Process Development for Hydrometallurgical Recovery of Base and Precious Metals from Waste Printed Circuit Boards

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ALTA 2023 27
30 April - 6 May | Perth, Australia

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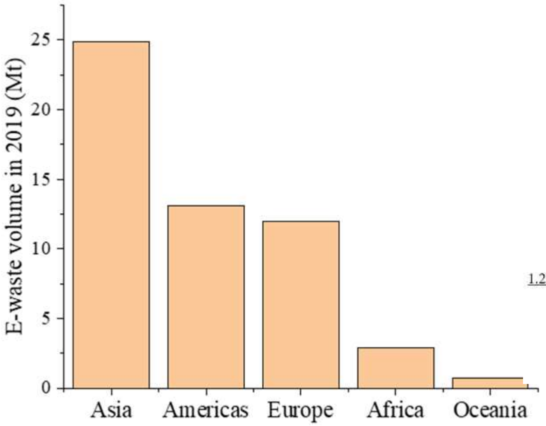
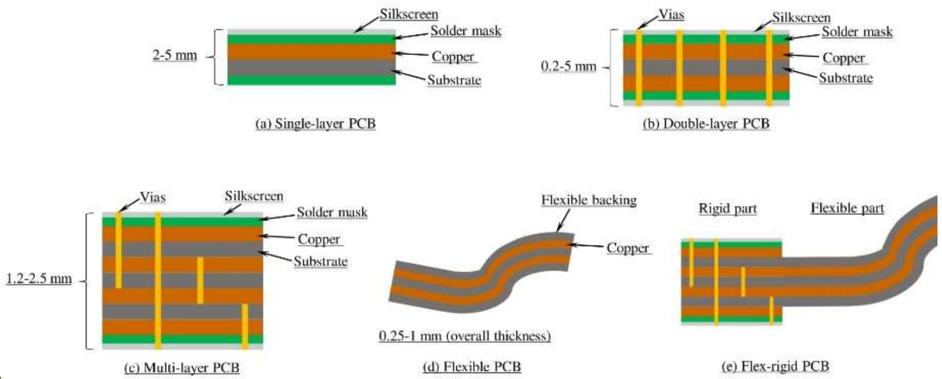
Outline

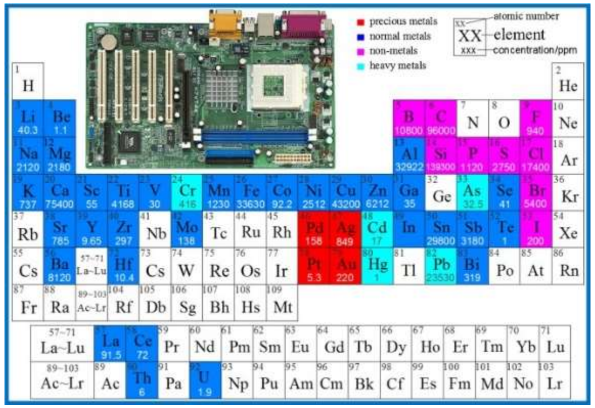
1. “Urban Mining” of e-waste
2. Development of glycine-based process
3. Development of sulfuric acid leaching process
4. Recommendations for future study
5. Acknowledgements

“Urban Mining” of e-waste

- Australia generated 554 kt of e-waste in 2019, ranking 5th worldwide per capita, and only 10.4% of them were documented to be collected and recycled.
- Waste PCBs are complicated e-waste in composition and contents: 40% metals, 30% plastics, 30% ceramics; ~40 types of metals and ~10 types of non-metals; metals locked in plastics & alloys.
- Proximity to the urban area – requiring a safe process.



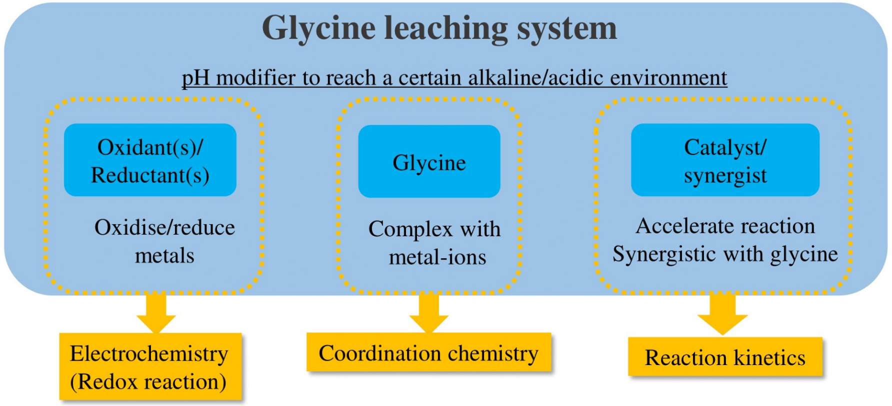




Source: Li, H., Eksteen, J. and Oraby, E., 2018. Resour. Conserv. Recy., 139: 122-139.
Lu, Y. and Xu, Z., 2016. Resour. Conserv. Recy., 113: 28-39

