Supporting Information

Waste Management of Printed Wiring Boards: A Life Cycle Assessment of the Metals Recycling Chain from Liberation through Refining

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Table S1. Inventory Analysis for Processes in the Formal Chinese PWB Recycling Chain

Processes	Upstream		Downstream	
	energy consumption	materials input	products	waste disposal
liberation, separation	liberation: 160 kWh; separation: 56.7 kWh	1 mt printed wiring boards	Fe: 51.7 kg; Al: 51.7 kg	Cr: 24 µg; Cd: 3.2 µg; Pb: 112 µg; PM ₁₀ : 40.4 mg; TSP: 56.5 mg; mixed metals: 246.5 kg
heavy metal recovery	197.2 kWh	mixed metals: 246.5 kg	Pb: 16.8 kg; Zn: 8.6 kg	mixed metals: 221.1 kg
leaching 1, leaching 2, electrolysis	299.2 kWh	sulfuric acid: 272 L, 1.8 kg/L; nitric acid: 708 L, 1.4 kg/L; hydrochloric acid: 2124 L, 1.2 kg/L; mixed metals: 221.1 kg	Au: 215 g; Pd: 82 g; Ag: 868 g; Cu: 140.4 kg	residues: 65.9 kg; effluent: 3104 L; NO: 48.1 g; NO ₂ : 203.8 g; H ₂ : 332 g

Table S2. Description, Source, and Region of the Metals Production Process ^a

Process	Description	Source	Region
Cu production	copper mix (99,999% from electrolysis), consumption mix, at consumer	PE ⁽²⁵⁾	DE
Au production	gold, at refinery	Ecoinvent ⁽²⁶⁾	US
Pd production	palladium, primary, at refinery	Ecoinvent ⁽²⁶⁾	ZA
Ag production	silver production, technology mix, consumption mix, at plant	PE ⁽²⁵⁾	RNA
Zn production	zinc redistilled mix, primary production, consumption mix, at consumer	PE ⁽²⁵⁾	DE
Pb production	lead (99,995%), primary production, production mix, at plant	PE ⁽²⁵⁾	DE
Fe production	iron and steel, production mix	USLCI/PE ^(25,27)	US
Al production	aluminum ingot, production mix, at plant	USLCI/PE ^(25,27)	US

^a PE: PE International Database; USLCI: United States Life Cycle Inventory Database; DE: Germany; US: United States; ZA: South Africa; RNA: North America.

Table S3. Environmental Impact Performance of the PWB Recycling Chain ^a

Impact categories	Collection process	Liberation process	Separation process	Heavy metal recovery	Leaching 1 process	Leaching 2 process	Electrolysis process
GWP 100 years (kg CO ₂ -Equiv.)	29	102	36	126	169	3140	211
AP (kg SO ₂ -Equiv.)	0.1	0.5	0.2	0.6	4	4	1
EP (kg phosphate-Equiv.)	0.03	0.02	0.008	0.03	0.07	2	0.07
ADP fossil (kg MJ-Equiv.)	404	1520	534	1880	5330	26400	2950
FAETP inf. (kg DCB-Equiv.)	0.07	0.2	0.06	0.2	0.7	5	0.5
HTP inf. (kg DCB-Equiv.)	0.7	6	2	7	6	39	11
MAETP inf. (kg DCB-Equiv.)	216	5230	1830	6440	4920	102000	14000
POCP (kg ethane-Equiv.)	-0.05	0.03	0.009	0.03	0.2	0.4	0.05
TETP inf. (kg DCB-Equiv.)	0.2	0.08	0.03	0.1	0.1	2	0.2

^a GWP: Global Warming Potential; AP: Acidification Potential; EP: Eutrophication Potential; ADP: Abiotic Depletion Potential; FAETP: Freshwater Aquatic Eco-toxicity Potential; HTP: Human Toxicity Potential; MAETP: Marine Aquatic Eco-toxicity Potential; POCP: Photochemical Ozone Creation Potential; TETP: Terrestrial Aquatic Eco-toxicity Potential; DCB: 1, 4-Dichlorbenzol.

