Electronics and Electrical Plastics Waste

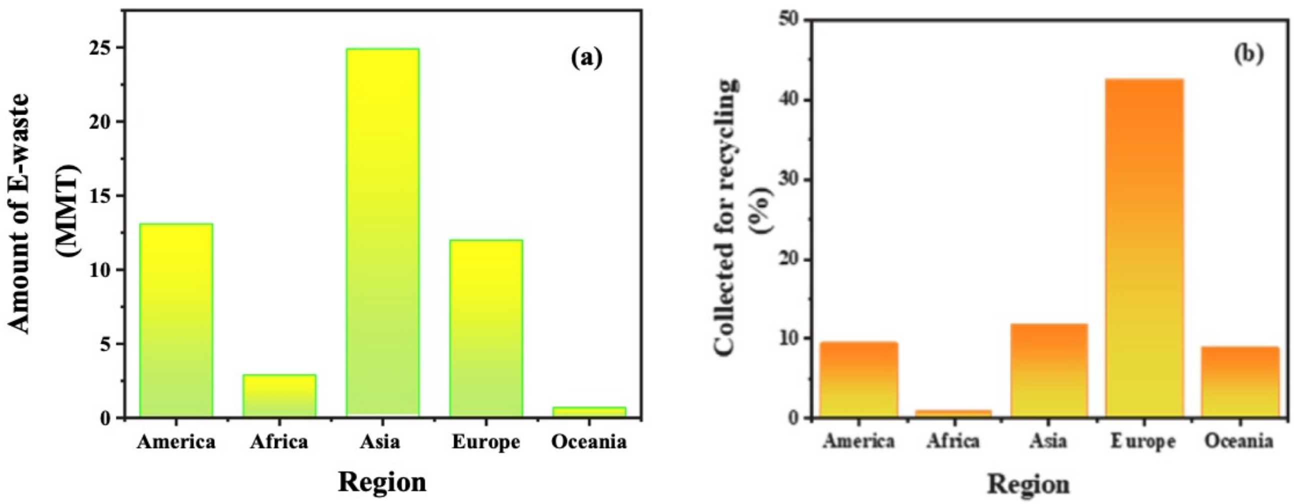


Fig. 1. Global scenario of e-waste in the year 2019 **(a)** E-waste produced **(b)** E-waste collected for recycling (%).

Waste Electrical and Electronic Equipment (WEEE)
Brominated Flame Retardants (BRFs)
Antimony Trioxide Flame Retardants

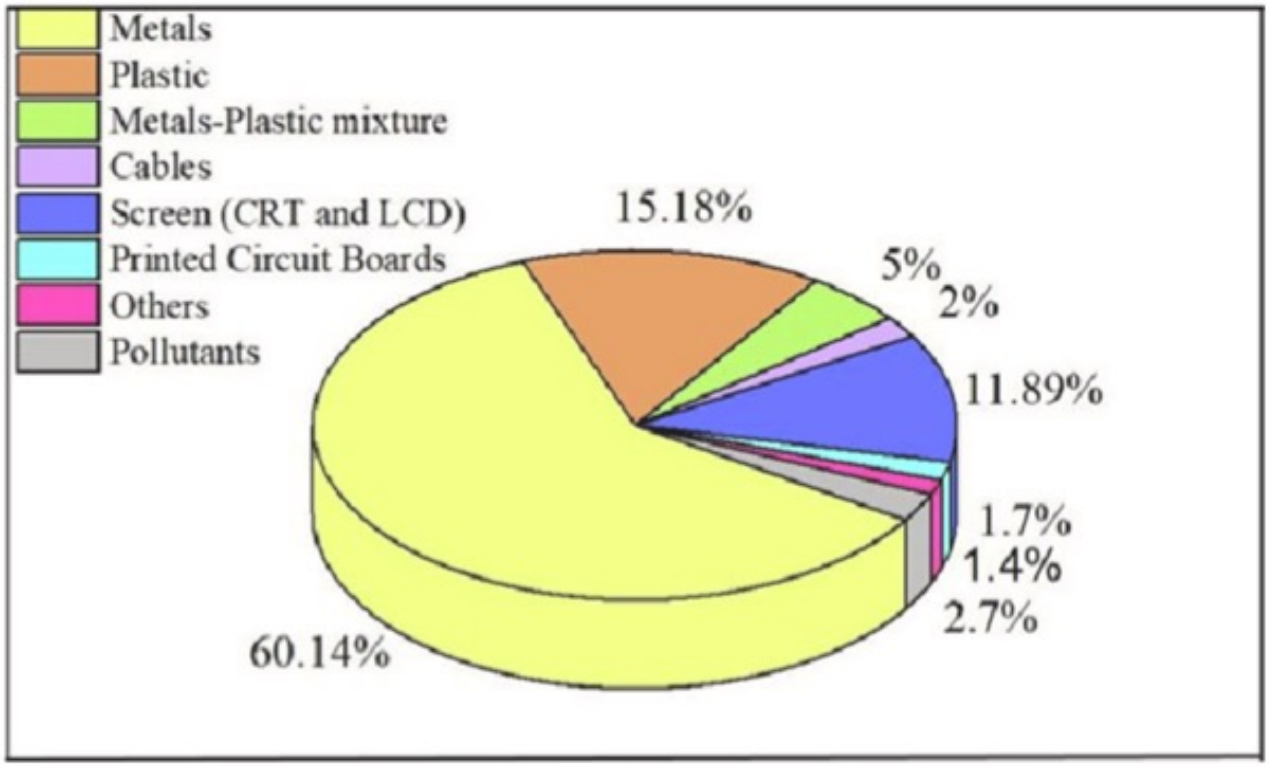


Fig. 3. Average composition of materials in e-waste (%).

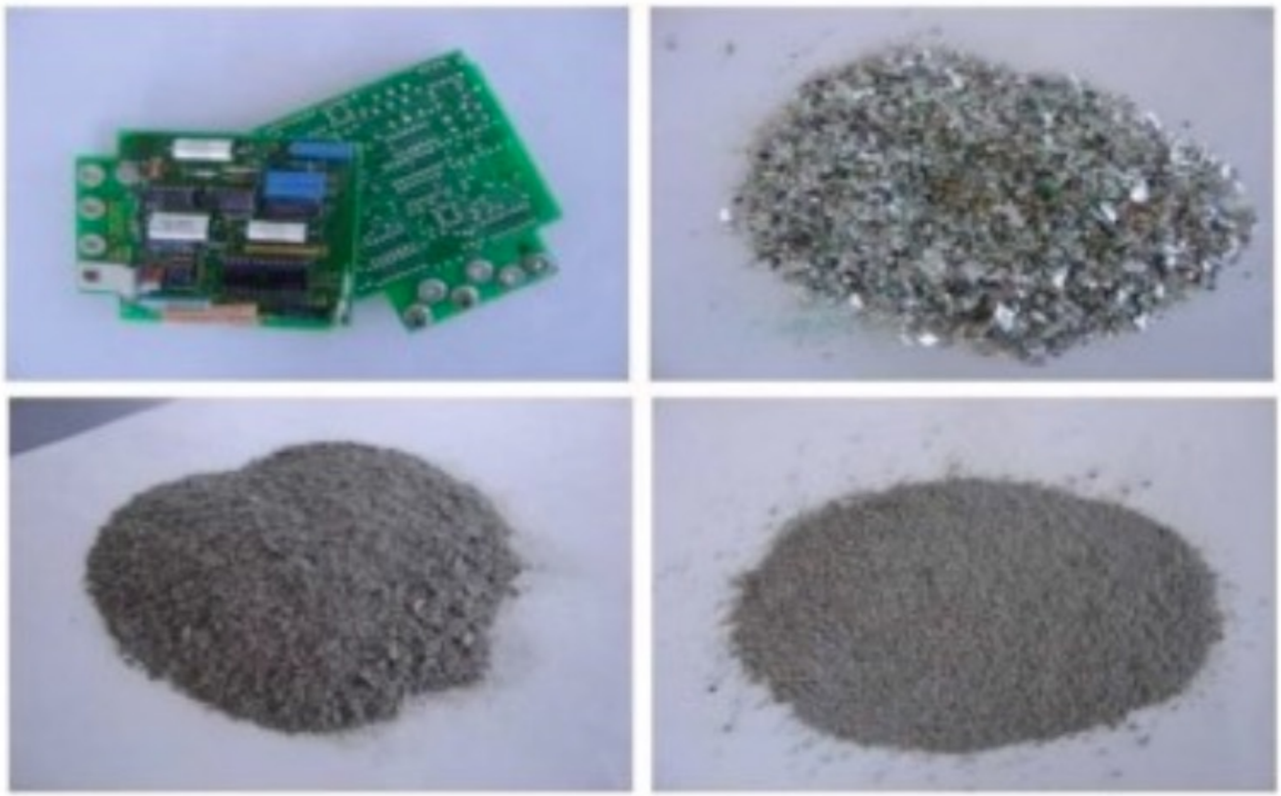


Fig. 1.6 WPCB before grinding and after shredding and sieving from 4 mm, fine grinding and sieving from 0.5 mm, and fine grinding and sieving from 0.25 mm

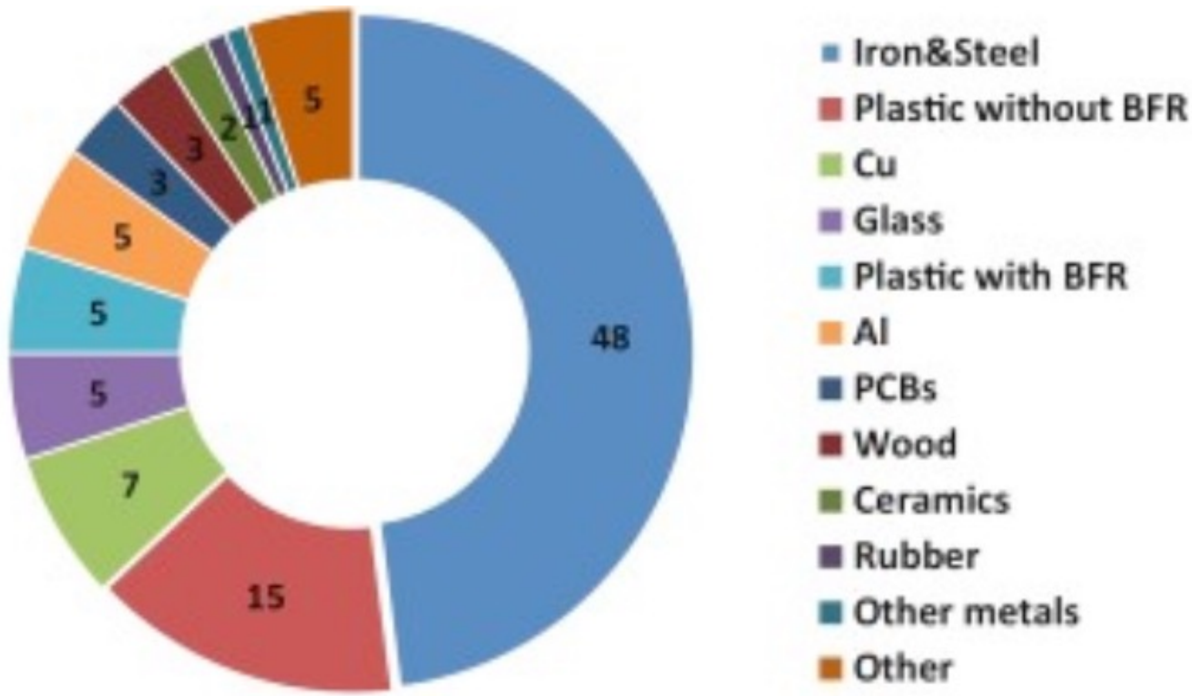
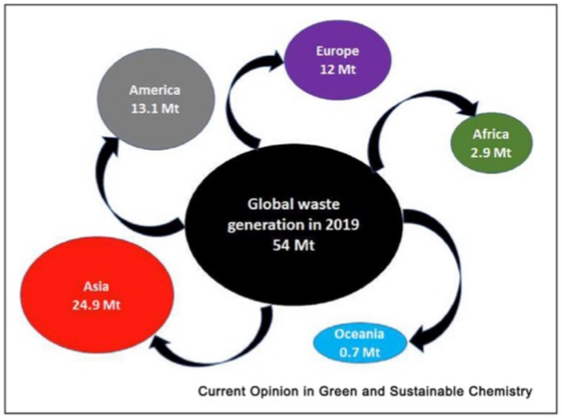


Fig. 1.7 Percent main materials found in electrical and electronic equipment (EEE)

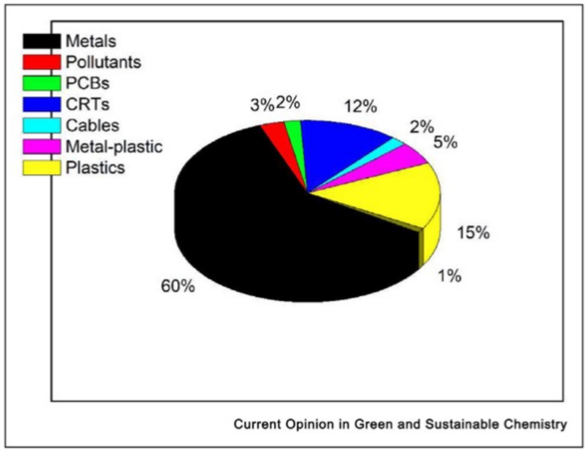
Electronics and Electrical Plastics Waste

Figure 1



Quantities of e-waste globally and e-waste quantities per continents.

