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Investigation into the Recovery of Valuable Metals from Waste Mobile Phone Printed Circuit Boards (PCBs): An Australian Case Study

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Abstract

Electrical and electronic equipment including mobile phone devices have developed rapidly and their useful lifespans reduced as a result of the changes in equipment features and designs. This creates a large waste stream and lately became a critical environmental issue. Printed circuit board (PCB) is one of the main components of the waste electrical and electronic equipment. PCB typically contains various metals including valuable (copper, gold, silver, platinum) and toxic heavy metals (mercury, lead, arsenic). Recycling of end of life mobile devices has the potential to solve many problems including resource depletion, environmental pollution, and landfill disposal. This article investigates the feasibility of the recovery of valuable metals from waste mobile phone PCBs through a city based induction smelting plant in the city of Sydney, Australia. Mobile phones from different companies, models, and year of manufacture collected and average weight percentages of materials content for each type of phone have been reported. A laboratory size smelter then utilized to recover precious metals out of waste mobile PCBs. It concluded that local electronic waste recycling in Australia is theoretically viable and prevent the ethical and legal issues raised from exporting these wastes.

Keywords Printed circuit boards (PCBs); Mobile phone; Precious metals; Recycling

Introduction

The use of electronic and electric equipment has risen dramatically over the two decades with the advancements in technology, material science, and manufacturing processes [1-5]. The global production of electronic waste is about 20-50 million tons per year [6,7] although more recent studies suggest that this figure could be on the low side as there is no standard practice for reporting waste electronic and electric equipment (WEEE) [8]. Mobile phones are significant contributors to the production of electronic waste (e-waste), with global sales passing one billion marks in 2009 [9]. According to statistics released by Australian Mobile Telecommunication Association (AMTA), Australians upgrade or exchange their mobile phones every eighteen months, meaning there are approximately 16 million unused mobile phones stashed away at home or in the office [10]. The average working life of a mobile phone is seven years but worldwide the average consumer changes their mobile every eleven months [11]. Australians purchased 40 million mobile phones in past five years including 9.28 million in 2007 [10]. Electronic waste contains more than 1000 different substances, many of which are toxic, such as lead, mercury, arsenic, cadmium, selenium, hexavalent chromium, and flame retardants, hence the safe and efficient disposal of waste electrical and electronic equipment (WEEE) is an issue of considerable scale [12]. Worldwide, Australia is ranked as the top ten countries for the consumption of electronic goods [13]. It is estimated that there are 30 million mobile phones in Australian households, with over 7 million more being imported each year [11]. In addition to the phones in use, there are around 56 million mobile phones in landfill across the country [11]. Currently, there are several companies that offer mobile phone recycling service in Australia, but the majority of these phones end up being treated in developing countries [14]. This number is constantly growing, with over seven million new mobile phones imported to Australia yearly [15]. There is generally no control over the disposal of e-waste into the landfill in Australia. The exception is the Australian Capital Territory [7]. As a result, 51% of portable items in Australia are being disposed of with normal domestic waste. Of particular concern is the toxic nature of many of the base materials used in the manufacture of electronic devices. Toxic heavy elements especially Pb, Cd, Hg, As and Cr are significantly present in PCBs, hence disposal of waste PCBs to landfill results in the accumulation of these toxic materials at landfill sites which pose a major problem for the future remediation and utilization of these sites [16,17]. Besides, PCBs represent the most economically attractive portion of WEEE and the loss of non-renewable resources such as scarce and precious metals highlight the need for the increased recycling of WEEE, not only within Australia but also on a worldwide scale [18]. In this work, a feasibility study has been carried out to assess the possibility of recycling precious metals (mainly silver and gold) out of waste mobile phones' PCBs through a city based induction smelting plant for the city of Sydney, Australia.