"Urban Mining" of e-waste

- Western Australia's scenario
  - Low e-waste volume – a pyrometallurgical process may not be highly economical
  - Vast geography – expensive road transport to a centralized location
- Why hydrometallurgy?
  - De-centralized; flexible in scales and modules; capital-friendly to SMEs
- Glycine leaching systems
  - Involving technologies invented at Curtin University and owned by Draslovka a.s.



Waste PCBs
⬇
Mechanical-physical processing
⬇
Pyrometallurgy
- Incineration
- Pyrolysis

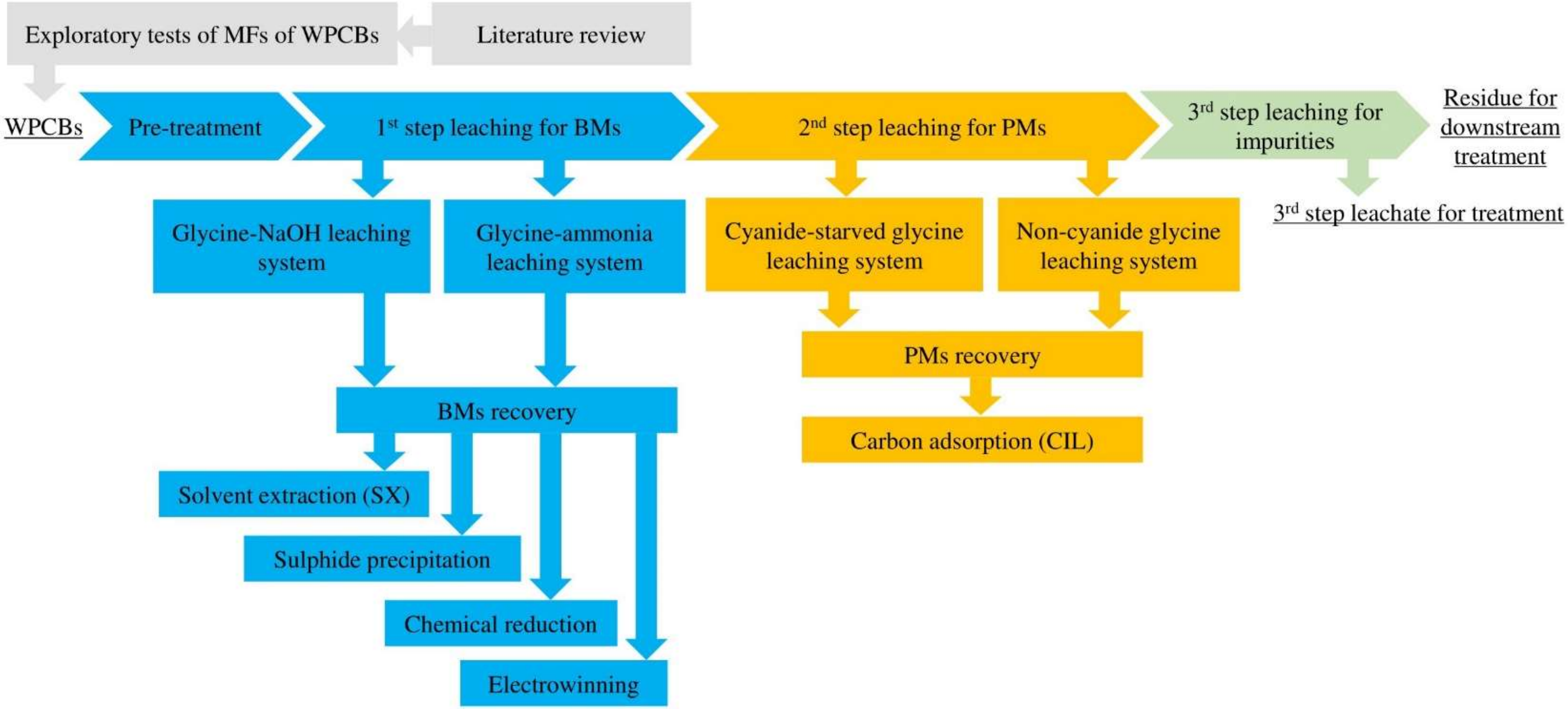
Hydrometallurgy
- Mineral acid
- Organic acid
- Ammonia
- Cyanidation
- Thio-system

Bio-metallurgy (bioleaching)

Source: Li, H., Eksteen, J. and Oraby, E., 2018. Resour. Conserv. Recy., 139: 122-139.