Figure 2



Components of e-waste. Redrawn from Ilankoon et al. [8].

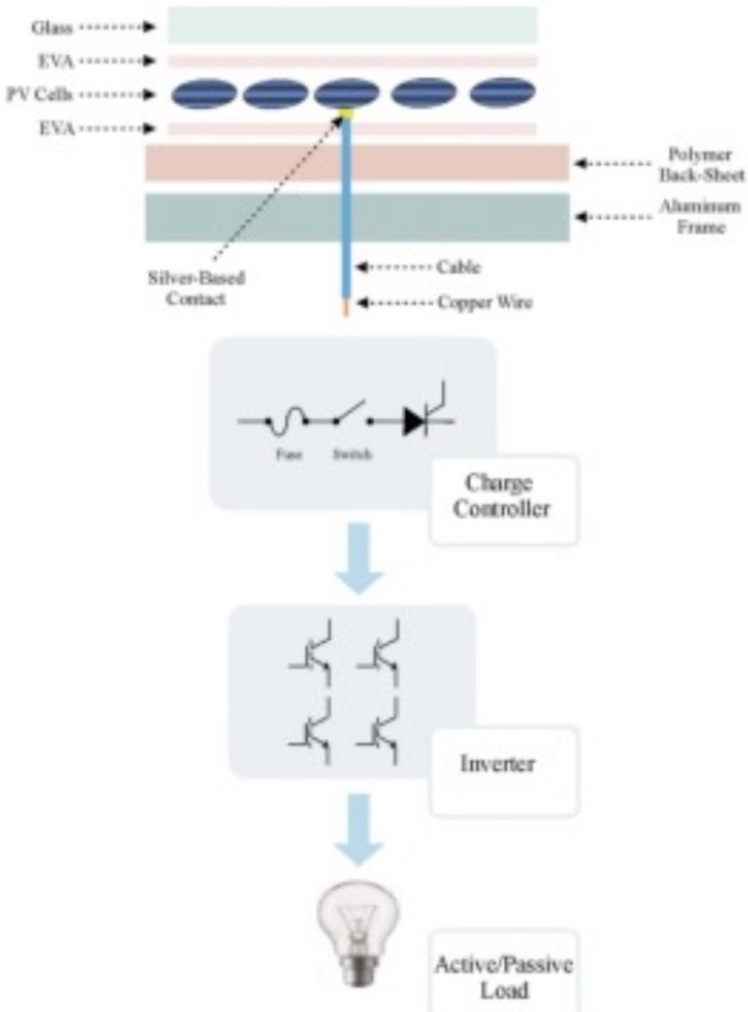


Figure 4.2 Structure of the crystalline PV panel and modules associated for operation during energy conversion. The picture lets us identify the components which can be recovered.

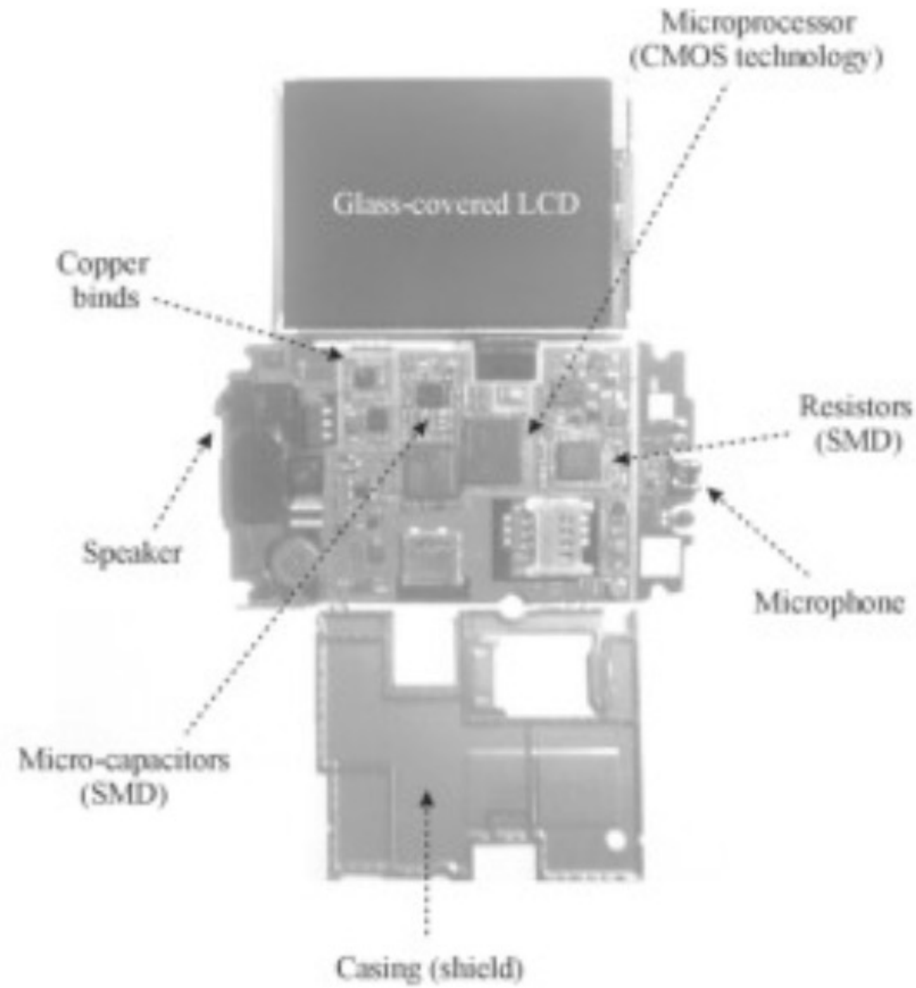


Figure 4.6 Functional blocks which integrate an earlier version of a cell phone circuit board, showing the pieces and modules that are failure-free after their lifecycle.

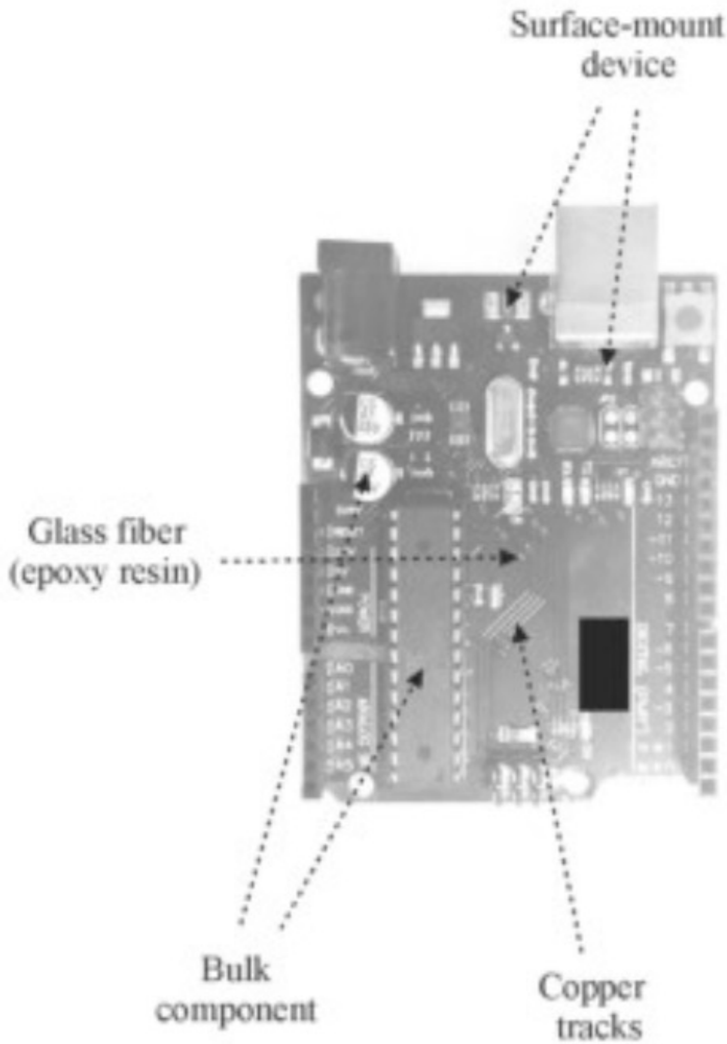


Figure 4.1 Materials included into a modern PCB where surface-mount devices might be a significant source of E-waste.

Electronics and Electrical Plastics Waste

Table 1.4 Classification of metals in WEEE

Precious metals (PMs)	Au, Ag
Platinum group metals (PGMs)	Pd, Pt, Rh, Ir, and Ru
Base metals (BMs)	Cu, Al, Ni, Sn, Zn, and Fe
Concern/hazardous metals (MCs)	Hg, Be, In, Pb, Cd, As, and Sb
Special/scarce metals (SEs)	Te, Ga, Se, Ta, and Ge

Table I. General composition of e-waste.[10–12,14]

General Composition	Type of Compounds	Type of Elements and Polymers	Remarks
Organic materials (30%)	Polymers	PE, PVC, PTE, PF, SAN, and nylon	Recyclable
	Organic pollutants	BFR, PBB, PBDE	
	Glass fibers	TBBPA, epoxy resins	Nonrecyclable
Ceramics (30%)		Silica, aluminum, and earth oxides	
Metals (40%)	Ferrous metals	Iron, nickel	Hazardous metals (Hg, Zn, Pb, Be)
	Nonferrous metals	Copper, aluminum, mercury, lead, zinc, tin, cadmium, gold	Precious metals (Au, Ag, Pt, Pd)
			Rare earth metals (Ta and Ga)

Table II. Concentration of metal in e-waste and ores.[15,16]

Element	From e-waste[17]	From e-waste[18]	From e-waste[19]	E-waste Average	From Ores
Copper (wt%)	20	14.6	19.56	18	0.5–3.0
Iron (wt%)	8	4.79	11.47	8	30–60
Tin (wt%)	4	5.62	3.68	4.5	0.2–0.85
Lead (wt%)	2	2.96	3.93	3	0.3–7.5
Nickel (wt%)	2	1.65	0.38	1.35	0.7–2.0
Gold (ppm and %)	0.1	0.02	0.03	0.05	0.0005
Silver (ppm and %)	0.2	0.045	0.05	0.098	0.0006

Table 1.1 Average metal content in various waste EEE and typical ore.

	Copper %	Aluminum %	Iron %	Gold ppm	Silver ppm	Palladium ppm
Air conditioner	6–19	7–9	46	15	58	–
Desktop	7–20	2–4	18–47	46–240	207–570	18–25
Laptop	1–19	1–2	20	32–630	190–1100	19
Mobile phone	10–33	3	5	30–1500	2000–3800	300–1700
Printed circuit board	12–19	2–8	0–11	29–1120	100–5200	33–220
Refrigerator	3–17	1–2	48–50	44	42	–
Television	1–21	1–15	13–43	5–300	120–600	0–20
Washing machine	3–7	0–3	52–53	17	51	–
e-Waste (average)	12–35	1.5–5	5–11	30–350	80–1000	30–200
Typical ore	0.5–3	20–24	30–60	0.5–10	5–10	1–10

Sources: Based on Bizzo et al. (2014), Calvo et al. (2016), Desjardins (2014), Işıldar (2016), Bizzo et al. (2014), Calvo et al. (2016), Desjardins (2014), Fornalczyk et al. (2013), Işıldar (2016), Khaliq et al. (2014), Liu (2014), McLeod (2014), Namias (2013), North American Palladium Ltd. (2018), Shah et al. (2014), Tickner et al. (2016), Zeng et al. (2016).

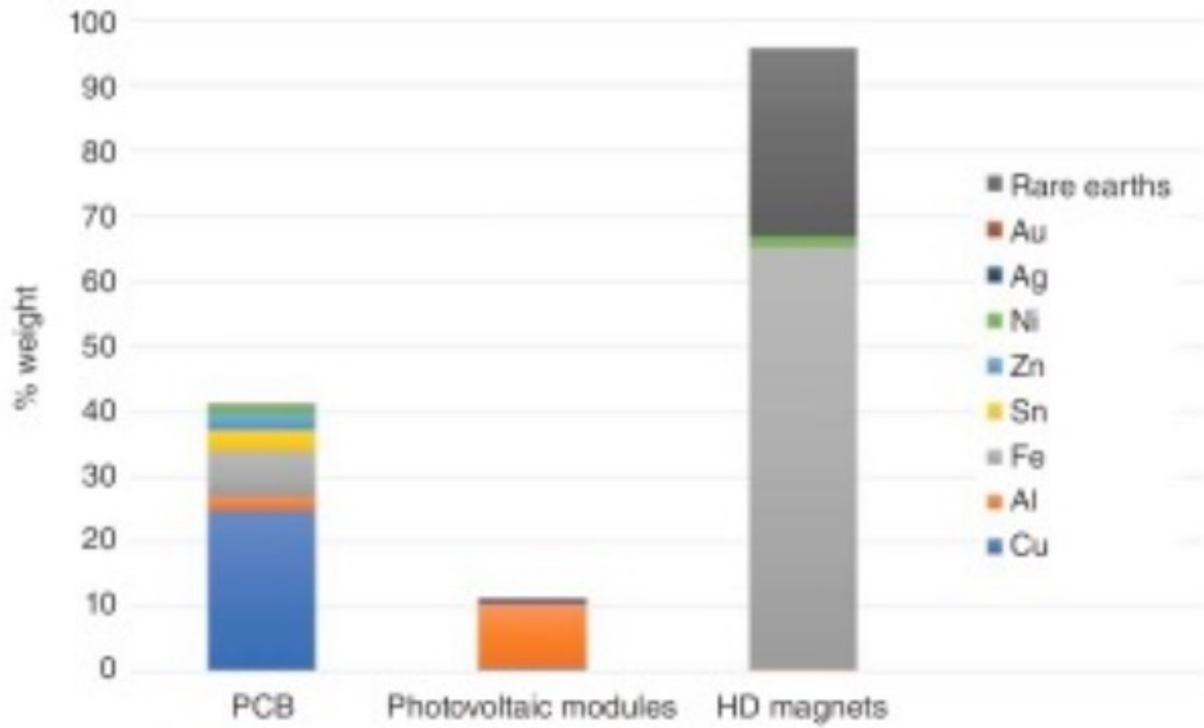


Figure 1.3 Average percent weight of some common metals found in PCB, photovoltaic modules, and HD magnets (Caldas et al. 2015; Dias et al. 2016, 2018; Kasper et al. 2011; München et al. 2018; München and Veit 2017; Petter et al. 2014; Rozas et al. 2017; Sant'ana et al. 2013; Silvas et al. 2015; Stuhlpfarrer et al. 2015; Yamane et al. 2011). Sources: Based on Caldas et al. (2015), Dias et al. (2016), and Kasper et al. (2011).