Materials and Methods

The recovery of valuable metals from selected waste printed circuit boards (PCBs) is quite difficult as the waste mobile PCBs are diverse and complex in terms of type, size, shape, components and composition and with time, the composition has been continuously changed. Besides; presence of numerous metallic elements leads to complex recovery process and the recovery process becomes more complicated when the elements are available in minute concentration. In this work, mobile phones from different companies, models, and year of manufacture were used. They were collected randomly to simulate the real situation. The mobile phones then manually disassembled and batteries and plastic frames were disjointed from PCBs, twenty of the collected phones were selected to be dismantled at the first stage of the study. The parts removed were sorted by their material and separated into groups. Each group was weighed in order to give an idea of what phones are made of and how they are assembled. This is an idealized situation as the treatment plant is likely to have an automatic dismantling process. For smaller devices such as mobile phones, it is easier to melt the entire circuit board without separating individual components. This is because the precious metals mainly accumulated in small parts that are not accessible and cannot be simply mechanically separated [19]. After dismantling the phones, the PCBs cut into pieces ranging from 1 cm^2 to 5 cm^2 and placed into the smelter with copper of a known purity. Copper was used as it is a readily available, affordable metal that captures precious metals of the melted PCBs.

The melting temperature set at 1200°C. The temperature monitored using a K type thermocouple. Copper rod with the composition of 99.9% copper, 0.005% lead, 0.001% bismuth and 0.094% other metals/impurities was used as the based metals for the smelting of PCBs. Three samples were taken in this study; the first one after copper passed its melting point, the second sample was taken after half the circuit board melted into the copper and the third one taken after 5 minutes once all PCBs chunks added to the copper. The three samples then were analyzed by an Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) to give a breakdown of the elements present in the samples. The breakdown of the common metals found in mobile phone circuit boards is given in Table 1 [20]. 16 samples were analysed. Brand A referred to mobile phones before 2005 and Brand B attributed to mobile phones produced after 2005 [20].

%	Brand A	Brand B	Other brands	Average
Copper	39.56	38.33	37.81	38.57
Aluminium	0.31	0.99	0.61	0.64
Lead	1.17	1.26	1.23	1.22
Iron	1.42	6.53	4.85	4.27
Tin	2.09	3.11	2.55	2.58
Nickel	3.42	1.67	2.54	2.I54
Zinc	3.43	0.97	1.82	2.07
Silver	0.06	0.06	0.05	0.06
Gold	0.06	0.1	0.09	0.08

Table 1: Common metals found in the mobile phone circuit boards (as percentage of total materials) [20].

From Table 1, it is estimated that out of 500 g circuit board, around 193 g of copper, 300 mg of silver and 400 mg of gold can be extracted. This indicates that by using 500 g circuit board and 1000 g of copper, 200 ppm silver, and 267 ppm gold can be recovered.

Results and Discussion

Collection

Essential to any recycling scheme is the collection of materials to be processed. For this project, a small-scale collection route with twenty phones was carried out. Collection on a larger scale proved to be more difficult as the benefits of e-waste recycling are yet unknown to the general public besides having access to an applicable system providing easy ways for donating unwanted items is not in place in most of the countries including Australia [11]. Collection point at mobile phone retailers is proposed by local councils in the state of New South Wales which facilitates the businesses and individuals' contribution in donating their end-of-life phones and other electrical/electronic equipment. In this project, each of twenty collected phones was given a reference number for disassembly and smelting. The phones were classified by the manufacturer, age, and design. Nokia was the most popular manufacturer, the majority of phones were between four and seven years of age and the simple bar design was the most common. The majority of phones collected (93%) were manufactured in the 2000's. Figure 1 shows the number of bar phones and slide phones collected per year of manufacture. As shown in Figure 1a bar phones followed a similar rise in popularity during the 2000's which indicates recycling processes should be focused on touchscreen smartphones in the future, but the trend may not take effect for the next four to seven years. Bar phones are still a popular design compared with other designs such as sliders and flip phones. As shown in Figure 1b, sliders which were the second most popular design of the phones collected, had a period of popularity in the late 2000's that has ended since then.

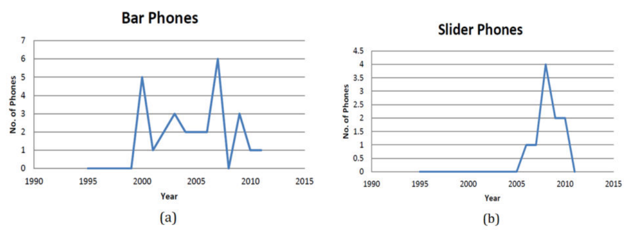

Figure 1: Number of phones collected per year of manufacture (a) bar phones, (b) Slider phones.