Development of glycine-based process

- Schematic diagram of process development



Development of glycine-based process

- Publications from glycine-based process development

Resources, Conservation & Recycling 139 (2018) 122–139
Contents lists available at ScienceDirect
Resources, Conservation & Recycling
journal homepage: www.elsevier.com/locate/resconrec

Review

Hydrometallurgical recovery of metals from waste printed circuit boards (WPCBs): Current status and perspectives – A review

Huan Li[a], Jacques Eksteen[a,*], Elsayed Oraby[a,b]

Waste and Biomass Valorization (2020) 11:3897–3909
https://doi.org/10.1007/s12649-019-00780-0

ORIGINAL PAPER

An Alkaline Glycine-Based Leach Process of Base and Precious Metals from Powdered Waste Printed Circuit Boards

Elsayed A. Oraby[1,2] · Huan Li[1] · Jacobus J. Eksteen[1]

Received: 2 April 2019 / Accepted
© Springer Nature B.V. 2019

Resources, Conservation & Recycling 154 (2020) 104624
Contents lists available at ScienceDirect
Resources, Conservation & Recycling
journal homepage: www.elsevier.com/locate/resconrec

Full length article

Extraction of copper and the co-leaching behaviour of other metals from waste printed circuit boards using alkaline glycine solutions

Huan Li[a], Elsayed Oraby[a,b], Jacques Eksteen[a,*]

Waste Management 125 (2021) 87–97
Contents lists available at ScienceDirect
Waste Management
journal homepage: www.elsevier.com/locate/wasman

Cyanide consumption minimisation and concomitant toxic effluent minimisation during precious metals extraction from waste printed circuit boards

Huan Li[a], Elsayed Oraby[a,b], Jacques Eksteen[a,*]
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Article history:
Received 20 September 2020
Revised 29 December 2020
Accepted 17 February 2021

ABSTRACT
Waste printed circuit boards (WPCBs) constitute a hazardous material with up to 40 different metals, including numerous many heavy metals and environmentally harmful metals. Most hydrometallurgical processing approaches use high concentrations of toxic reagents and generate significant amounts of harmful effluents. This research investigates the use of cyanide-starved glycine solution containing no

Hydrometallurgy 199 (2021) 105540
Contents lists available at ScienceDirect
Hydrometallurgy
journal homepage: www.elsevier.com/locate/hydromet

Recovery of copper and the deportment of other base metals from alkaline glycine leachates derived from waste printed circuit boards (WPCBs)

Huan Li[a], Elsayed Oraby[a,b], Jacques Eksteen[a,*]

Minerals Engineering 181 (2022) 107501
Contents lists available at ScienceDirect
Minerals Engineering
journal homepage: www.elsevier.com/locate/mineng

Extraction of precious metals from waste printed circuit boards using cyanide-free alkaline glycine solution in the presence of an oxidant

Huan Li[a], Elsayed Oraby[a,b], Jacques Eksteen[a,*]

Resources, Conservation & Recycling 187 (2022) 106631
Contents lists available at ScienceDirect
Resources, Conservation & Recycling
journal homepage: www.elsevier.com/locate/resconrec

Full length article

Development of an integrated glycine-based process for base and precious metals recovery from waste printed circuit boards

H. Li[a], E.A. Oraby[a,b,*], J.J. Eksteen[a]

Hydrometallurgy 216 (2023) 106008
Contents lists available at ScienceDirect
Hydrometallurgy
journal homepage: www.elsevier.com/locate/hydromet

Review

Amino acids as lixiviants for metals extraction from natural and secondary resources with emphasis on glycine: A literature review