Table S4. Normalization Equivalences of CML2001 - Nov. 2010, World ^a

Impact category	Equivalences	Unit	Factor
GWP 100 years	41840400000000	(kg CO ₂ -Equiv.)	2.39003451209835E-14
AP	239000000000	(kg SO ₂ -Equiv.)	4.18410041841004E-12
EP	158338000000	(kg phosphate-Equiv.)	6.31560332958608E-12
ADP fossil	379928000000000	(kg MJ-Equiv.)	2.63207765681919E-15
FAETP inf.	2364675046689	(kg DCB-Equiv.)	4.22891086620974E-13
HTP inf.	2578779441627	(kg DCB-Equiv.)	3.87780352153295E-13
MAETP inf.	194199000000000	(kg DCB-Equiv.)	5.14935710276572E-15
POCP	36827478616	(kg ethane-Equiv.)	2.7153637380972E-11
TETP inf.	1092990000000	(kg DCB-Equiv.)	9.14921453993175E-13

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Table S5. Life Cycle Assessment Results for the Scenario Modeling of the PWB Recycling Chain ^a

Impact categories	Scenario A1	Scenario A2	Scenario A3	Scenario A4	Scenario B1	Scenario B2	Scenario B3	Scenario B4	Scenario C1	Scenario C2	Scenario C3	Scenario C4
GWP 100 years (kg CO ₂ -Equiv.)	140	150	210	120	3600	3700	3650	3800	29	29	26	22
AP (kg SO ₂ -Equiv.)	0.66	0.72	0.84	0.076	8.8	8.9	9.0	9.0	0.13	0.078	0.12	0.15
EP (kg phosphate-Equiv.)	0.030	0.033	0.034	0.014	2.2	2.2	2.2	2.3	0.031	0.016	0.028	0.036
ADP fossil (kg MJ-Equiv.)	2100	2300	2200	2000	37000	37000	37000	38000	404	396	363	299
FAETP inf. (kg DCB-Equiv.)	0.25	0.27	0.12	0.16	6.4	6.5	6.5	6.6	0.069	0.067	0.062	0.052
HTP inf. (kg DCB-Equiv.)	8.0	8.8	13	0.69	64	66	64	66	0.75	0.62	0.67	0.74
MAETP inf. (kg DCB-Equiv.)	7100	7800	6800	210	130000	130000	130000	130000	216	212	195	160
POCP (kg ethane-Equiv.)	0.036	0.040	0.047	0.012	0.64	0.65	0.65	0.66	-0.048	-0.021	-0.043	0.071
TETP inf. (kg DCB-Equiv.)	0.11	0.12	0.14	0.018	2.9	2.9	2.9	3.0	0.22	0.21	0.19	0.16

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Table S6. Life Cycle Assessment Results of the Metals Primary Production Process ^a

Impact categories	Cu production	Au production	Pd production	Ag production	Zn production	Pb production	Fe production	Al production
GWP 100 years (kg CO ₂ -Equiv.)	515	3760	871	528	22	29	42	330
AP (kg SO ₂ -Equiv.)	3	40	16	25	0.1	0.8	0.1	3
EP (kg phosphate-Equiv.)	0.2	637	14	0.1	0.006	0.009	-0.05	0.1
ADP fossil (kg MJ-Equiv.)	7000	54900	15500	5970	375	352	497	3650
FAETP inf. (kg DCB-Equiv.)	21	162000	4150	5	0.2	0.2	28	19
HTP inf. (kg DCB-Equiv.)	423	234000	4690	2320	4	9	-1	134
MAETP inf. (kg DCB-Equiv.)	178000	459000000	9890000	42000	2790	1490	2030	826000
POCP (kg ethane-Equiv.)	0.2	4	0.8	1	0.007	0.04	0.03	0.2
TETP inf. (kg DCB-Equiv.)	3	87	7	8	0.3	0.1	0.006	0.2

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