - electronic waste 3, 34, 45, 50, 61–62, 95, 110, 137, 146–157, 165, 180, 190–191, 260, 284, 303, 310
 - ellagitannins 268
 - empirical degradation models 274
 - end-of-life (EoL) 15–16, 18, 23, 33, 35, 40–41, 43–44, 46–47, 66, 86, 90, 165, 174, 231, 257, 276, 285, 300
 - energy band bending 261
 - engineered composting facility 278, 282
 - Environmental Handling Fees (EHF) 46
 - environmental impact, of WEEE recycling systems 235–236
 - eumelanin 265–267
 - European Green Deal 311
 - European Recycling Platform 43, 119, 122
 - European WEEE Directive 34–35
 - Exiguobacterium aestuarii* 284
 - extended producer responsibility (EPR) 16, 18, 41–42, 44–45, 49–50, 52
 - extracellular polymeric substances (EPS) 196–198
- f**
- Falcon centrifugal concentrator 114–115
 - fayalite slag 138–139

- feature phone formal collection scenario 241–243
- feature phone informal collection 243–244
- fiberglass 112, 117, 214–216, 218–223, 305
- flash smelting 139–140
- float-sink test 115–116
- fluorescent lamps (FL) 3, 86, 88, 178, 180, 199, 236
- fluorinated pentacenequinone (FPCQ) 262
- foreign downstream recycling enterprises 18
- formal government-certified recycling companies 249
- froth flotation 116–220, 168, 198, 220
- full recovery end-of-life photovoltaic (FRELPA) 174, 175
- fusion proteins 193–196
- g**
- galena (PbS) 142
- gallium recovery, from LED waste 179
- gallotannins 268
- Gaudin–Schuhmann equation 101
- Global E-waste Monitor 66, 255
- global market economy 299
- global warming potential (GWP) impact 241
- gravitational classifiers 105
- gravity separation 111–116, 157, 219–220
- green organic electronics 258, 269, 285
- greenhouse gas (GHG) 135, 222, 241–250
- emissions 243, 244, 248–250
- gross domestic product (GDP) 15, 19, 33, 61, 62
- h**
- hammer mill 96–98, 102–103, 106, 174, 219
- hard disk magnets
- average percent weight of common metals 6
- Harmonized System (HS) codes 67
- H-bonded organic pigments 259
- H-bonded organic semiconductors 259, 261
- H-bonded pigments 259
- high impact polystyrene (HIPS) 155, 236
- high performance quinone-based OFETs 263
- high voltage pulse fragmentation 97–99
- high-intensity magnetic separators 106–108
- high-temperature electrochemical processes 135
- high-temperature electrolysis 148–149
- hybrid car batteries 180
- hydrocyclone 102, 104–105, 111, 115, 219
- hydrolyzable tannins 268
- hydrometallurgical processing 7
- for batteries 176–178
- of e-waste 166
- metals recovery in LED waste 178–180
- hypothetical biodegradable electronics end of life of 272
- i**
- impact assessment, LCA 233–234
- Indium, in LCD screens 81
- induced roll magnetic separator 108
- industrial composter 281–282
- informal end-of-life e-waste practices 23
- Information Revolution 1
- inoculation, of compost 283
- international legislation 34–41, 49
- international WEEE management 18–19
- inverse gas chromatography (IGC) 117, 123
- ionic liquids 8, 150–151, 180
- IT and telecommunications equipment
- computers and notebooks 78–79
- mobile phones 81–83
- monitors and screens 79–81
- printed circuit boards 83–85
- j**
- jigs 111, 112, 219
- k**
- Kayser recycling system 141
- Knelson centrifugal concentrator 114–115
- knife mill 100
- l**
- large household appliances (LHA) 75–77, 166
- LCD screens 81