Huan Li[a], Zixian Deng[a], Elsayed Oraby[a,b], Jacques Eksteen[a,*]
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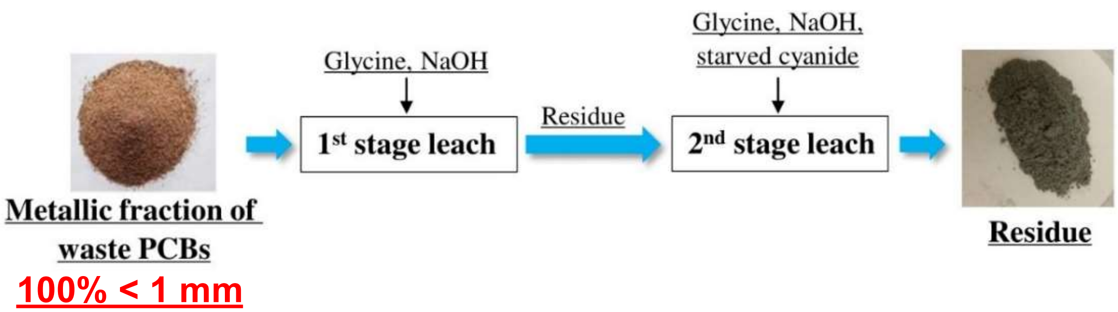
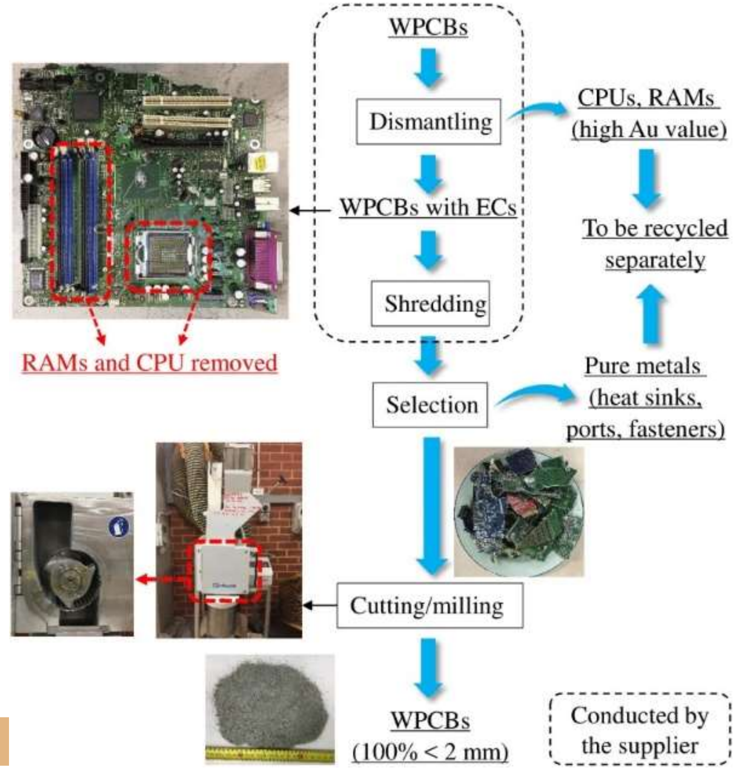
Keywords:
Glycine
Leaching
Recovery
Precious metals
Base metals

ABSTRACT
The past decade has seen significant interest in non-conventional lixiviants, particularly the growing interest in organic acids and amino acids. Of the amino acids, glycine has much coverage in the hydrometallurgical and mineral processing literature as a reagent that is non-toxic, non-volatile, and recyclable. The glycine leaching system (i.e., an aqueous system typically consisting of glycine or one of its alkali metal salts, a pH modifier, an oxidant and sometimes, other catalysts or modifiers) has been shown effective in selectively extracting base and precious metals from various resources. Using a glycine leaching system can, therefore, be considered a promising substitute for traditional methods in the hydrometallurgical industry. This paper reviews the application of amino acids and emphasizes the glycine leaching system to extract valuable metals from natural and secondary

Development of glycine-based process

Preliminary flowsheet:





Simple pre-treatment:

- ❑ PCBs source: PC motherboards
- ❑ Electronic components remained
  - Except high-values
- ❑ No complicated physical processing

	Metal content and economic value										
	Metal content in wt. %							Metal content in ppm			
	Cu	Fe	Al	Sn	Pb	Zn		Ni	Co	Au	Ag	Pd
Metal content	22.60	1.83	3.18	2.81	0.34	0.69		865.50	59.72	106.77	170.50	10.37
Metal value (%)	18.2	-	0.8	6.7	0.1	0.2		0.2	0.03	66.4	1.2	6.2

Source: Oraby, E.A., Li, H. and Eksteen, J.J., 2019. Waste Biomass Valori., 11(8): 3897-3909.
Li, H., Oraby, E., and Eksteen, J., 2020. Resour. Conserv. Recy., 154:104624.

