MATERIAL	USE IN ELECTRONICS	AMOUNT USED	POTENTIAL RECOVERY VALUE (HIGH/LOW)	MATERIAL AVAILABILITY CONSIDERATIONS (Y/N)	ELECTRONICS USE DOMINANT (Y/N)	RESPONSIBLE MATERIAL EXTRACTION (Y/N)	REPORTABLE (Y/N)	CIRCULARITY PATHWAY- "4Rs": 1&2 Reuse [product, component], 3 Refurbish, 4 Recycle	SOLUTION/TECHNOLOGY DESCRIPTION TO ACHIEVE 4Rs	4 Rs TRL: TODAY -2023	4 Rs TRL: 3 YEARS -2026	4 Rs TRL: 5 YEARS -2028	4 Rs TRL: 10 YEARS -2033
Antimony*	Sb - Diodes, FR-IC packaging, solders	Very low	Low	Y	N	Y	N	Recycle	Recoverable via Hydrometallurgy (Zn, Pb)	7	7	7	7
Arsenic*	GaAs/GeAs transistors	Low	Low	Y	N	Y	Y	Recycle	Typically lost to essential metals	3	4	6	8
Barium*	BaTi, BaO -passives	Medium	Low	N	N	N	N	Recycle	Typically lost to essential metals	7	7	7	7
Aluminum*	Mech parts, capacitors	High	high	N	N	N	N	Reuse and recycle	Essential carrier metal	9	9	9	9
Beryllium*	Be, BeO - Heat sinks, EMC shielding, connectors, lasers	Med-low	Low	N	N	N	N	Recycle	Typically lost to essential metals, unless specifically separated and recovered	7	7	7	7
Bismuth*	Bi, BiO – solder, passives	Low	Low	Y	N	Y	N	Recycle	Recoverable via smelt/refine (Cu, Ni)	8	8	9	9
Boron*	B – ICs, capacitors, TIMs	Low	Low	N	N	N	N	Recycle	Typically lost to essential metals	3	3	5	7
Cobalt*	Co - batteries	Medium	high	Y	N	Y	N	Recycle	Solution extraction [2]	9	9	9	9
Copper*	ICs, circuit boards, packaging	High	High	N	Y	Y	N	Reuse	Design for reuse	9	9	9	9
	ICs, circuit boards, packaging	High	High	N	Y	Y	N	Recycle	Pyro	9	9	9	9
	ICs, circuit boards, packaging	High	High	N	Y	Y	N	Reuse	Hydro	7	9	9	9
	ICs, circuit boards, packaging	High	High	N	Y	Y	N	Recycle	Bio	4	7	9	9
Fluorine*	PFAS – Teflon, Fluorides - passives. Florinate compounds in wetting agents	Med-low	Low	Y	N	Y	Y	Recycle	Typically lost to essential metals	2	4	5	6
Gallium*	GaAs transistors; GaN power power supplies	Low	Low	Y	Y	Y	N	Recycle	Engineered bio-extraction	3	4	6	9
Germanium*	GeAs transistors	Low	Low	Y	Y	Y	N	Recylce	Recoverable via smelt/refine (Cu, Ni, Zn, Pb)	7	7	8	8
Gold	Connectors, IC bond wires, PWB surface finish	Low	High	N	N	Y	N	Recycle	Recoverable via smelt/refine (Cu, Ni, Zn, Pb)	9	9	9	9
Hafnium*	ICs	Very low	Low	N	N	N	N	Recycle	Typically lost to essential metals	1	3	5	7
Helium*	Semiconductor mfg	Low	Low	N	N	N	N	Recycle	Typically lost to essential processes	1	3	5	8
Heavy rare-earth elements (HREE)*	Magnetics, lasers, fiber optics, Opto components	Very low	Low	Y	N	Y	N	Recycle	Essential carrier metal, if in separated and economically recoverable form	3	5	7	9
Indium*	Semiconductors, touch screens, HD flat panels	Low	Low	N	Y	Y	N	Recycle	Recoverable via smelt/refine (Cu, Ni)	1	3	5	7
Iridium*	Semiconductor recrystallization processing	Very low	High	N	N	Y	N	Recycle	Typically lost to essential metals, unless specifically separated and recovered	5	7	8	9
Lithium*	Batteries	High	Low	N	N	Y	N	Recycle	Essential carrier metal	9	9	9	9
Light rare-earth elements (LREE)*	Magnetics, lasers, RF components	Very low	Low	N	N	Y	N	Recycle	Essential carrier metal, if in separated and economically recoverable form	3	5	7	9
Magnesium*	Heat sinks, alloys for high heat dissipation	Low	Low	Y	N	N	N	Recycle	Essential carrier metal	9	9	9	9
Manganese*	Mn – steel alloys and in Li batteries; MnO – passives	Low	Low	N	N	Y	N	Recycle	Essential carrier metal	9	9	9	9
Nickel*	Ni – steel alloys, batteries, PWB surface finish, NiO – passives	Medium	Low	N	N	Y	N	Recycle	Essential carrier metal	9	9	9	9
Niobium*	Nb – optical modulators	Low	Low	N	N	Y	N	Recycle	Typically lost to essential metals, unless specifically separated and recovered	4	4	4	4
Osmium*	Os – alloys for electrical contacts	Very low	Low	N	N	Y	N	Recycle	Typically lost to essential metals, unless specifically separated and recovered	6	6	6	6
Palladium*	Pd – capacitors, connectors	Very low	High	N	N	Y	N	Recycle	Recoverable via smelt/refine (Cu, Ni)	9	9	9	9