- leaching techniques 7
 - lead bullion 142–144, 146
 - lead smelting processes 142–146
 - Li batteries, organic vs. inorganic
 - electrode materials 264
 - life cycle assessment (LCA) 231
 - hazardous potential of WEEE
 - management and recycling 236
 - heavy metal risk assessment 236
 - impact assessment 234
 - noise assessment 236
 - purpose of 233
 - theory of 232–234
 - waste mobile phone recycling 237
 - functional unit 237–238
 - life cycle inventory data 238–241
 - system boundaries 238
 - in WEEE management 232
 - life cycle cost (LCC) analysis 248
 - life cycle environmental impacts
 - of cathode ray tubes (CRTs) 234
 - of feature phone formal collection
 - scenario 241–243
 - of feature phone informal collection
 - 243–244
 - of smartphone formal collection
 - scenario 244–245
 - of smartphone informal collection
 - scenario 246–247
 - life cycle inventory (LCI) analysis 231, 233–241
 - light emitting diodes (LEDs) 2–3, 79–81, 86, 88, 89, 167, 178–180, 191, 236, 257
 - lightning equipment 86
 - lignin 259, 266, 268–270, 279–283
 - degradation 270
 - lignin/PEDOT composite 269
 - lignin/PPy hybrid electrode material 269
 - linear model economy 299
 - lithium-ion batteries (LIBs) 1, 7, 114, 269
 - low vapor pressure metals 141
 - low-grade scrap 142, 151
 - low-intensity magnetic separators 106–108
 - low-temperature electrolysis 149–152
- m**
- magnetic nanoparticles 181
 - magnetic separation 96, 106–108, 138, 157, 166, 172, 177, 220
 - marinobactin 198
 - market supply method 63
 - Carnegie Mellon method 64
 - distribution delay method 63–64
 - simple delay method 63
 - mass balance method 64
 - material efficiency 302–305
 - material-selective peptides 194
 - mechanical recycling, of waste PCB 96
 - mechanical size classification equipment 106
 - melanin/carbon paper electrodes 267
 - melanins 265–268
 - metal concentrations, in PCB 83
 - metal electronic refining process 241–250
 - metallothioneins (MT) 193, 195
 - Metso equation 103
 - microbiology techniques 276, 277
 - microbiome 270–272, 274, 276–285
 - mobile phones (MP) 81–83
 - Cu recovery from mobile phone 172
 - waste mobile phone recycling 237–242
 - molten salt oxidation treatment 152–153
 - monitors and screens 79–81
 - Monte Carlo simulation (MCS) 241, 243, 244, 246
 - municipal composting facility 278, 281–282
 - municipal recycling strategy 255–256
- n**
- nanocatalysts 200
 - nanoparticles 181, 193, 195, 199–201
 - National Electrical Manufacturers Association (NEMA) classification 49, 214
 - National Environmental Management Act 49
 - National Solid Waste Plan 47
 - National Television and Computer Recycling Scheme (NRCRS) 50, 51
 - naturally occurring conjugated polymers 260
 - N*-butyl sulfonate pyridinium hydrosulfate 151
 - Neodymium-Iron-Boron (NdFeB) magnets 89
 - neuromelanin 265

- N*-heteropentacenequinones (NHPCQ) 261, 262
- Ni-ion biosorption process 195
- Nigeria's e-waste management system 50
- noble metals 138, 141, 146, 147, 151, 190
- noble metal and rare-earth recovery 151
- non-homogeneous waste 307
- non-metal fraction composition, PCBs 214–215
- non-metal fraction recycling
- chemical recycling 221
 - PCBs 215
 - economic benefits 215–216
 - environmental protection and public health 216–218
 - physical recycling 218
- Noranda process 137, 141, 146
- Norway's Waste Regulations 44
- O**
- organic electronics 257–258, 259, 269, 271, 276, 285
- organic field-effect transistors (OFETs)
- bis(trifluoromethylethynyl)-9,10-anthraquinones 262
 - functionalized quinone thin film-based organic semiconductor channels 262
 - high-performance 261
 - quinacridones 262–263
 - source and drain metal electrodes 260
- organic semiconductors, molecular structures of 257, 258
- organic waste treatment facilities 276
- P**
- particle size analysis 100–102
- PbS-O₂-S₂-(SiO₂)_{0.4}(FeO)_{0.3}(CaO)_{0.1} predominance diagram 144, 145
- Pd(0) nanoparticles 200
- perforated vibratory screen deck 103
- photovoltaic (PV) panels 85–86
- photovoltaic modules (PV modules) 6, 172
- average percent weight of common metals 6
 - types of 174
- physical recycling, NMF 218
- electrical separation 220
 - froth flotation 220
 - gravity separation 219–220
 - magnetic separation 220
 - size classification 219
- phytochelatins (PCs) 18, 20, 22, 45, 48, 84, 193
- PLACID process 177
- plastics 141
- recycling 240
 - waste 111, 116, 136, 219, 284
- PLINT process 177
- polychlorinated biphenyls 79, 217
- polydopamine-coated few-walled carbon nanotubes 265
- primary batteries 176
- printed circuit boards (PCB) 83, 136, 213
- average percent weight of common metals 6
 - non-metal fraction composition 214–215
 - non-metal fraction recycling
 - benefits 215–216
 - chemical recycling 221
 - physical recycling 218
 - potential usage 221–223
 - percentage weight of 213
 - types 214
- producer responsibility organizations (PRO) 21, 44, 50
- “product-as-service” business model 309
- purchasing power parity (PPP) 61, 62, 67
- pyrolysis 155–157
- pyrolysis process
- drawbacks 7
- pyrometallurgical recycling routes 7
- pyrometallurgy 135
- advantage 135
 - distillation 153–155
 - electrochemical processes 147–148
 - molten salt oxidation treatment 152–153
 - Noranda process 137
 - printed circuit boards (PCB) 136–137
 - pyrolysis 155–157
 - roasting 152
 - smelting 135, 138
- Q**
- QLED 90
- quinacridones (QAs) 261–263