Development of glycine-based process

Glycine-NaOH leaching of base metals:

- Restrained by solids%: <2-5% – waste PCBs are highly metal-rich!
- Slow leaching kinetics: ~3 days to complete copper leaching

Metals recovery from leachates:

Method	Impurity	Conditions required	Kinetics	Co-precipitation	Product
Hydrazine (N_2H_4) reduction	None (N_2 and H_2O)	pH > 12 Cu > 5g/L	>90% Cu recovery within 0.5-2 hours	Sn, Pb	Cuprite (Cu_2O) or metallic copper
Sulfide precipitation	Sulfur	Cu/HS^- molar ratio ≤1:1.2	Fast kinetics: >90% copper recovery within 5 min	Zn, Pb, Sn, Ni	Covellite (CuS) at 87.9% purity
Solvent extraction (Mextral 54–100 and Mextral 84H)	-	15% Mextral 84H & 200 g/L H_2SO_4; 30% Mextral 54–100 & 80 g/L H_2SO_4	85-95% Cu extraction; 99% Cu stripping	Ni (Pb and Sn not investigated)	Metallic copper or copper sulfate after downstream treatment

Source: Li, H., Oraby, E., and Eksteen, J., 2021. Hydrometallurgy, 199: 105540.
Li, H., Oraby, E., and Eksteen, J., 2020. Resour. Conserv. Recy., 154:104624.

Development of glycine-based process

Glycine-ammonia leaching of base metals:

- Solids% increased to 15%~: >40 g/L copper in PLS
- Copper leaching shortened to 24 hours
- Ammonia concentration reduced by ~80%, compared with conventional ammoniacal leaching
- Ammonia played the key roles of:
    - ✓ pH modifier
    - ✓ Synergist
    - ✓ Copper stabilizer

Cyanide-starved glycine leaching of precious metals:

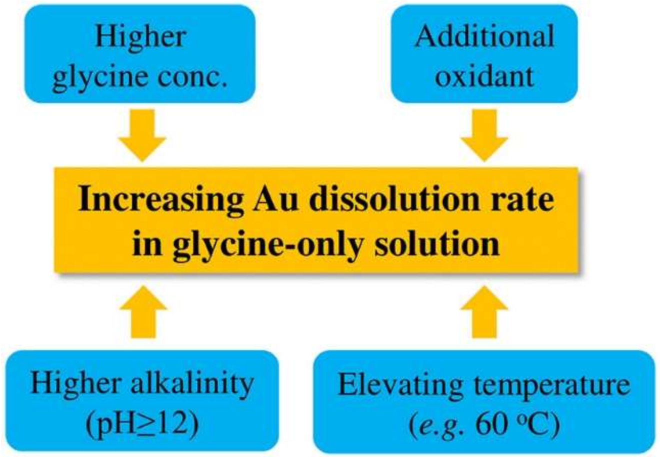
- Cyanide acted as “catalyst” for copper and silver dissolutions
- Similar or better PMs extraction, compared with stoichiometric or intensive cyanidation
- Cyanide use was reduced by 70-90% (250 ppm *vs* 3500 ppm, no free cyanide after 4 hours)

Source: Li, H., Oraby, E., and Eksteen, J., 2022. Resour. Conserv. Recy., 187: 106631.
Li, H., Oraby, E., and Eksteen, J., 2021. Waste Manage., 125: 87-89.

Development of glycine-based process

Non-cyanide glycine leaching of precious metals:

- Permanganate or ferricyanide with glycine solution effectively leached PMs, namely glycine-oxidant leaching system
- Similar or comparable PMs extraction, compared with cyanide-starved glycine leaching or intensive cyanidation
- Rapid decomposition of glycine was observed when permanganate added
- Oxidant consumptions were high, i.e., 630 kg/t K-permanganate or 610 kg/t K-ferricyanide

