SUPPORTING INFORMATION

Simple gold recovery from e-waste leachate by selective precipitation using a quaternary ammonium salt

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FIGURES

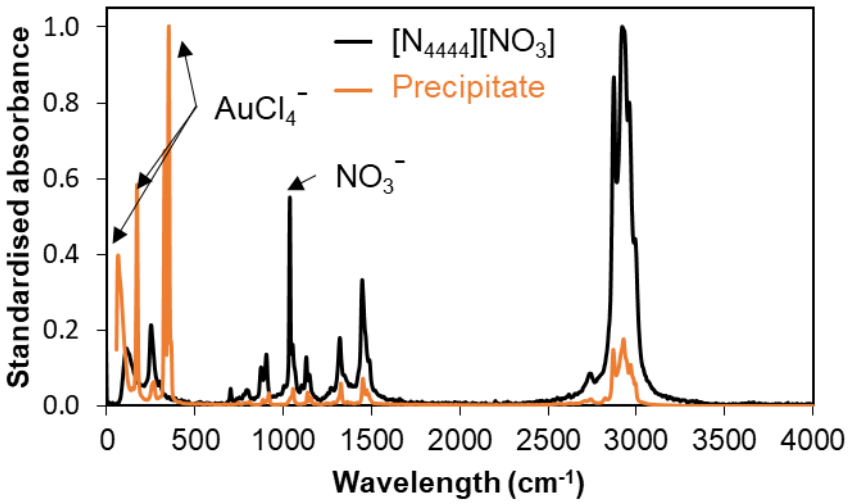

Figure S1. Raman spectra of the as-received $[N_{4444}][NO_3]$ precursor and the precipitate obtained after 30 min for an Au:IL ratio of 20. The lower wavenumber region at 168, 324, and 347 cm^{-1} are characteristic of anionic $[AuCl_4]^-$ complexes.[1]

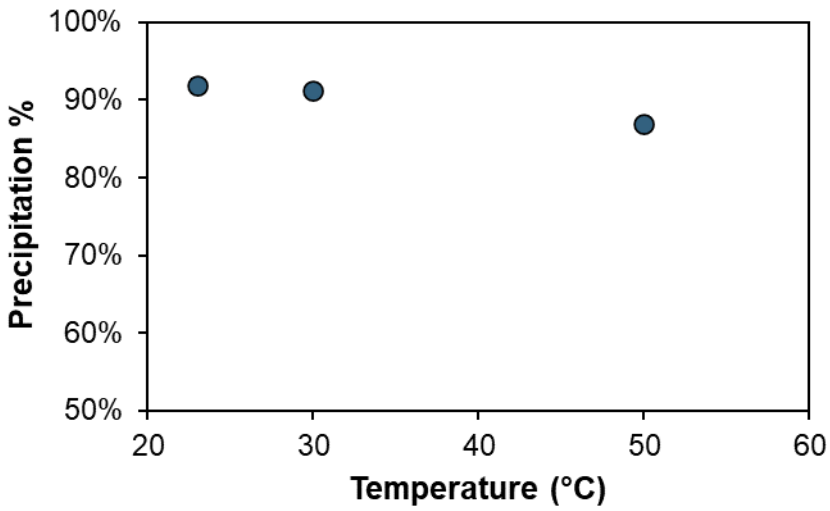

Figure S2. Precipitation of gold from solution after three hours at different temperatures ([Au] = 10 ppm, Au:IL = 1:20, [*Aqua regia*] = 10 vol.% and t = 0.5 h). Error bars are within the data point.