80% goes to landfill

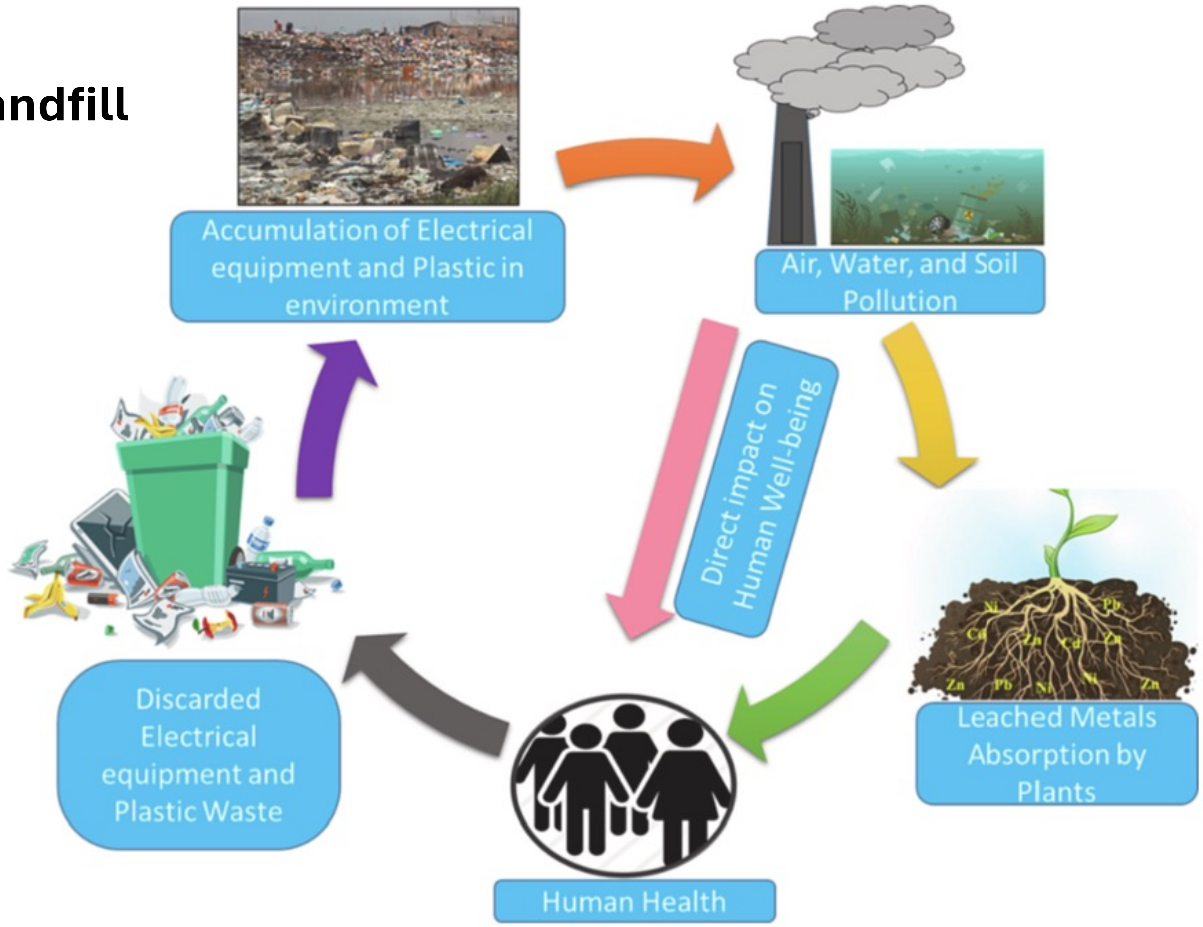


Fig. 5. The effect of improper disposal of e-waste and plastic waste on human health and the environment [22,23].

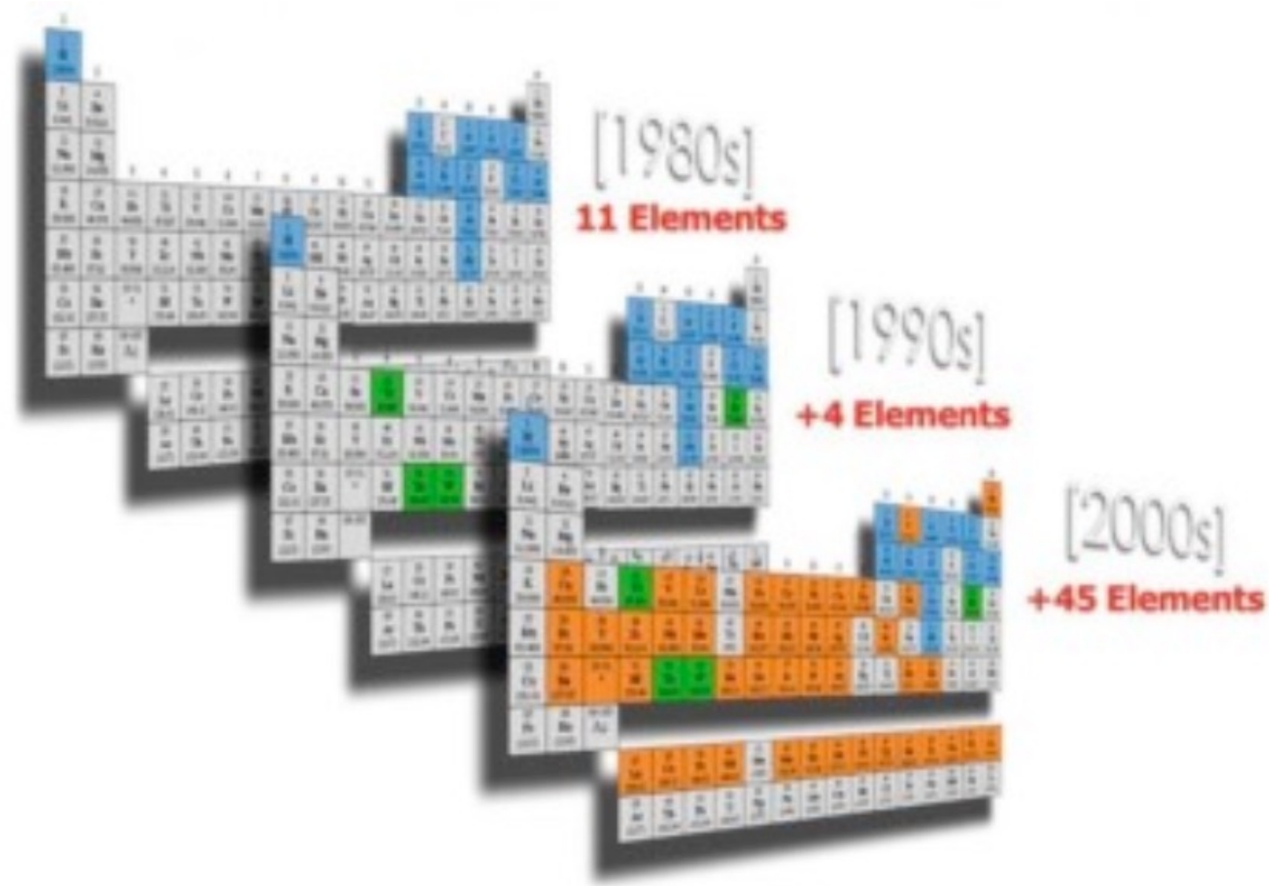


Fig. 1.2 Growth of technology metals used in ICT circuitry [15]

Table 1.2 Some of the hazardous and useful elements/chemical substances contained in WEEE/EEE

Hazardous material (harmful/toxic)	Materials and components usage in EEE	Possible adverse health effects
Lead (Pb)/PbO PbS	Solder on PCBs, CRT TVs/monitors (Pb in glass), Pb-acid battery, gasket in monitors, light bulbs, fluorescent tubes, cabling, solar batteries, and photocells	Vomiting, diarrhea, convulsions, anemia, coma or even death, appetite loss, abdominal pain, constipation, fatigue, sleeplessness, irritability, skin damage, and headache. Damage to the central and peripheral nervous systems, blood systems, and reproductive system and kidney damage. Gastric and duodenal ulcers. Affects brain development of children
Mercury (Hg)	Fluorescent tubes, tilt switches, flat screen switches, some alkaline batteries, switches, PCBs, sensors, relays, thermostats, medical equipment, data transmission, telecommunication, mobile phones, flat screens, thermostat, LCD, CRT	Brain, kidney, and central nervous system effects and liver chronic damage. Causes anemia. Respiratory and skin disorders due to bioaccumulation in fishes
Chromium VI (Cr^{6+}) (Corrosion protection of untreated and galvanized steel plates or hardener for steel housing)	Data tapes, floppy discs, metal housings, oxidative stress	Highly toxic. Human carcinogens, impacts on neonates, reproductive and endocrine functions. Irritating to the eyes, skin, and mucous membranes. Asthmatic bronchitis. DNA damage. Defect in neurodevelopment. Multiple organ failure
Barium (Ba) and strontium (Sr)	Getters in CRT, funnel glass	Brain swelling, muscle weakness, damage to the heart, liver, and spleen
Nickel (Ni) and cadmium (Cd)	NiCd rechargeable batteries, contacts and switches, fluorescent layer (CRT screens), printer ink and toners, SMD chip resistors, IR detectors, semiconductors, pins, PCBs	Highly biotoxic and bioaccumulation in the environment. Symptoms of poisoning (weakness, fever, headache, chills, sweating, and muscle pain), lung cancer, and kidney damage. Increased risk of cardiovascular disease, neurological deficits, and developmental deficits in childhood and high blood pressure. Respiratory system, bone problem, and defects in neurodevelopment of fetus. Toxic on human health. Accumulates in the kidney and liver. Causes neural damage. Teratogenic
Arsenic (As) and gallium (Ga)	Gallium arsenide in light-emitting diodes (LEDs), laser, photo/tunnel diodes	Skin diseases, decrease nerve conduction velocity, lung and bladder cancer. Affect breathing, cardiovascular diseases. Liver and renal disease. Gastrointestinal disturbances. Carcinogenic
Copper (Cu) and CuO	Wires, cables PCBs, coils, diodes	Copperiedus
Americium (Am) (Radioactive source)	Smoke alarm detectors	Radioactive element
Antimony (Sb)	Flame retardants in plastics, CRT glass, alloying element, photocells (ATO)	Carcinogenic potential
Beryllium (Be), Cu-Be alloys, BeO ceramics	Motherboards, connectors, heat sinks, power supply boxes	Affects organs such as the liver, kidneys, heart, nervous system, and lymphatic system. Carcinogenic (lung cancer). Inhalation of fumes and dust causes chronic berylliosis. Skin disease such as warts
Indium (In)	LCD display units (indium tin oxide (ITO) (90% In_2O_3+ 10% SnO_2)), chips, white LEDs, thin film PV cells, InGaN in LEDs Diodes, transistors, semiconductors, PVs (In_2O_3, Cu(In, Ga)Se_2, ICs (InP)	Taking in by mouth might results in damage to the kidney, heart, liver, and other organs. Breathing in indium might irritate the lungs. Applying In to the skin might cause skin irritation
Selenium (Se)	Diodes, electro-optic, photocopy machines, solar cells, semiconductors	Gastrointestinal disorder, hair loss, sloughing of nail, fatigue, irritability, and neurological damage
Bromide (Br) (HBr)	Flame retardant in plastics (BFR)	Disrupts thyroid function, increases risk of preterm birth and birth defects, slow neural and cognitive development, DNA damages, carcinogenic potential, toxic to kidney, hearing loss, skin disorder
Barium (Ba)	Sparkplugs, fluorescent lamps, and CRT gutters in vacuum tubes (2–9% Ba)	Causes brain swelling, muscle weakness/twitching, damage to the heart, liver, and spleen though short-term exposure. Low blood potassium, respiratory failure, dysfunction paralysis, high blood pressure

Table 1.2 (continued)