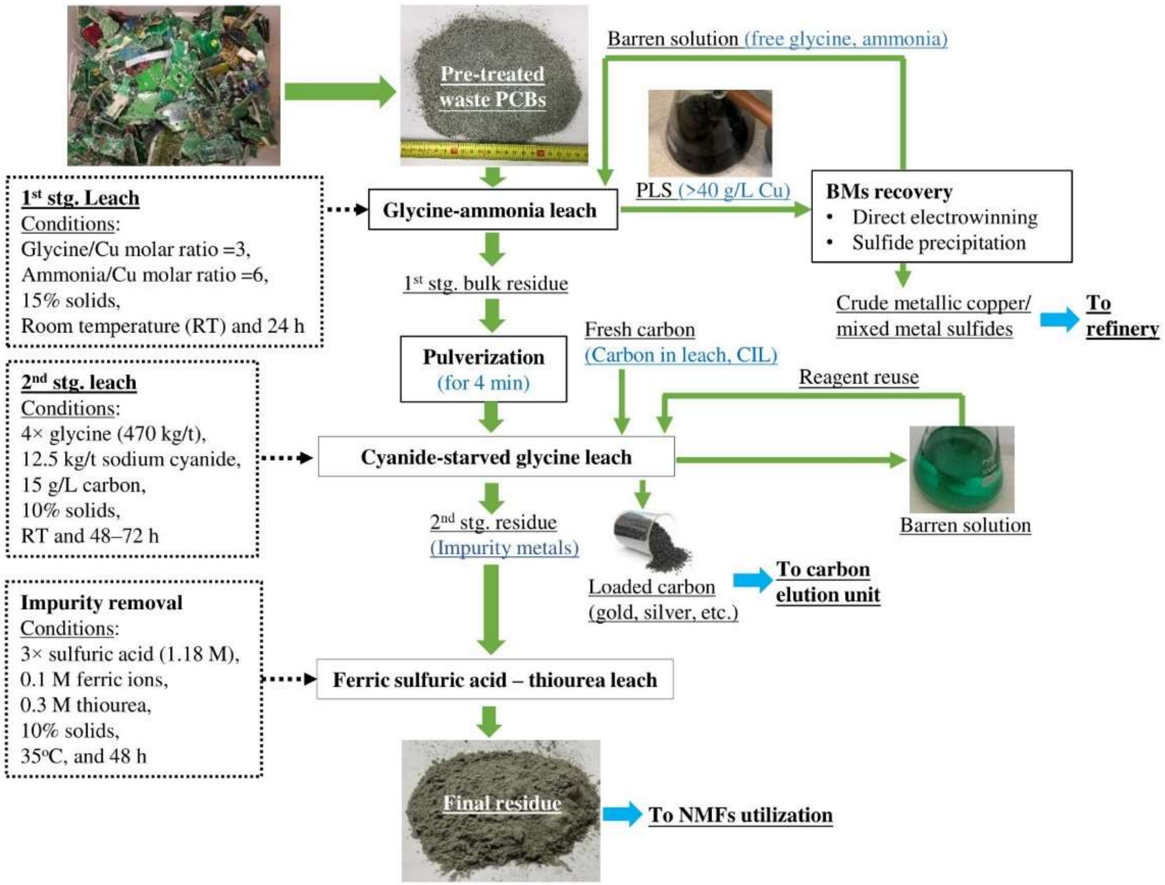


Source: Li, H., Oraby, E., and Eksteen, J., 2022. Minerals Engineering, 181: 107501.

Development of glycine-based process

An improved process:

- 1^{st} step glycine-ammonia leaching at 15% solids
- Pulverization used to liberate precious metals from plastics
- 2^{nd} step cyanide-starved glycine leaching at 10% solids
- 3^{rd} step sulfuric acid – Fe^{3+} – (thiourea) leaching at 10% solids

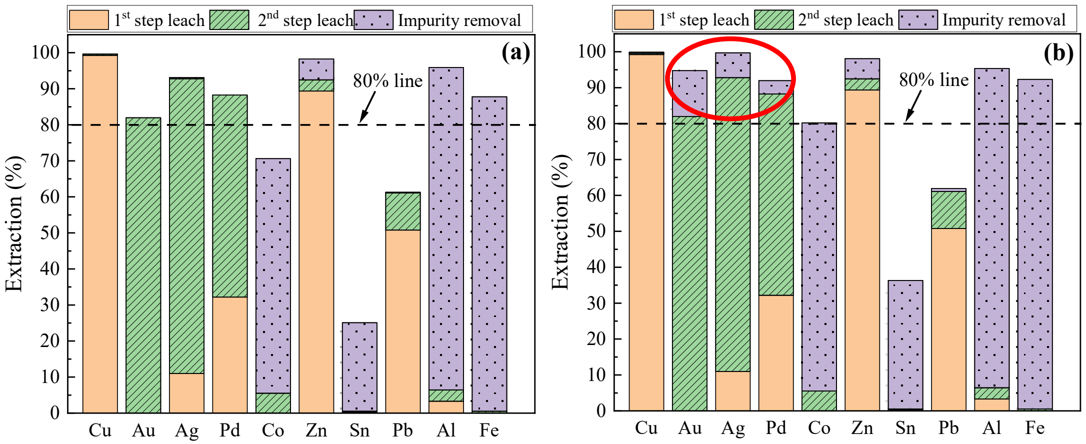


Source: Li, H., Deng, Z., Oraby, E., and Eksteen, J., 2023. Resour. Conserv. Recy., 187: 106631.