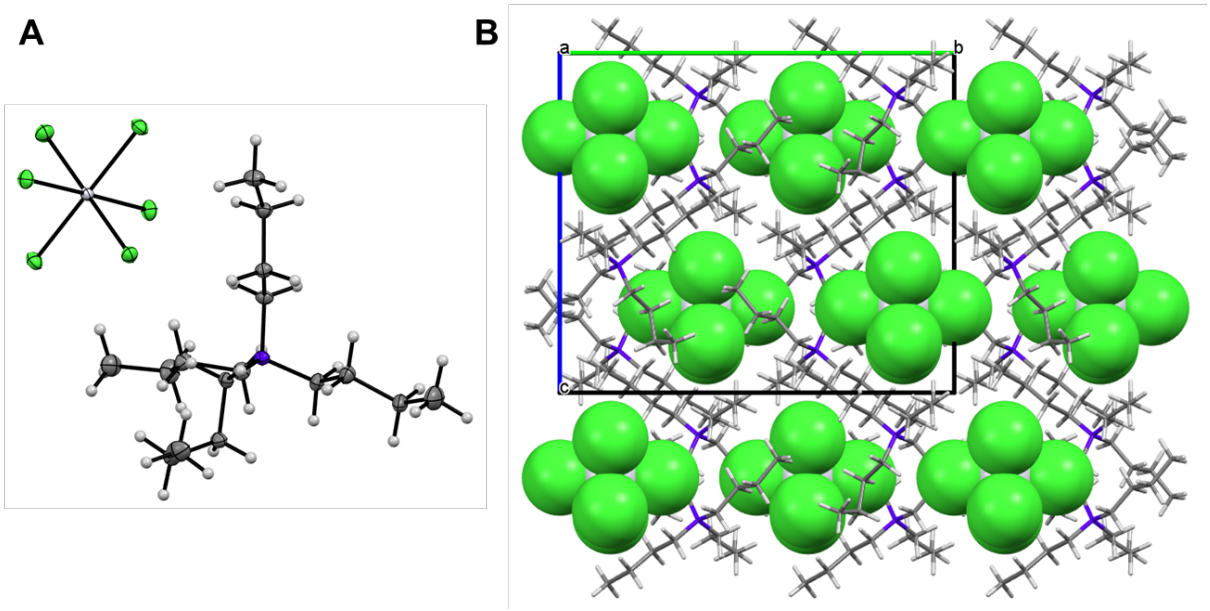

Figure S3. A) X-ray crystal structure of $\{[N_{4444}][PtCl_6]\}^-$ with thermal ellipsoids (50 % probability level). Atom colours: blue = N; grey = C; white = H, green = Cl; silver = Pt. B) crystal packing of $[N_{4444}]_2[PtCl_6]$ along the a-axis.

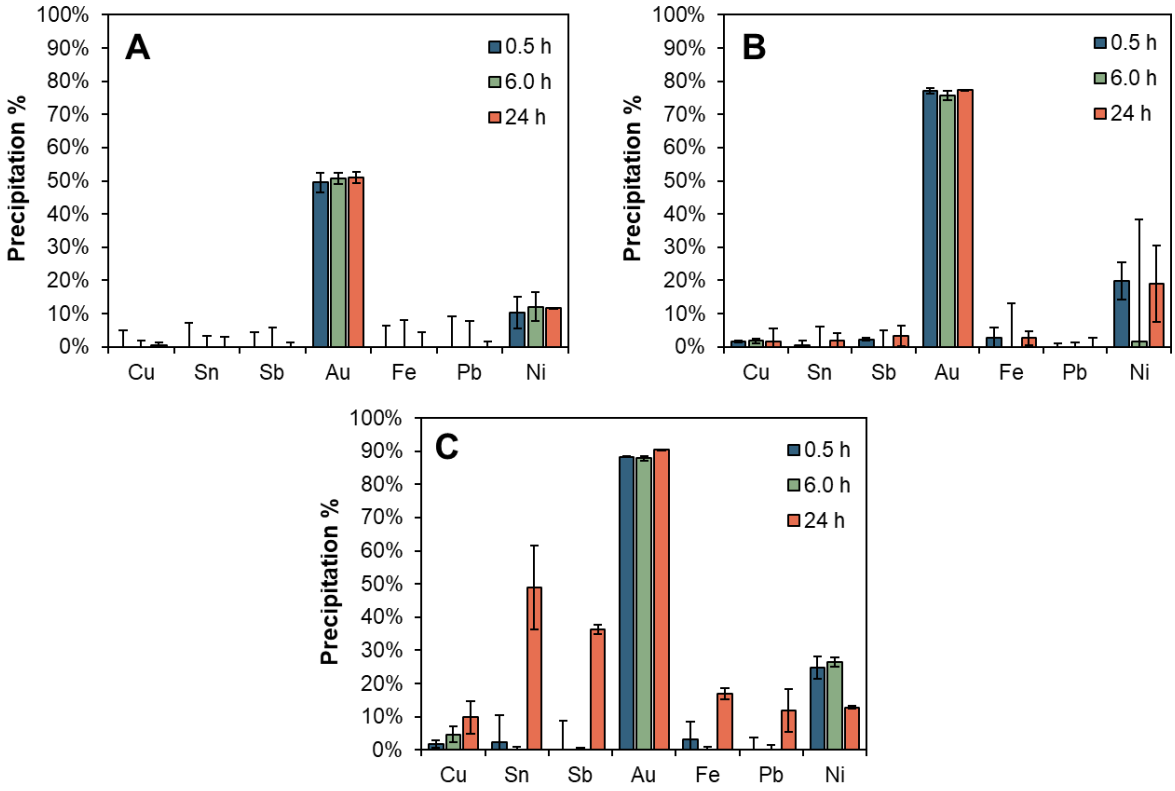

Figure S4. Precipitation of metals from the diluted PCB leachate sample at three different gold to ionic liquid ratios: A) 1:5 Au:IL; B) 1:10 Au:IL; C) 1:20 Au:IL.