Lithium (Li) and cobalt (Co)	LiON (23–25% Li, 2–3% Co), NiCd, NiMH rechargeable batteries (SmCo, NdFeB), $LiPF_6$ electrolyte, $LiCoO_2$, CRTs, and PCBs	Nausea, diarrhea, dizziness, muscle weakness, fatigue, and a dazed feeling. Fine tremor, frequent urination, and thirst. Affect gastrointestinal and neurological system. Co is absorbed by the skin and the respiratory tract. Co itself may cause allergic dermatitis, rhinitis, and asthma
Zinc (Zn)	CRTs (30–35%), metal coatings, batteries. Plating/galvanizing for steel parts	Increased risk of Cu deficiency (anemia, neurological abnormalities)
Phosphors (P)	CRT	White phosphorus is widely poisonous, and exposure to it will be fatal. Too much phosphorous can cause kidney damage and osteoporosis. Phosphors can cause skin burns
Chlorofluorocarbon (CFC/HCFCs)	Cooling units, insulation foams	Deleterious effect on the ozone layer, increased incidence of skin cancer, and/or genetic damages
Polychlorinated biphenyls (PCB)	Condensers, transformers, older capacitors, heat transfer fluids	Cancer, effects on the immune systems, reproductive system, nervous system, endocrine system, and other health effects. Liver damage
PBDEs, PBBs; PBDD/Fs; PCDD/Fs	Flame retardants in plastics, PCBs, plastic housings, keyboards, and cable insulation	Hormonal effects, under thermal treatment possible formation of dioxins and furans
Polyvinylchloride (PVC)	Insulation for cables, plastic parts, computer housings and monitors	Carcinogenic furan and dioxins when burned which are highly persistent in the environment and toxic even in very low concentrations. Reproductive and developmental problems. Immune system damage. Interference with regulatory hormones. HCl can cause respiratory problems.
1,2-Ethanediol	Al electrolytic capacitor (AEC) electrolyte primary solvent or additive	Harms the liver, kidney, and central nervous system, causes kidney failure and brain death

Table 1.2 (continued)

Methyl cellosolve	Al electrolytic capacitor (AEC) electrolyte primary/secondary solvent	Damages the nervous system, blood, bone marrow, kidney, and liver as well as could lead to a reproductive and developmental toxicity
Useful material (Harmless)	Material and components usage in EEE	Elements detrimental to recycling (reduce the recycling value)
Tin (Sn)	Solder, Pb-free solders, ITO in LCDs, PV cells, miniaturized capacitors	
Copper (Cu) and CuO	Wires, cables PCBs, coils, diodes	Hg, Be, (*As*, *Sb*, *Ni*, *Bi*, *Al*)
Aluminum (Al)	Heat sinks, capacitors, cables, casings	Cu, Fe, (*Si*)
Iron (Fe), ferrous metal	Steel chassis, casings, fixings, magnets, magnet coils	(*Cu*, *Sn*, *Zn*)
Magnesium (Mg)	Casings, body of cameras	
Silicon (Si)	Glass, transistors, ICs, PCBs	
Gold (Au)	Connector plating, pins, contacts, EPROM, ROM, RAM, CPU, IC, transistors, diodes, switches	
Silver (Ag)	Batteries, solders, switches, relays, USPs, stabilizers, contacts, capacitors, RFID chips, PV cells	
PGM-palladium (Pd)	Multilayer capacitors, connectors, transistors, diodes, Ag-Cu-Pd solder	
Ruthenium (Ru)	HD, plasma displays	
PGM-platinum (Pt)	HD, thermocouples, fuel cells, sensors, switching contacts	
Germanium (Ge)	The 1950s and 1960s transistors, semiconductors, diodes, PV cells, glass fiber	
Tantalum (Ta)	Capacitors	
Tellurium (Te)	Thin film PV cells, photoreceptors, photoelectric devices	
Gallium (Ga)	ICs (GaAs), PVs (GaN, InGaN, GaAs, Cu(In, Ga)Se_2), LED (GaN, InGaN, GaAsP, GaAs, GaP, AlGaInP), LED (AlGaInP), photodetectors, PV cells, integrated switches	

Table 1.2 (continued)

REE-neodymium (Nd)	HDD drive magnet, microphones, speakers	
REE-cerium oxide (CeO_2/Ce_2O_3)	CRT faceplate glass, fluorescent lighting, LEDs	
REE-yttrium (Y), terbium (Tb), europium (Eu)	Used as phosphors in display units (PV panels, fluorescent lamps (5–7% Y), CRTs (15–20% Y) (Y_2O_3, Eu_2O_3, Tb_2O_3), LEDs)	
REE-lanthanum (La)	NiMH batteries (La_2O_3)	
REE-gadolinium (Gd) and yttrium (Y)	White LEDs	
Sulfur (S)	Pb-acid battery	
Carbon (C)	Steel, plastics, resistors. In almost all electronic equipment	
Bismuth (Bi)	Solders, capacitors, heat sinks	
Niobium (Nb), nickel (Ni)	Gold coatings, super alloy magnets, capacitors, Nb steel alloys	
Tungsten (W)	Tungsten carbide, electrodes, cables, CRT tubes	

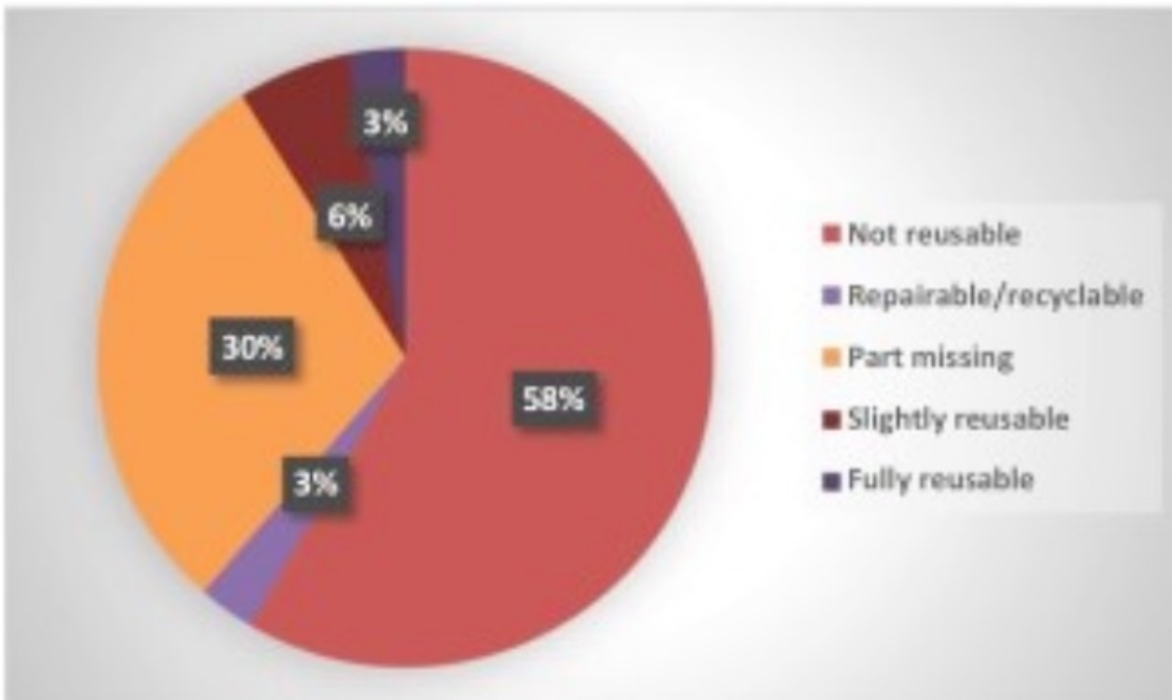


Fig. 1.13 Functionality of collected WEEE

E-Waste Value Chain

- Distributers – who buy new/used equipment to consumers directly
- Consumers
- Collectors – also known as waste pickers e-waste and usually work in unhygienic conditions
- Repairers and refurbishers
- Dismantlers or segregators – involved in breaking down equipment into marketable components
- Recyclers – convert e-waste to secondary raw materials, products which are sold to suppliers of manufacturing industries.
- Downstream vendors – buy the different components that have been separated, dismantled, and recovered by recyclers

According to The Global E-waste Monitor 2020, it was reported that in 2019, about 54 million metric tonnes of e-waste was annually produced of which only 17% was collected and recycled. The rest (estimated to have a monetary value of US $ 64 billion) is dumped in landfills or illegally exported to African and Asian countries where it is managed/recycled by informal workers.

70% of hazardous waste in landfills are WEEE

Figure 2.3 Known sources, destinations, and suspected destinations of WEEE transboundary movement worldwide. Source: Kumar et al. (2017).

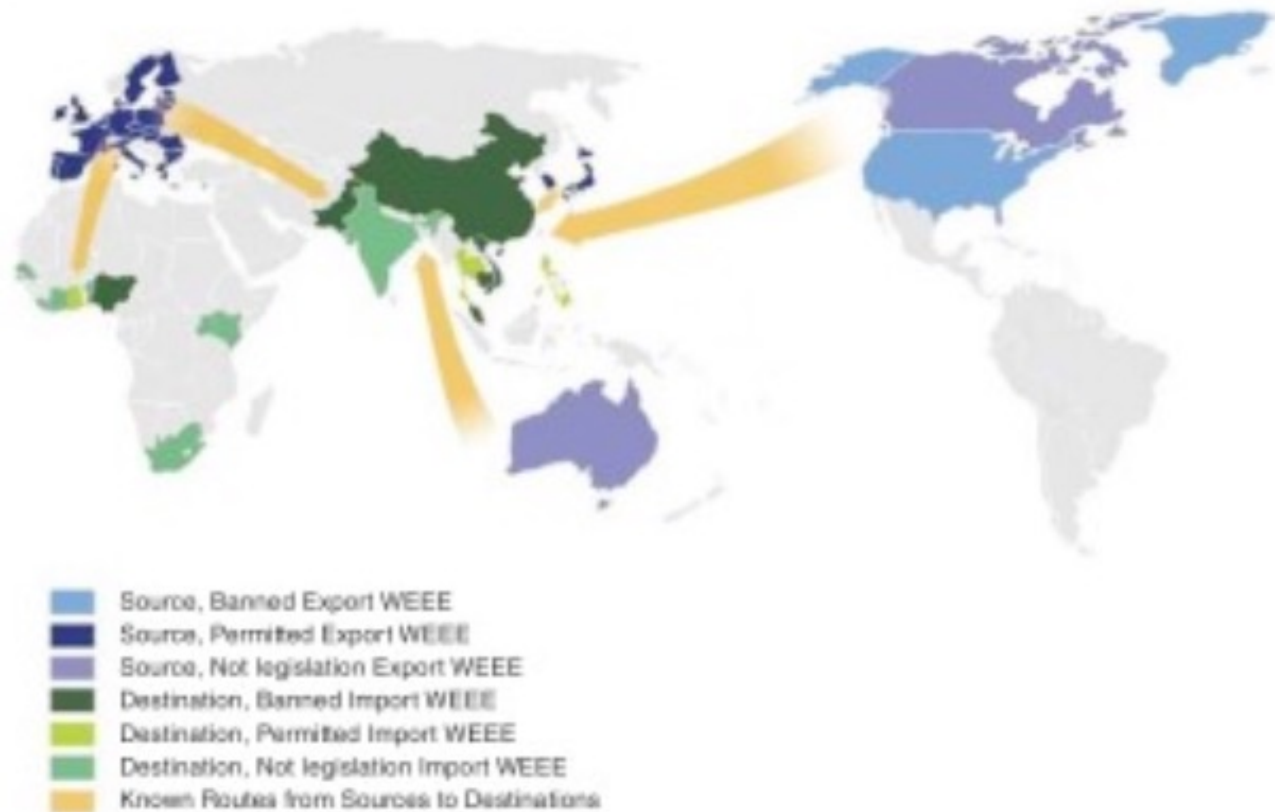


Figure 3.1 Known routes and permissions/bans for the WEEE imports/exports in 2013. Source: Li et al. (2015).

The following are the challenges for e-waste recycling:

- There are no accurate figures/estimates of the rapidly increasing e-waste generation, disposal, and imports in the world.
- Low/little level of awareness among manufacturers, consumers, and e-waste workers on the hazards of incorrect e-waste disposal/recycle.
- Major portion of e-waste in the world is processed by the informal/unorganized backyard scrap dealers using rudimentary acid leaching and open-air burning techniques which results in severe environmental damages and health hazards.
- Informal recyclers use vulnerable social groups like women, children, immigrants, prisoners, and immigrant workers for high-risk backyard recycling operations.
- Informal recycling only recovers Au, Ag, Pt, Cu, etc. with substantial losses of material value and resources.

How e-Waste is Recycled

Tracking e-Waste

EPA Publishes Webpage on New International Requirements for Electrical and Electronic Waste

On September 26, 2024, EPA published a webpage about the recently adopted amendments to the Basel Convention for international shipments of all electrical and electronic waste and scrap. The amendments seek to prevent improper recycling and disposal and help direct these materials to facilities equipped to recover such resources in an environmentally sound manner. The webpage covers:

- An overview of the new amendments.
- How the new Basel e-waste amendments will impact U.S. exports and imports.
- What requirements apply to U.S. exports and imports.
- Frequent questions.
- Resources.

Find out more on the new webpage.

EPA Swaps Times for October 30 Webinars about the New International Requirements for Electronic Waste and Scrap

Due to a scheduling conflict, we had to switch the time of webinars we will hold on October 30 about the new Basel Convention amendments for electrical and electronic waste and scrap. We will host the webinar for federal, state, and local governments from 1:00 – 2:00 pm Eastern Time. Register now for the webinar for governments.

We'll hold the webinar for the regulated community from 3:00 – 4:00 ET. Register now for the webinar for the regulated community.

New International Requirements for Electrical and Electronic Waste

As a result of the recently adopted amendments to the Basel Convention, starting January 1, 2025, international shipments of electrical and electronic waste (e-waste) and scrap, for recovery (including recycling) or disposal, are allowed only with the prior written consent of the importing country and any transit countries (i.e., countries shipments may pass through before arrival in the importing country). This marks the first time that non-hazardous e-waste and scrap is controlled under the Basel Convention.