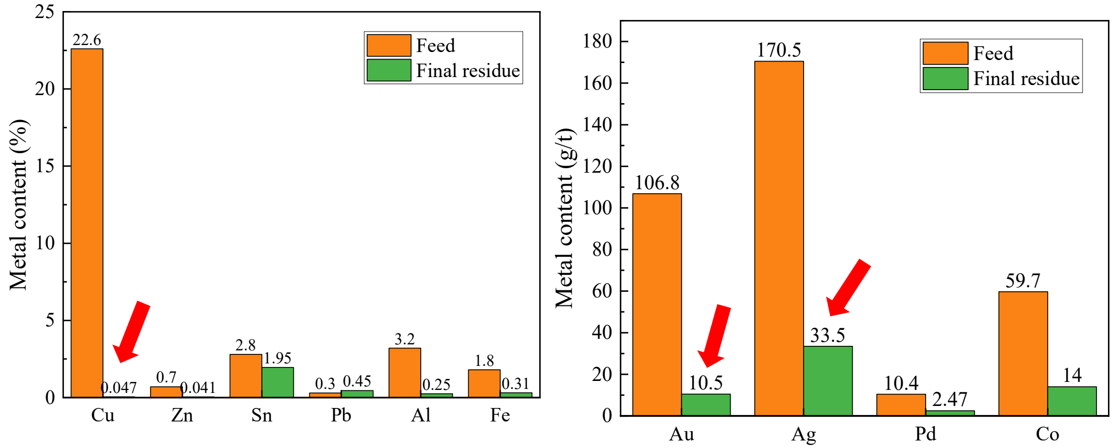
Development of glycine-based process

An improved process:

- Overall extraction: >99% copper, >90% gold, >95% silver and >85% palladium
- Metal content in residue: 0.047% copper, <1% base metals (except tin), <35 ppm precious metals



Figures above: Extraction of metals at each step of leaching, (a) without and (b) with thiourea in the 3rd step.



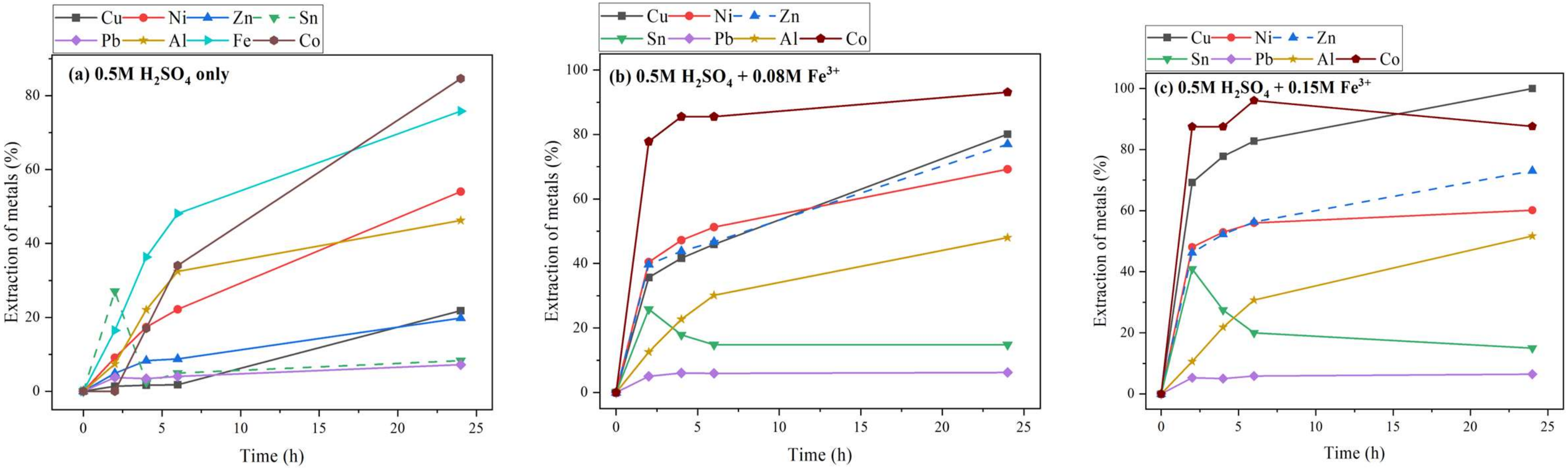
Figures above: Metal contents in the final residue after three leaching steps with thiourea in the 3rd step.

Source: Li, H., Deng, Z., Oraby, E., and Eksteen, J., 2023. Resour. Conserv. Recy., 187: 106631.