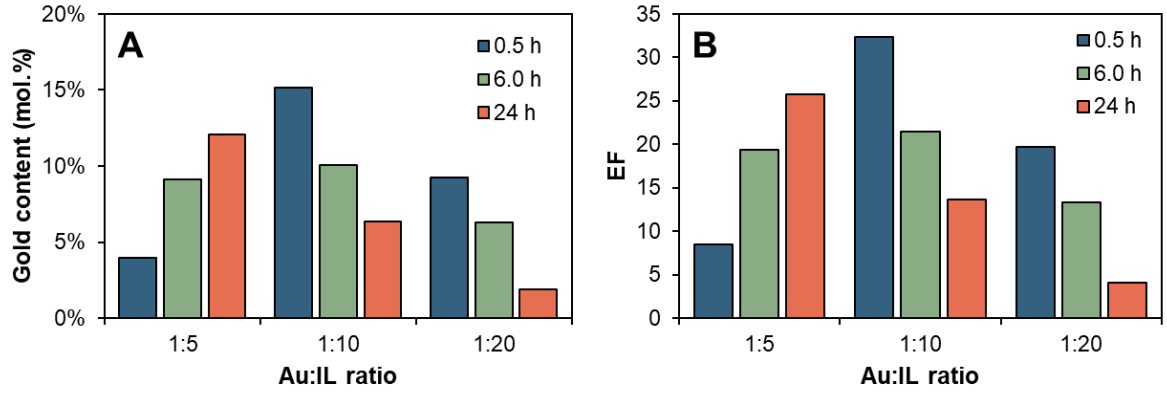

Figure S5. A) Gold content and corresponding B) enrichment factor (EF) in the recovered precipitate from the diluted PCB leach solution (10 vol.% *aqua regia*) as a function of the Au:IL ratio and time.

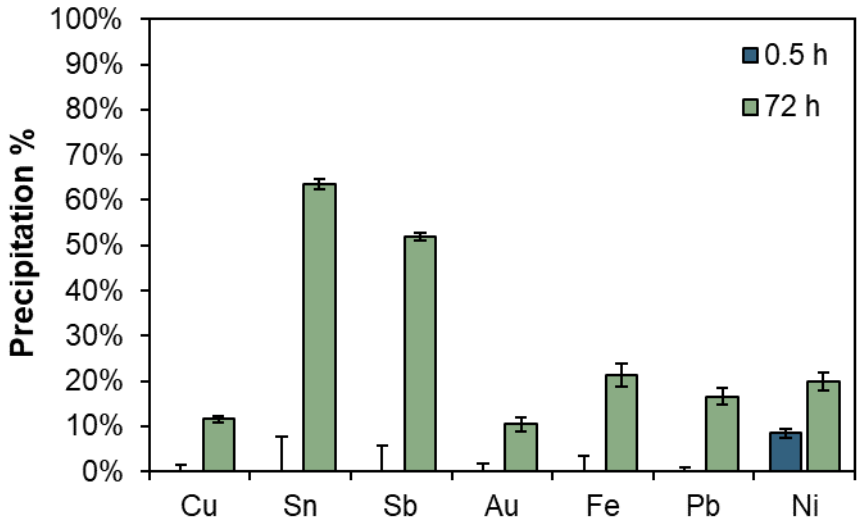

Figure S6. Dilution-induced precipitation of metals from the *aqua regia* leachate in the absence of IL addition as function of time. The final *aqua regia* concentration after dilution is 10 vol.%

TABLES

Table S1. The properties of isolated tetraalkylammonium cations ($[N_{xxxx}]^+$) as a function of the alkyl chain length. All values are taken from Marcus (2008).[2] The McGowan volumes are larger than the van der Waals volumes since they also include the preclusion volumes into which neighbouring atoms and molecules cannot penetrate. These intrinsic volumes should be independent of the counter-ion and of the solvent. r_{VdW} – van der Waals radius, r_X – McGowan radius; $\Delta_{Hyd}H^o$ – standard molar enthalpy of hydration; $\Delta_{Hyd}S^o$ – standard molar entropy of hydration.

$[N_{xxxx}]^+$	V_{VdW} ($cm^3\ mol^{-1}$)	r_{VdW} (nm)	V_X ($cm^3\ mol^{-1}$)	r_X (nm)	$\Delta_{Hyd}H^o$ ($kJ\ mol^{-1}$)	$\Delta_{Hyd}S^o$ ($J\ K^{-1}\ mol^{-1}$)
x=1	54.7	0.279	79.4	0.316	-203	-144
x=2	95.6	0.336	135.7	0.378	-219	-229
x=3	136.5	0.378	192.1	0.424	-206	-333
x=4	177.4	0.413	248.8	0.462	-182	-418

Table S2. Crystal data and refinement parameters of $[N_{4444}][AuCl_4]$ and $[N_{4444}]_2[PtCl_6]$