On this page:

Upcoming Webinars

EPA will host two webinars about these new requirements.

For federal, state and local governments:
October 30, 2024
1-2 pm Eastern time
Register now.

For the regulated community:
October 30, 2024
3-4 pm Eastern time
Register now.

Overview of the Basel Convention Electrical and Electronic Waste Amendments

In June 2022, 189 Parties to the Basel Convention agreed to control international trade in electrical and electronic waste and scrap to prevent improper recycling and disposal and help direct such material to facilities equipped to recover such resources in an environmentally sound manner. As a result of these changes, transboundary shipments of all electrical and electronic waste and scrap (i.e., e-waste and scrap) are controlled or regulated. The Basel Convention electrical and electronic waste amendments change the way international shipments of e-waste and scrap are controlled under the Convention.

As of January 1, 2025, hazardous and non-hazardous e-waste and scrap are subject to Basel Convention requirements. In other words, Basel Party countries exporting e-waste and scrap must obtain the importing country's agreement in writing to accept such exports before allowing the shipments to depart the country, a procedure known as prior informed consent. Additional Basel Convention requirements also apply. Historically, only hazardous e-waste was controlled, and non-hazardous e-waste could generally be traded freely.

The amendments establish two new “listings” or classifications for hazardous and non-hazardous e-waste and scrap. Each listing covers three categories:

- Whole equipment.
- Components (e.g., circuit boards, display devices), unless covered by another existing Basel listing.
- Fractions resulting from the processing (e.g., shredding or dismantling) of whole equipment or components, unless covered by another existing Basel listing.

Scrap and other material outputs from the processing of electrical and electronic waste and that are covered by an existing Basel listing (read frequent question #5) are not classified as e-waste for the purposes of these amendments and are subject to the rules that already apply. For hazardous waste or other Basel-controlled waste, Basel prior informed consent requirements continue to apply.

Recycling of e-Waste
-Step 1 Collection
-Step 2 Manual sorting
-Step 3 Dismantling
-Step 4 Shredding
-Step 5 Mechanical separation
Metals from non-metal
Plastics: PC, ABS, HIPS, PA, PP, PE,
polyesters, epoxy fiberglass composites
BFRs

Table 1.3 International legislation and initiative programs combating e-waste problem

Participating countries	Governing body	Initiative	Date adopted
167 countries of the UN (excluding Afghanistan, Haiti, and the USA)	UN Environmental Programme	Basel Convention (No transboundary movement of hazardous waste)	1989
The EU	EUREKA Project (EU1140)	A comprehensive approach for the recycling of electronics (CARE) "Vision 2000"	1994
Japan	Ministry of the Environment, Government of Japan	Home Appliance Recycling Law (HARL) (Home appliance manufacturers must take back and recycle end user products)	2001
The USA	Silicon Valley Toxics Coalition		2002
International	Basel Convention	Mobile Phone Partnership Initiative (MPPI)	2002
The EU	Recycling WEEE	2002/96/EC	2002
The EU	European Parliament	RoHS Directives (Restriction of Hazardous Substances). This Directive aims to limit the use of six hazardous substances (Pb, Hg, Cd, Cr^{6+}, polybrominated biphenyls, polybrominated diphenyl ethers) and applies to all new products put on European market, whether imported or manufactured in the EU. Lead-free solder use	2003
The EU	European Parliament	WEEE directives (Reuse/recycle electronic parts: manufacturers internalize take-back/recycling costs) (Recycling rate 25–40%)	2003–2007
International	G8 (UNCRD)	3Rs Initiative	2005
Intended for OECD countries	Organization for Economic Cooperation and Development (OECD)	Environmentally Sound Management of Water: Reclaim E-Waste	2003
International	UNU-IAS SCYCLE	Solving the E-Waste Problem (StEP)	2007
International	Basel Convention	Partnership for Action on Computer Equipment (PACE)	2008
The EU	European Parliament	HydroWEEE-231962, (Innovative Hydrometallurgical Processes to recover metals from WEEE including lamps, CRTs, PCBs, and batteries)	2009
The EU	ErP Directive		2009

Table 1.3 (continued)

Participating countries	Governing body	Initiative	Date adopted
		Energy-related products (2009/125/EC)	
China	Ministry of Industry and Information Technology (MIIT)	China RoHS 1 and RoHS 2 Reduction of Pb, Hg, Cd, Cr, and BFR	2006–2016
China	Ministry of Commerce	Circular economy promotion law	2008–2009
China (Guiyu city)	Ministry of Environmental Protection	A pilot program of an integrated e-waste recycling industrial park (2500 acres)	2010–2015
The USA	National Strategy for Electronic Stewardship (NSES)	Improve design of electronic products	2011
India	Ministry of Environment and Forestry	E-waste management and handling, similar to EU WEEE and EPR directives	2011–2012
The EU	European Parliament	Better regulate WEEE generation and disposal. Encourage the reuse and recycle metals and resins (2012/19/EU)	2012
The EU	European Parliament	RECLAIM (Reclamation of Gallium, Indium, and Rare-Earth Elements from photovoltaics, Solid-State Lighting, and Electronics Waste)	2013
The EU	European Parliament	SCARE (Strategic Comprehensive Approach for Electronics Recycling and RE-use)	2013
The EU	European Parliament	TV Target (Eco-efficient Treatment of TV Sets and Monitors)	2013
The EU	European Parliament	CONCEERN - CONex Central European Electr(on)ics Recycling Network	2013
The EU	European Parliament	ReLCD (Liquid Crystal Display Re-use and Recycling)	2013
The EU	European Parliament	MobileRec (Collection, Disassembly, and Recycling of Mobile Telecommunication Equipment)	2013
The EU	European Parliament	Demonstration Plant for the Economic Disassembly of Printed Circuit Boards	2013
The EU	European Parliament	AREP (Advanced Recycling, Recovery, and Reuse)	2013
The EU	European Parliament	European Innovation Partnership (EIP) on Raw Materials	2013

Table 1.3 (continued)

Participating countries	Governing body	Initiative	Date adopted
The EU	EU Member States	ERA-MIN roadmap coordination of RM-related research funding between EU Member States	2013
The UN	The UNEP	StEP E-Waste Academy (Solving the E-Waste Problem)	2013
UNEP	UNEP Resource Panel	www.unep.org/resourcepanel with new report "Metal Recycling: Opportunities, Limits, Infrastructure"	2013
The UK	WRAP-ESAP	EEE sustainability action plan	2014
The UK	The UK	CLEVER (Closed Loop Emotionally Valuable E-Waste Recovery)	2013–2016
African countries	Nigeria, Kenya, S. Africa, etc.	Poor regulatory frameworks and poor policing of the industry. Illegal e-waste trade	

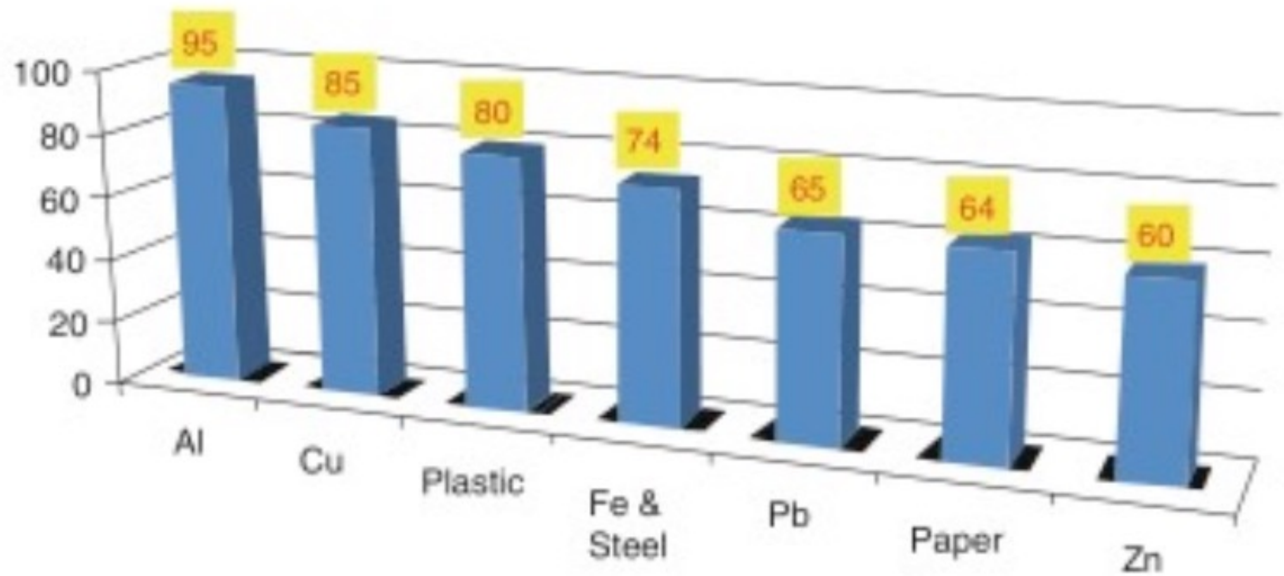


Fig. 1.12 Recycled material energy savings over virgin materials [34]

Printed Circuit Boards (PCBs)