- quinone-based redox active biomolecules
and biopolymers 265
- quinones 261, 262, 264–265, 267
- r**
- rare earth elements (REE) 1, 2, 6, 86, 89,
149, 151, 157, 178, 181, 190, 305,
306
- rare earth roll separator 106
- re-cycling efficiency 136
- reactive metals 141, 146, 148
- rechargeable batteries 176, 264, 268
- recycling 302
chemical recycling 221
circular economy 302–304
physical recycling 218
processing routes 7
- recycling methods, for e-waste 95
centrifugal classifier 104–105
classification process 104–106
comminution/size-reduction 97–100
cryogrinding 100
hammer mill 98
high voltage pulse fragmentation
98–99
knife mill 100
shredders 97
- electrical separation 108–109
corona electrostatic separation 108
eddy current separation 110–111
triboelectric separator 109–110
- end-processing stage 95
- froth flotation 116–119
- gravitational classifiers 105–106
- gravity separation 111–116
centrifugal concentrators 114–115
concentration criterion 112
dense media separation 115–116
jigs 112
shaking tables 113–114
spirals 112
zig-zag classifiers 114
- high-intensity magnetic separators
107–108
- low-intensity magnetic separators
106–107
- magnetic separation 106–108
- particle size analysis 100–101
- pre-processing stage 95
- sensor-based sorting 119
- size separation 102–106
screening 102–103
- REE recovery, from LED waste 178, 179
- refining copper, from waste mobile
phones 248
- resource conservation 74
- roasting 148, 152, 153
- RoHS Directive 34, 90
- Rosin-Rammler distribution 101
- ruminant-hay natural ecosystem
279–280
- S**
- sales method 63
- SASIL photovoltaic waste treatment
project 174–175
- scrap materials 40, 41
- screening process 102–103
- sensor-based sorting 119
- shaking tables 113–114
- short-range π -electron delocalization
261
- shredders 96, 97
- simple delay method 63, 64
- sintering-smelting 143
- small household appliances (SHA)
76–78
- smartphones 178, 180, 235, 237–240,
244–250, 302, 309, 311
- smartphone formal collection scenario
244–245
- smartphone informal collection scenario
246–247
- smelting 138
advantages 146–147
copper smelting processes - secondary
smelters 142
copper smelting processes - sulfide
route 138–142
lead smelting processes 142–146
limitations 147
- SO₂-rich gaseous phase 138
- solid waste management 19, 234
- solution-based processing, of organic
electronic materials 258
- specialized inoculant
adapted to heavy metals 283–284
adapted to organic matter 282–283
- spirals 105, 112–113, 220
- steel recycling 166
- StEP Initiative 73
- submerged tuyere smelting 139

- substrate degradation models 274
 - supercritical fluid technology 180, 181
 - sustainability 1, 136, 147, 234, 300, 302, 306, 307, 309–311
 - sustainability principles 307
 - synthetic eumelanin 267
- t**
- Taiwan Environmental Protection Administration (TEPA) 25, 49
 - tannins 268
 - technological innovation 255–256
 - termite-wood natural ecosystem 280–281
 - tetrabromobisphenol A (TBBPA) 155
 - 2,3,7,8-tetrachlorodibenzo-p-dioxin (tetra-CDD) 217
 - time step method 64–65
 - TNO process, for NiCd batteries 176, 177
 - Toxco process 177
 - toxic dioxins and furans (PCDD/Fs) 217, 218
 - toxic emissions 135, 155
 - toxicity equivalency (TEQ) 217, 218
 - transboundary WEEE movement 18–19
 - transistors 73, 167, 257, 259, 260–263
 - triboelectric separation 109–110, 220
 - true environmental sustainability 300
- u**
- Umicore process 140, 143, 177
 - urban mining 5, 52, 86, 95, 136, 165
- v**
- vertical-lance smelting (ISASMELT) 140
 - Vibrating Screen Manufacturers Association (VSMA) equation 103
 - volatile metals 141, 178
- w**
- waste cellphones 238
 - battery disposal 240
 - electronic refining for materials 241
 - formal collection process 239
 - informal collection process 239
 - mechanical dismantling 239–240
 - plastic recycling 240
 - screen glass recycling 240
 - waste electrical and electronic equipment (WEEE) 15, 135, 302
 - characterization and recycling 74
 - generic material composition 75
 - recycling 8
 - standard categorizations 74
 - waste printed circuit boards (WPCBs) 136, 167, 172
 - Cu recovery from mobile phone 172
 - of digital video discs (DVD) 167–168
 - extraction and recovery by leaching process 170–171
 - mass percentage of main metals 167–168
 - metal recycling/recovery 167
 - non-magnetic fraction 170
 - of vacuum cleaners 167, 168
 - whole recycling value chain 167, 169
 - WEEE categories 74
 - future trends 89–90
 - IT and telecommunications equipment
 - computers and notebooks 78–79
 - mobile phones 81–83
 - monitors and screens 79–81
 - printed circuit boards 83–85
 - large household appliances (LHA) 75–76
 - lightning equipment 86
 - photovoltaic (PV) panels 85–86
 - small household appliances (SHA) 76–78
 - toys, leisure and sport 86–89
 - WEEELABEX 40
 - Weibull distribution 63, 66–68
 - white goods 76
 - white rot fungi 270
- y**
- yersinobactin 196
- z**
- zig-zag classifiers 114