Recycling Printed Circuit Boards to Recover Valuable Metals

Ethan Zhou
Advisor: Dr. Kevin Crowthers, Ph.D.

Introduction

In recent years, humans have become increasingly reliant on technology. Accordingly, there has been a rise in both electronic waste (e-waste) and demand for metals to supply production. Thus, recovering useful materials from these waste streams becomes critically important to supply the needed metals for the sustainable development of human society. This project proposes an efficient approach to recycle printed circuit boards (PCBs), a type of e-waste that is considered the most valuable e-waste for recycling since they contain more than 80% of the total metal recovery value.

Problem Statement

The increasing demand for metals and the growing volume of electronic waste in landfills highlight the urgent necessity for the effective recycling of e-waste. Nevertheless, existing recycling techniques are not sustainable and require significant amounts of energy and resources.

Project Goal

In order to solve the problem, this project aims to establish a scalable, effective, and sustainable process to reclaim and recycle valuable metals from printed circuit boards through a combination of mechanical and chemical methods.

Contribution To Field

Current prevailing PCB treatment methods include landfill and pyrometallurgy. However, the disposal of PCBs in landfills wastes valuable materials and can result in releasing harmful pollutants into the environment. Pyrometallurgy, which involves burning PCBs at high temperatures for recovery of metals, is energy-intensive, demands large capital investment, and utilizes harmful substances. Additionally, the fumes released by this treatment are toxic for the environment. There has yet to be a standard method for recycling PCBs that is not resource intensive or environmentally harmful.

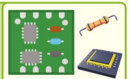
Main Takeaway:

Recycling PCBs effectively and sustainably can be achieved through a process combining hydrometallurgical and mechanical methods.

METHODS

COMPONENT SEPARATION

The first step to recycling is removing the PCBs electrical components through chemical dissolution.



SOLDER MASK REMOVAL

The solder mask is then removed through chemical stripping. Now, the circuitry is exposed.

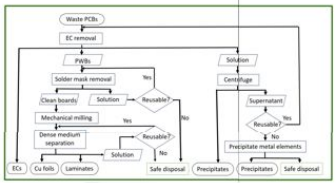
MECHANICAL MILLING

In order to obtain the metals, the PCB is then shredded into a fine powder.

METAL SEPARATION

Finally, the powder undergoes density separation, which separates the metals from the nonmetals.

Proposed Process:



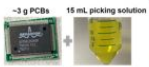
EC removal design

1. Pickling solution inlet; 2. Basket with small mesh for ECs; 3. Basket with big mesh for PWBs; 4. Pickling solution outlet.

Nitric acid concentration testing:

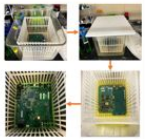
PCB start weight (g)	HNO_3 concentration	time	PCB end weight (g)
1.09	40 vol%	38 mins	0.93
0.739	35 vol%	70 mins	0.60
0.839	30 vol%	Did not fully remove EC after 90 minute	N/A
0.839	25 vol%	Did not fully remove EC after 90 minute	N/A
0.709	20 vol%	Did not fully remove EC after 90 minute	N/A

~3 g PCBs / 15 mL picking solution

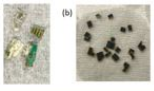


Products of pickling solution treatment. 1. PWB; 2. EC; 3. used pickling solution; 4. precipitate obtained by centrifuge.

Lab set-up



NaOH vs KOH for solder mask removal:



PWBs treated at 90°C for 90 min with a Solid-to-liquid ratio (S/L) of 1g:5ml. (a) in 2M NaOH. (b) in 2M KOH.

Optimized condition: 2M KOH, 90 °C, 90 minutes, S/L ratio 1g/1ml.

PWBs (after pickling)	After KOH
	

Advantages:

- Previous reported optimized condition: 3M NaOH at 70 °C for 2 h with solid-to-liquid ratio 1g:5ml (Kang et al., 2021).
- NaOH at $0.31/KG vs. KOH at $0.747/KG (Mike, 2022; *Potassium Hydroxide Price, 2023*).
- Advantage of KOH: shorter time and significant improvement in S/L ratio.
- Will result in significant cost savings in operations and less alkaline waste at the end of process (if any).

Conclusion

- Despite the high value of metal contents, PCBs are recycled at a low rate due to the low efficiency of manual dismantling and pyrometallurgical recycling methods.
- The project combines hydrometallurgical and mechanical methods and creates an efficient and sustainable process for recycling PCBs.
- Valuable products from this multiple-step process include ECs, precipitate that contains Sn, Au, Ag and Ni, Cu foils, laminate pieces, and precipitate that contain Cu, Sn, Fe, Pb, and other metal elements.
- The reuse of chemicals, including pickling, KOH, and acetone/TBE solutions will be studied.

Future Work

1. Experiment with other factors such as other acids for EC removal, pressure, and agitation
2. Conduct large scale study to understand the challenges during industrial implementation.
3. Talk to industry about technology transfer and explore patent filing.
4. Study the recovery of Ga from ECs. There is little work done on this front.
   a. Integrated circuits account for 74% of domestic Gallium consumption (U.S. Geological Survey, 2023).
   b. No domestic primary Ga has been recovered since 1987.

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