Compound	**$[N_{4444}][AuCl_4]$**	**$[N_{4444}]_2[PtCl_6]$**
Molecular weight	581.22	892.70
T (K)	150	150
a (Å)	14.7687(8)	14.0090(11)
b (Å)	8.8039(4)	18.1403(12)
c (Å)	18.1106(9)	17.0279(14)
α (deg)	90	90
β (deg)	107.053(2)	113.537(3)
γ (deg)	90	90
V ($Å^3$)	2251.25	3967.24
Space group	$P2_1/n$	C2/c
Z	4	4
Dc (mg m^{-3})	1.715	1.495
μ/ [mm^{-1}]	7.007	3.964
F(000)	1144	1832
Crystal size [mm^3]	0.22x0.20x0.02	0.30x0.10x0.04
θ range for data collection (°)	2.595-29.175	1.943-30.532
Index ranges	-20<h<20, -12<k<12, -24<l<24	-20<h<20, -25<k<25, -24<l<24
Reflections collected	63325	71874
Unique reflections, [Rint]	6005[0.0445]	5858[0.0377]
R1, wR2 [I>2σI]	0.0187, 0.0391 [5067]	0.0126, 0.0452[5718]
R1, wR2 (all data)	0.0276, 0.0428	0.0127, 0.0283
Data/restraints/ parameters	6005/0/203	5858/0/191
Goodness-of-fit on F2	1.070	1.054
CCDC identifier	2224974	2224983

Table S3. Metallic content in the leachate and in the precipitate after recrystallization (SD – standard deviation).

Element	Aqua regia leachate		Precipitate	
	mol%	SD	mol%	SD
Fe	0.60	0.05	2.08	0.24
Ni	0.07	0.01	0.39	0.04
Cu	83.17	4.89	0.24	0.04
Sn	14.24	0.77	0.00	0.00
Sb	1.38	0.04	2.95	0.28
Au	0.47	0.09	91.42	1.05
Pb	0.04	0.01	0.02	0.00
Zn	0.03	0.01	2.89	0.23

Table S4. Experimental binodal data for the $[N_{4444}][NO_3]$-HNO_3-H_2O systems at various temperatures. All concentrations are reported in weight percent (wt.%) and the water content of the acids used in *aqua regia* is subtracted from the percentages.

T = 298K		T = 323 K	
$[N_{4444}][NO_3]$ (wt%)	**[*Aqua Regia*] (wt%)**	**$[N_{4444}][NO_3]$ (wt%)**	**[*Aqua Regia*] (wt%)**
33.3	11.4	51.2	12.5
30.6	11.4	38.6	9.6
29.4	11.6	36.7	9.4
27.0	11.7	34.8	9.4
24.8	12.0	33.2	9.2
23.0	12.2	32.2	9.1
20.9	12.8	30.8	9.0
17.1	14.1	26.9	8.6
13.7	15.6	26.2	8.5
10.9	16.8	25.5	8.5
8.7	17.8	24.8	8.6
-	-	24.4	8.7
-	-	24.0	8.8
-	-	22.4	8.7
-	-	21.0	8.6
-	-	20.6	8.6
-	-	20.0	8.7
-	-	19.5	8.8
-	-	19.2	8.9

-	-	18.6	9.1
-	-	18.0	9.0
-	-	17.6	9.1
-	-	17.2	9.2
-	-	16.8	9.3
-	-	16.3	9.5
-	-	15.7	9.5
-	-	15.4	9.5
-	-	15.1	9.5
-	-	14.7	9.6
-	-	14.4	9.7
-	-	14.1	9.8
-	-	13.9	9.8
-	-	13.6	10.0
-	-	13.1	10.0
-	-	12.7	10.2
-	-	12.3	10.3
-	-	12.0	10.5
-	-	11.8	10.6
-	-	11.5	10.7
-	-	11.1	10.8
-	-	10.8	11.0
-	-	10.5	11.1
-	-	10.1	11.4
-	-	9.7	11.5
-	-	9.4	11.8
-	-	9.0	12.0
-	-	8.7	12.3
-	-	8.2	12.6
-	-	7.4	13.3

REFERENCES

[1] J.A. Peck, C.D. Tait, B.I. Swanson, G.E. Brown, Speciation of aqueous gold(III) chlorides from ultraviolet/visible absorption and Raman/resonance Raman spectroscopies, Geochim. Cosmochim. Acta. 55 (1991) 671–676. https://doi.org/10.1016/0016-7037(91)90332-Y.

[2] M.C. Simoes, K.J. Hughes, D.B. Ingham, L. Ma, M. Pourkashanian, Estimation of the Thermochemical Radii and Ionic Volumes of Complex Ions, Inorg. Chem. 56 (2017) 7566–7573. https://doi.org/10.1021/ACS.INORGCHEM.7B01205.