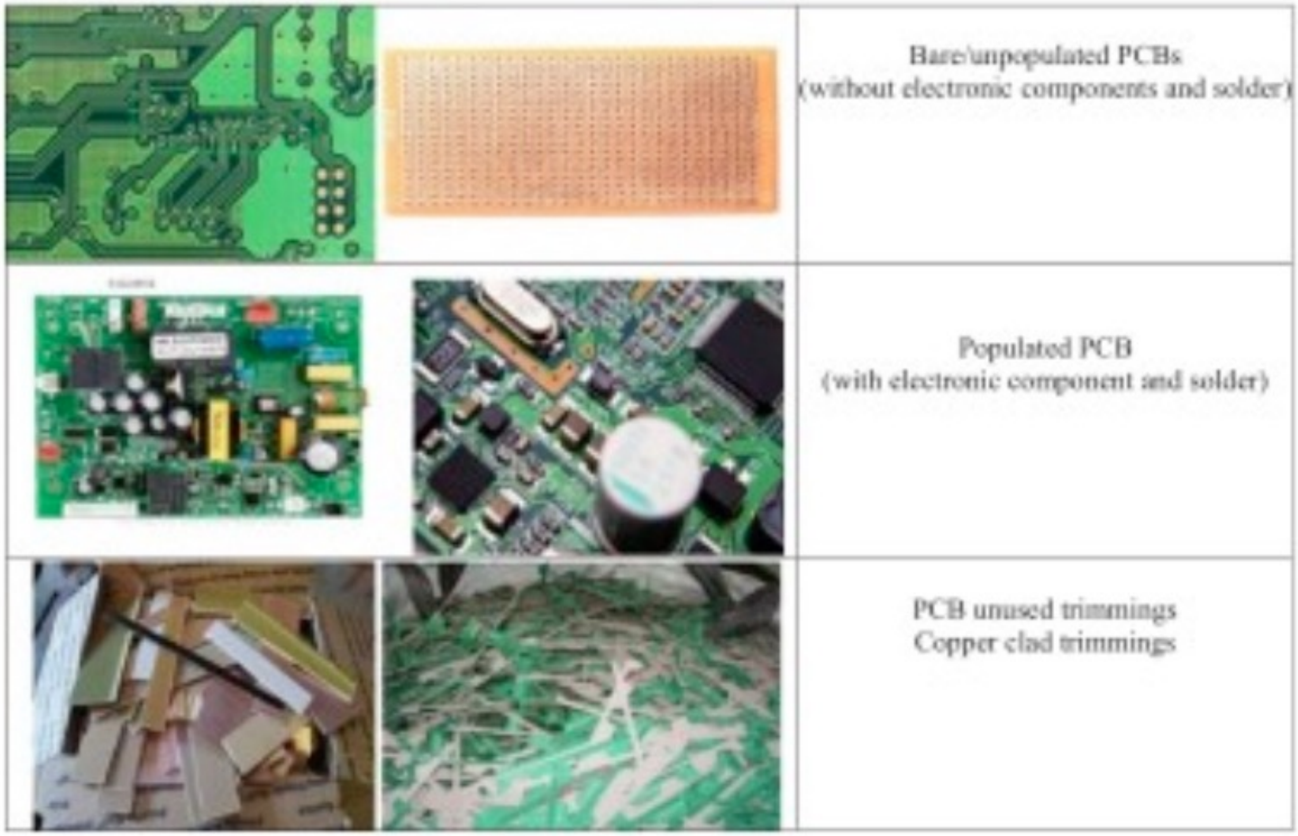


Fig. 2.1 PCB types

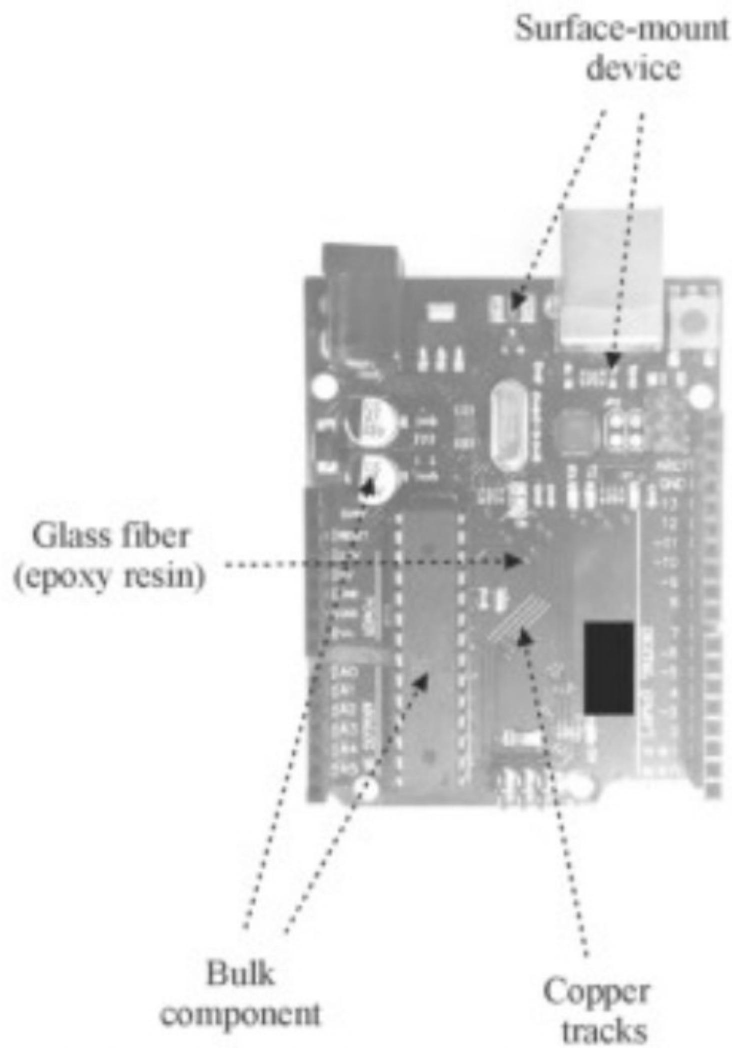
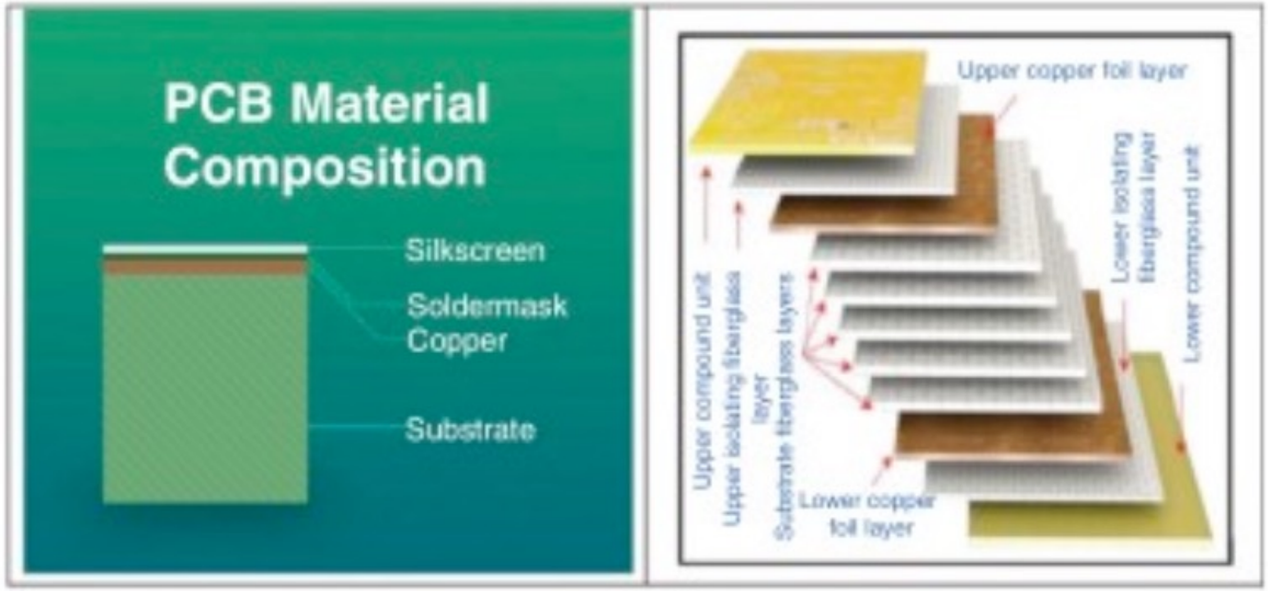


Figure 4.1 Materials included into a modern PCB where surface-mount devices might be a significant source of E-waste.

Paper and phenolic resin
(low grade brown)

Epoxy and fiber composite
(high grade green)



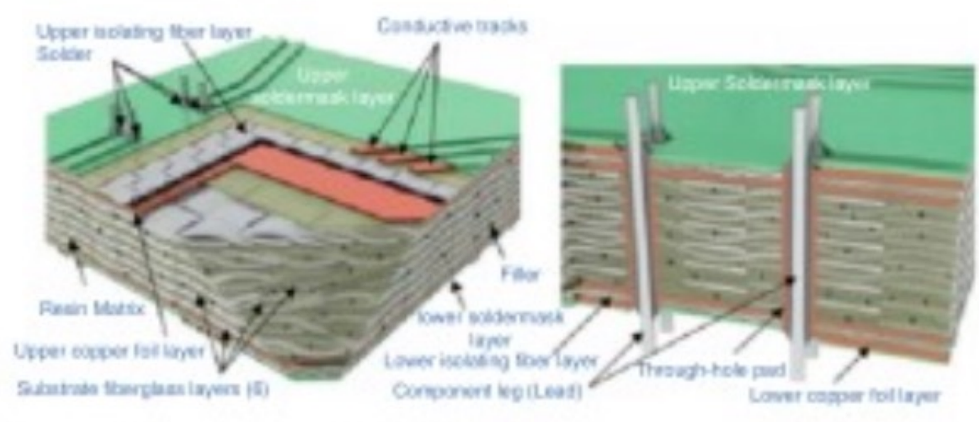


Fig. 2.2 Layers and components of WPCBs [1, 2]

Table 2.1 PCB material composition (compiled from [11–13])

Metals up to 40%	Percentage (%)	Ceramics up to 30%	Percentage (%)	Plastics up to 30%	Percentage (%)
Cu	6–31	SiO_2	15–30	PE	10–16
Fe	0.7–15.2	Al_2O_3	6.0–9.4	PP	4.8
Al	1.3–11.7	Alkali-earth oxides	6.0	PS	4.8
Sn	0.7–7.4	(BeO)	3.0	Epoxy	4.8
Pb	0.8–6.7	Titanates-micas		PVC	2.4
Ni	0.2–5.4			PTPE	2.4
Zn	0.2–2.2			Nylon	0.9
Sb	0.2–0.4				
Au (ppm)	9.0–2050				
Ag (ppm)	110–5700				
Pd (ppm)	3.0–4000				
Pt (ppm)	5–40				
Co (ppm)	1–4000				

Table 2.2 Unpopulated PCB and EC compositions

Composition (%)	Bare PCB	ECs	Total (populated PCB)
Sn	**10.12**	**3.20**	6.0
Pb	3.20	0.68	1.7
Cu	**21.62**	**13.80**	19.9
Fe	0.21	**19.49**	11.8
Al	1.36	6.91	4.7
Zn	0.056	5.66	3.4
Ni	0.036	0.65	0.4
Cr	0.027	0.53	0.3
Cd ($g\ t^{-1}$)	0.53	14.45	8.9
Au ($g\ t^{-1}$)		**40.76**	24.4
Ag ($g\ t^{-1}$)	**194.91**	**112.68**	**145.7**

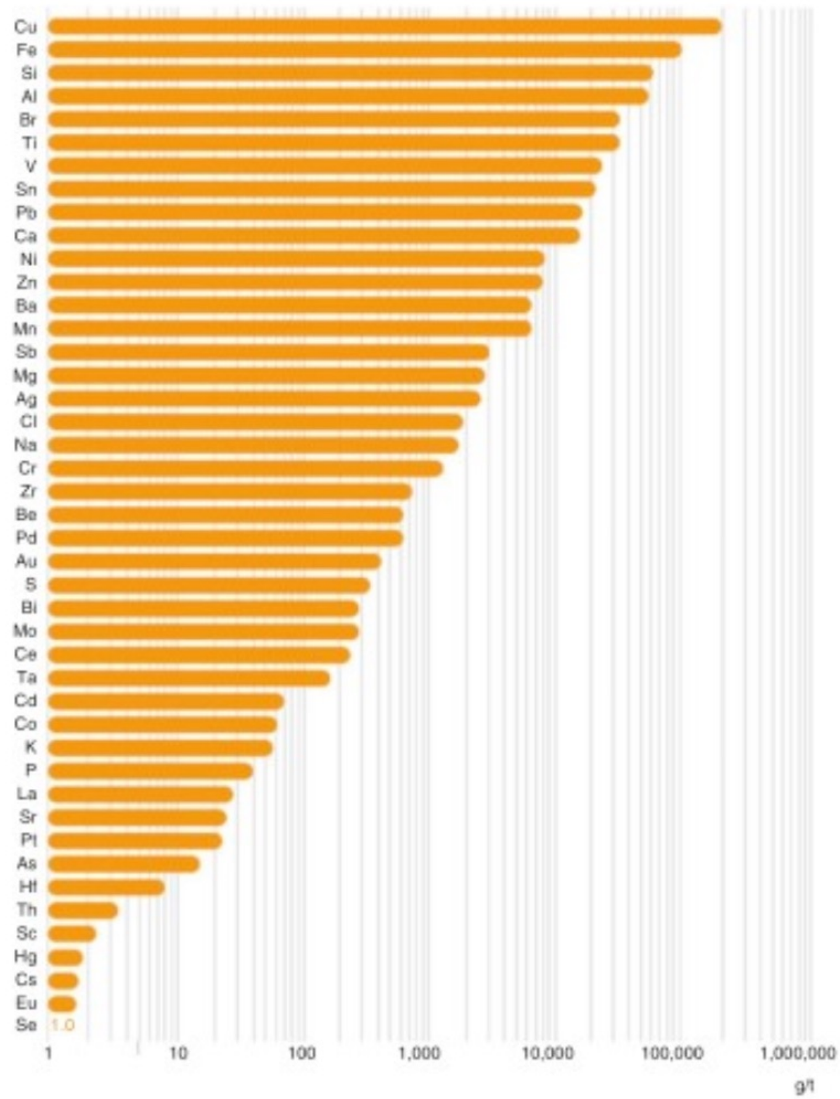


Fig. 2.3 Metals found in PCBs [4]