Development of sulfuric acid leaching process

Leaching of pre-treated waste PCBs (100%< 2mm):

- Oxidant, e.g., Fe^{3+}, was essential for copper leaching
- Leaching time can be shortened to ~24 hours
- Tin and lead (e.g., solder materials) remained low extractions (<20%)
- No gold and palladium were leached; silver leaching was <15%.

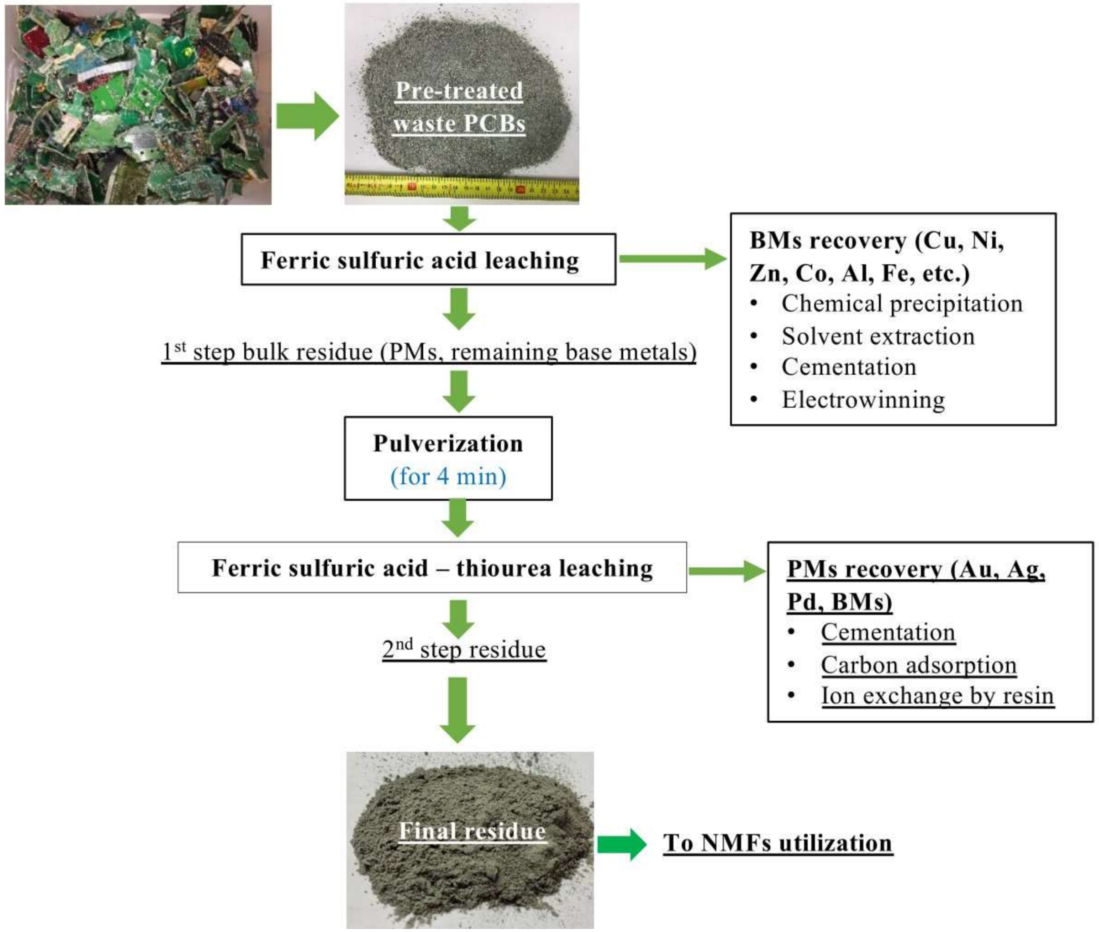


Figures above: Extraction of metals using different sulfuric acid leaching at 2% solids and room temperature.

Development of sulfuric acid leaching process

Sulfuric acid leaching process:

- Well known in chemistry
- Non-selective for base metals
- 1st step sulfuric acid – Fe^{3+} leaching of copper & base metals
- 2nd step sulfuric acid – Fe^{3+} – thiourea leaching of precious metals & remaining base metals
- Physical separation is suggested prior to hydrometallurgical leaching



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Recommendations for future study

- More fundamental studies
- Mechanical-physical separation of bulk of metals
- Ferricyanide regeneration and reuse
- Glycine recycling and reuse
  - Glycine decomposition
  - Glycine quantification
- Residue utilization
- Pilot scale tests
- Techno-economic assessment

Acknowledgements

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NEW INDUSTRIES WA

total green recycling

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Thank you for your attention!