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Phosphorus*	P – etchants in SC processing, black P – opto-electronics	Low	Low	N	N	N	N	Recycle	Typically lost to essential metals	1	3	5	6
Platinum*	Pt – plating for electrical contacts	Very low	High	N	N	Y	N	Recycle	Recoverable via smelt/refine (Cu, Ni, Zn, Pb)	9	9	9	9
Rhodium*	Rh – electrical contacts	Very low	High	N	N	Y	N	Recycle	Recoverable via smelt/refine (Cu, Ni)	9	9	9	9
Ruthenium*	Ru – electrical contacts, resistors	Very low	High	N	Y	Y	N	Recycle	Typically lost to essential metals, unless specifically separated and recovered	6	7	8	9
Scandium*	ScAlN – semiconductors, high-intensity lighting; ceramic fuel cells	Very low	High	Y	N	Y	N	Recycle	Typically lost to essential metals, unless specifically separated and recovered	1	3	5	7
Silicon metal*	Si – semiconductors, Ics, SiO – passives, fillers	Medium	Low	N	Y	Y	N	Recycle	Typically lost to essential metals, unless specifically separated and recovered	3	5	6	9
Silver	Pastes, surface finishes, imaging films	Low	High	N	N	Y	N	Recycle	Chemically dissolved or via smelting via Cu	9	9	9	9
Strontium*	Sr – ferrite magnetics, passives	Low	Low	N	N	N	N	Recylce	Typically lost to essential metals	2	4	5	6
Tantalum*	Ta – capacitors	Med-low	Low	Y	Y	Y	N	Recycle	Recoverable via smelt/refine (Cu, Ni)	6	7	8	9
Tin	Solder	Med-low	Low	N	Y	Y	N	Recycle	Recoverable via smelt/refine	9	9	9	9
Titanium*	Ti – passives, TiO – passives, semiconductors	Med-low	Low	N	N	N	N	Recycle	Essential carrier metal	1	3	5	7
Tungsten*	W – high-power semiconductors, heat sinks, electrical contacts	Low	High	Y	N	Y	N	Recycle	Typically lost to essential metals, unless specifically separated and recovered	1	3	5	7
Vanadium*	V – semiconductors, RF circuits; mechanical housing	Low	Low	N	N	Y	N	Recycle	Typically lost to essential metals	2	4	5	6
Zirconium	Ferrules in optical terminations; capacitors	Low	Low	N	N	N	N	Recycle	Essential carrier metal	1	3	5	7

[1] 1.Ministry of Commerce and the General Administration, China, "Announcement No. 23 [2023] of the Ministry of Commerce and the General Administration of Customs Announcement on the Implementation of Export Control on Items Related to Gallium and Germanium," http://www.mofcom.gov.cn/article/zwgk/gkzcfb/202307/20230703419666.shtml, 2023.

[2] Haruka Pinegar, York R. Smith, "Recycling of End-of-Life Lithium Ion Batteries, Part I: Commercial Processes", *Journal of Sustainable Metallurgy*, vol. 5, pp. 402–41, 2019.

[3] Matt Blois, "Big battery recycling site planned for Europe", *Chemical & Engineering News, May 13, 2023*

Table Key

In-table color key	Range of Technology Readiness Levels	Description
2	TRL: 1 to 4	Levels involving research
6	TRL: 5 to 7	Levels involving development
9	TRL: 8 to 9	Levels involving deployment

Spreadsheet column category	Explanation
Use in electronics	Applications of the named material
Amount used	Is the quantity of material used significant in absolute terms?
Potential recovery value (high/low)	If extracted through processes like recycling, does the quantity of material have significant commercial value?
Material availability considerations (y/n)	Is the primary extraction of the material confined to a limited number of regions globally?
Electronics use dominant (y/n)	Is the electronics industry the major user of the material or do other industries have a bigger share?
Responsible material extraction (y/n)	Are there issues around the primary extraction (e.g. mining, refining, etc.) of the material?
Reportable (y/n)	Are there legal requirements to report the use of the materials, for toxicological/environmental reasons?