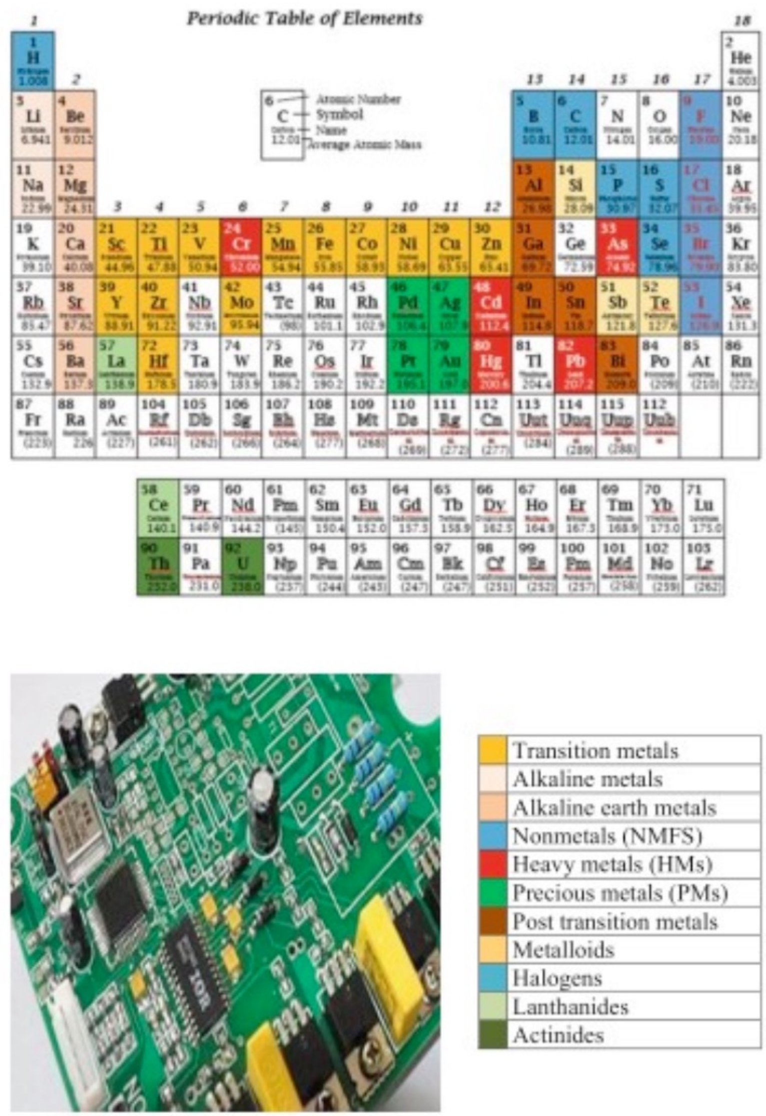


Fig. 2.5 Elements (metals, nonmetal, and metalloids) used in the PCB manufacture

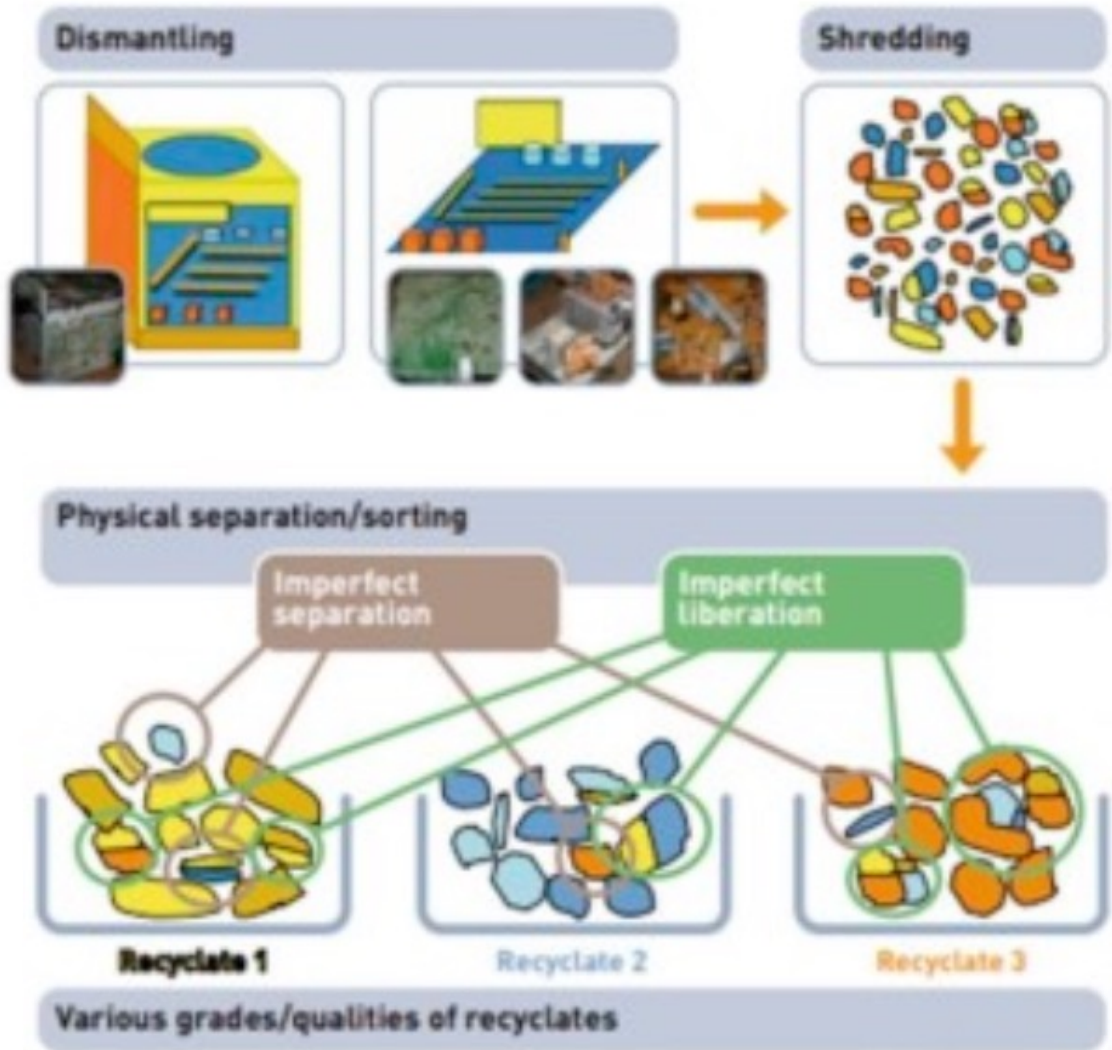


Fig. 3.2 Imperfect liberation leads to imperfect separation

Fig. 4.3 Drum-type dismantling machine with air cleaning system and dismantled WPCBs and ECs developed in China

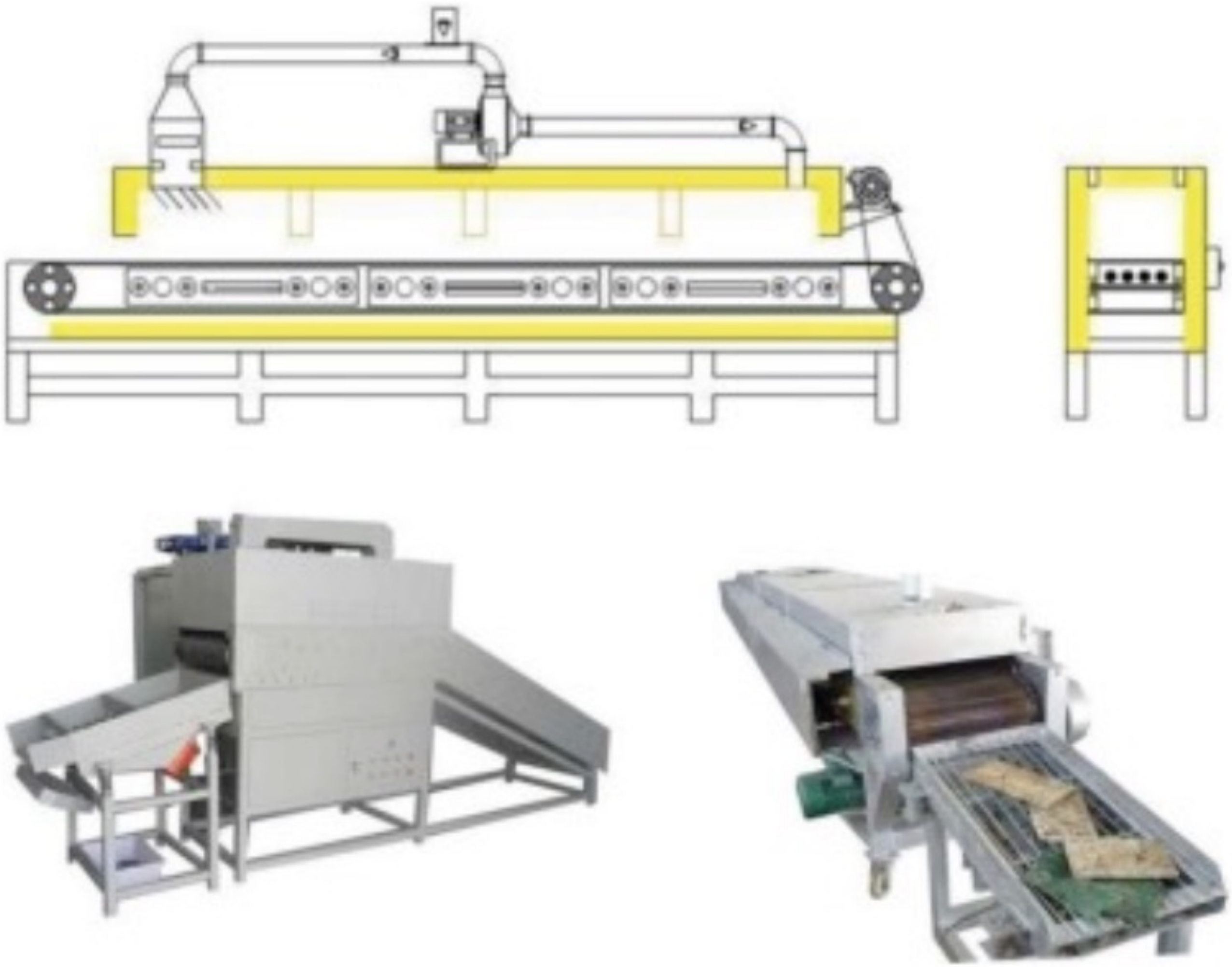


Fig. 4.5 Schematic view and photos of tunnel-type, heated dismantling machines [29]

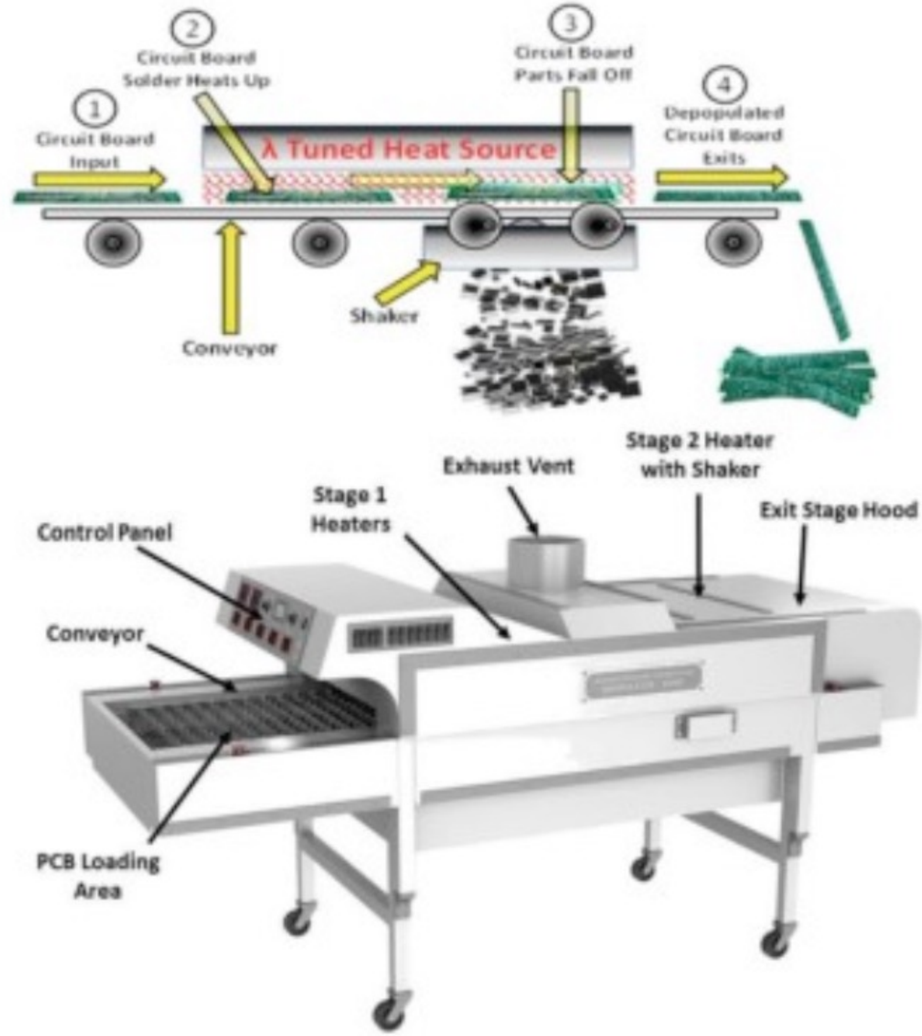


Fig. 4.6 Depopulator schematic diagram and rendering of the D2000 – the production depopulator [30]

PCB Recycling

Fig. 1.4 Illegal primitive WPCB recycling operation photographs in China and India

Non-metallic Fraction (NMF) from waste printed circuit boards (WPCBs)

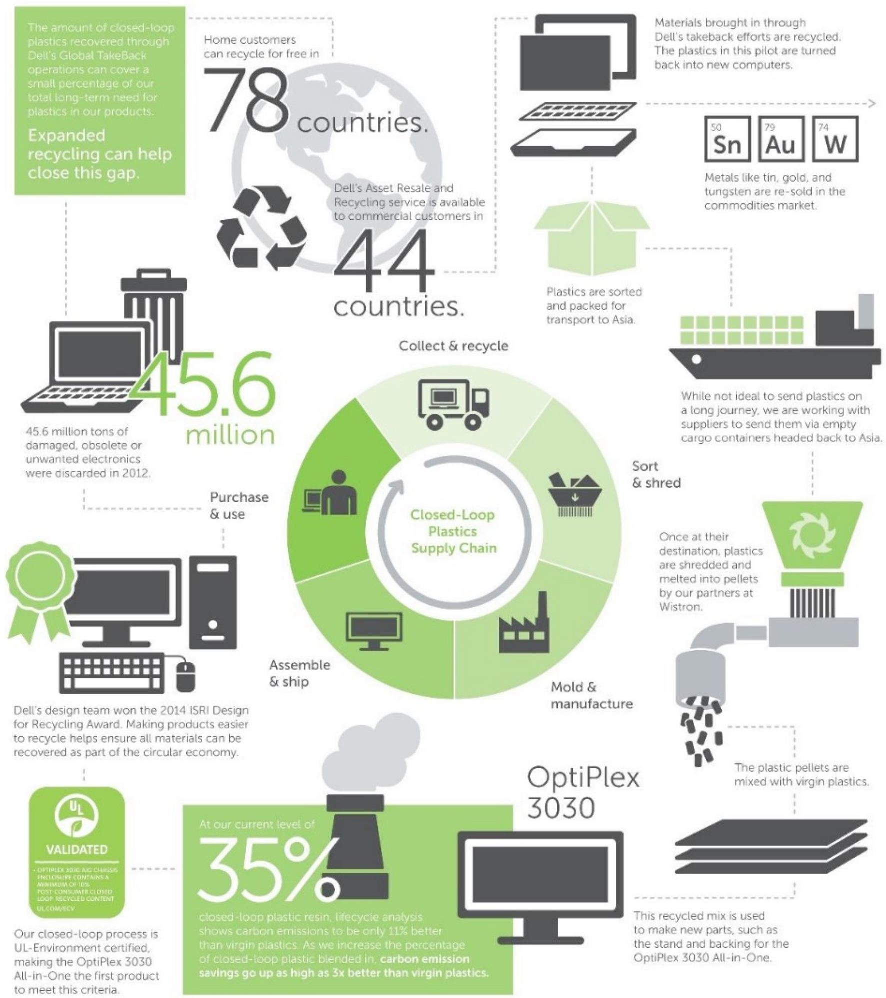
Brominated flame retardants are a problem (BFRs)

Use as filler or concrete additive (16%)

Combustion, Pyrolysis (Ash contains metals)

Dell's Closed-loop Recycling Process

Dell becomes the first to offer a computer made via the UL Environment certified closed-loop process with the launch of the OptiPlex 3030 All-in-One. By using plastics collected through our existing takeback and recycling programs to build new systems, we are helping drive a circular economy for the IT industry.



Case Study: Benefits of closed-loop plastics

In addition to long-term value maintenance, a closed-loop system generates significant environmental benefits. In 2015 Dell conducted a study (Table 2) which found that closed-loop ABS plastic resulted in avoided environmental costs of USD 1.3 million annually compared to the use of virgin ABS plastic. Accordingly, the natural capital net benefit of closed-loop ABS vs. virgin ABS was 44% (natural capital calculations include a range of environmental metrics, such as climate change, ecotoxicity, water pollution, respiratory effects, fossil fuel depletion, smog, air pollution and human health)[31]. According to the same study, avoided environmental costs would be USD 700 million/per year if the entire computer sector would use recycled ABS instead of virgin ABS plastic.

Table 2: Dell Study on avoided environmental costs: Natural Capital Values of Environmental Impacts: Virgin ABS and Closed-loop ABS

Environmental impact	Virgin ABS (in USD)	Closed-loop ABS (in USD)	Net benefit of closed-loop ABS
Human health			
Human health	-1,045,000	-392,000	+62%
Respiratory effects	-186,000	-172,000	+8%
Energy and fossil fuels			
Climate change	-1,173,000	-686,000	+42%
Fossil fuel depletion	-60,000	-21,000	+65%
Air pollution			
Smog	-538,000	-517,000	+4%
Air pollution	-82,000	-78,000	+5%
Water and land pollution			
Water pollution	-44,000	-28,000	+36%
Ecotoxicity	-14,000	+134,000	+1,057%
Cumulative	*-3,143,000*	*-1,760,000*	*+44%, USD +1,383,000*

CLEVER PROJECT

Closed Loop Emotionally Valuable E-waste Recovery

Janet L. Scott, University of Bath

CLEVER

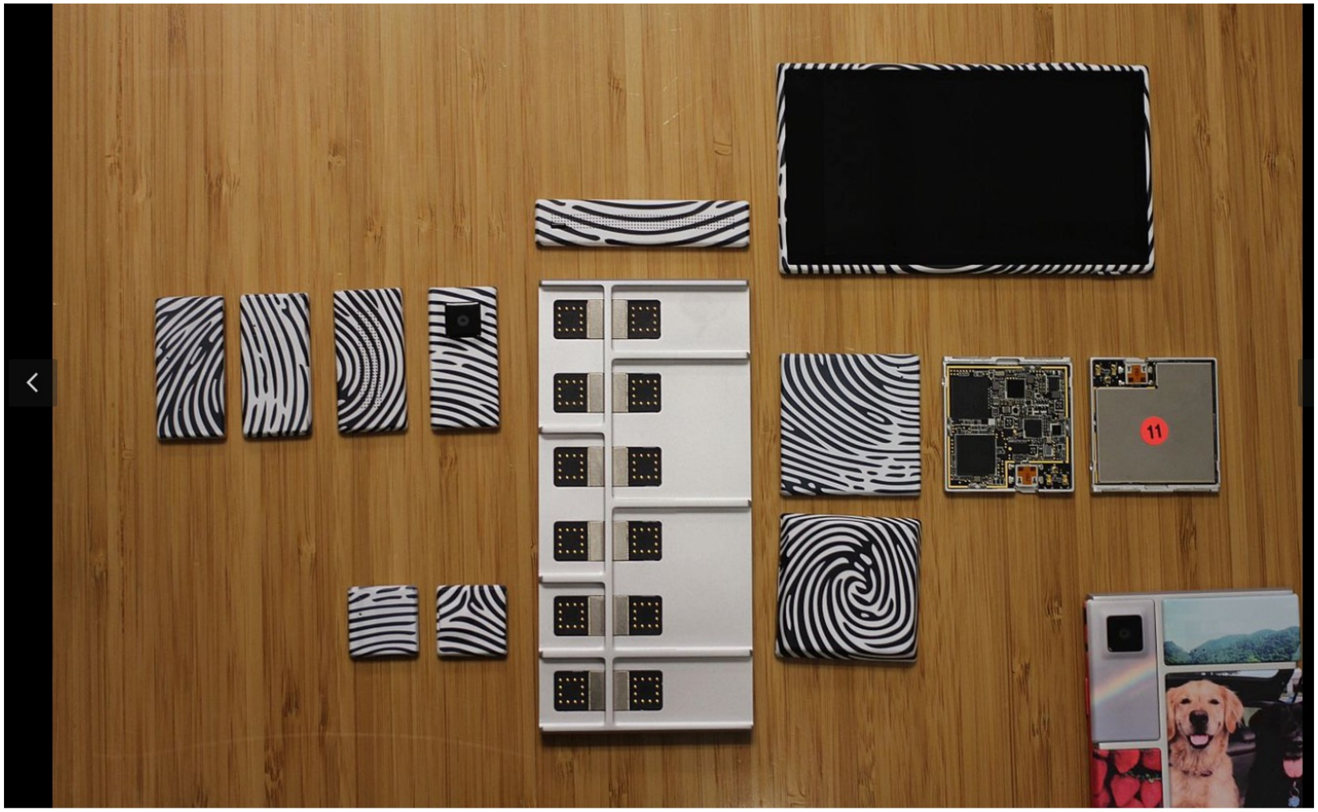
With some confidential data redacted

Modular Smart Phones

Front and back of a Fairphone 2 with a transparent case, showing the modular design. The individual components can be highlighted in the annotated image.

Main Board
Camera
Batteries
Open-Source Hardware
Reduce e-Waste
Customizable
Repairable
Component Lending

Modular Smart Phones



Project Ara Spiral 2 Prototype

More det

Modo 2006 Israel
Google purchased 2011 made Ara
No product

Modular Smart Phones

An exploded view of the Phonebloks concept.

Modo 2006 Israel
Phonebok merged with ARA in 2013
Google purchased Modo 2011
made Ara
No product

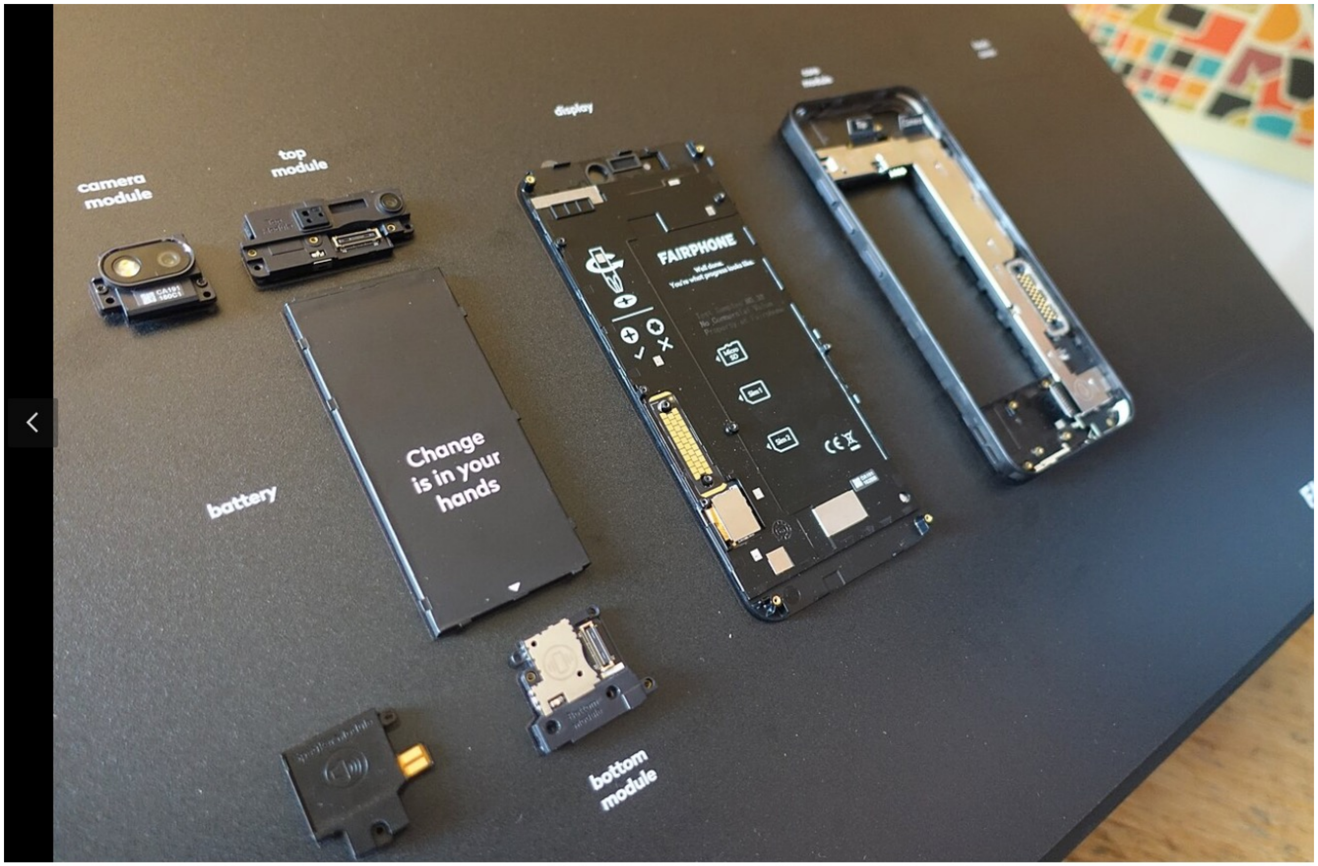
Modular Smart Phones

Fairphone 3 _ Angle

Modo 2006 Israel
Google purchased 2011 made Ara

Fairphone. 2019

Modular Smart Phones

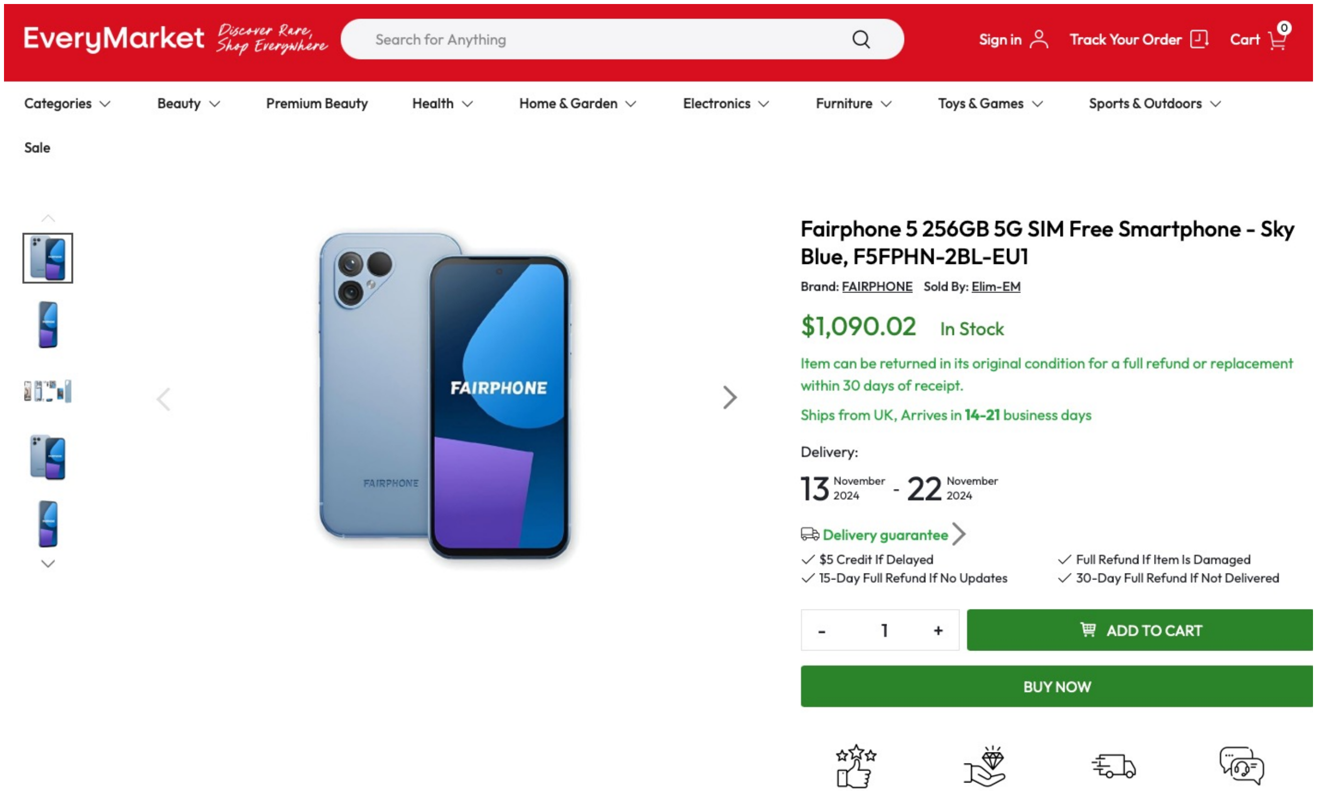


The individual modules in an opened Fairphone 3

Modo 2006 Israel
Google purchased 2011 made Ara
No product

Fairphone. 2019

Modular Smart Phones



Modular Smart Phones

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