Figure 2 shows the number of phones used in this study that fit into each category. The bar design is the most popular with 47% (28) of the phones collected and used fitting into this category. This could be due to the popularity of Nokia phones as 24 of the 28 bar phones collected and utilized in the test were manufactured by Nokia. 20 of the 24 phones were also released before 2008, making this by far the most popular type of phone collected. It is believed that the bar phones will not contain as much of the undesired materials such as plastics, rubber and metal other than copper and the precious metals, making this a desirable result. Ten slider phones were also collected, making this the only other result of note. All of the types of phone have experienced a period of popularity, some greater than others. Currently touch screen smart phones are in fashion. This would indicate that in the near future the number of bar phones will decrease and the touch screen smart phones will become the more popular design type.

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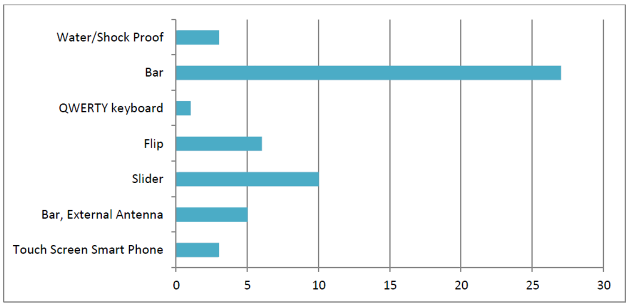

Figure 2: Number of phones collected and used by design.

As shown in Figure 3, Nokia is overwhelmingly the most popular manufacturer with 58% of the phones collected manufactured by Nokia. All the other popular brands of phone including Sony Ericson, Motorola, HTC and Samsung are represented but with none exceeding 11% of the phones donated. Although, the Apple iPhone is an exception as none were collected. This could be due to the general age of the phones. Most phones (58%) were first introduced before 2008, which is when the iPhone was first released in Australia. Another possible cause could be the market for second hand mobile phones. Apple iPhones carry a high price in this market as well as in the primary market.

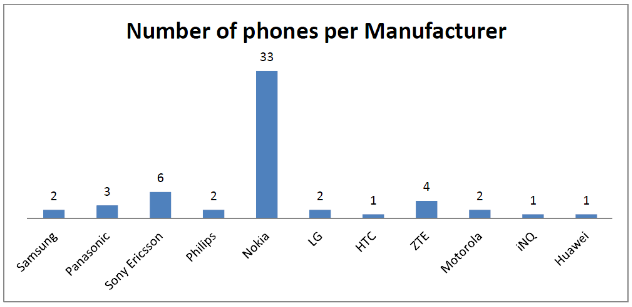

Figure 3: Number of phones by Manufacturer.

Disassembly

The manual disassembly process is an idealized situation as any potential recycling plant use automatic processes. The labour cost of manual disassembly heavily outweighs any economic value gain from the recycling process. On average, it takes about ten to fifteen minutes to disassemble one phone. A form of automatic disassembly was not investigated in this study but a quality disassembly system is critical for any recycling plant. The twenty phones selected for disassembly in this study were of different ages, types, and manufacturers hence, the material content varied quite noticeably. Figure 4 shows the weight percentage of circuit board per phone for the selected phones. As it can be seen from this figure, the PCBs weight varied from 14.58% to 33.52% of each phone. However, the average value is consistently around 24%. Figure 5 shows the weight percentage of different materials and part categories (plastic casting, circuit board, rubber/plastic, battery, glass, etc.) for the selected phones in this study. As it can be seen from this figure, plastic casing makes up the majority of the mobile phones followed by the battery and printed circuit boards (PCBs). In this paper, the collected end-of-life phones were classified into seven different design categories: phones with an external antenna, water and shockproof phones, bar phones, QWERTY keyboard phones, flip phones, slider phones and touchscreen smartphones. It is found that phones with an external antenna have higher metal content. This is also the case for the slider phones. These metals are mostly steel and not one of the desired precious metals or copper. Water and shockproof phones have higher plastic and rubber content.

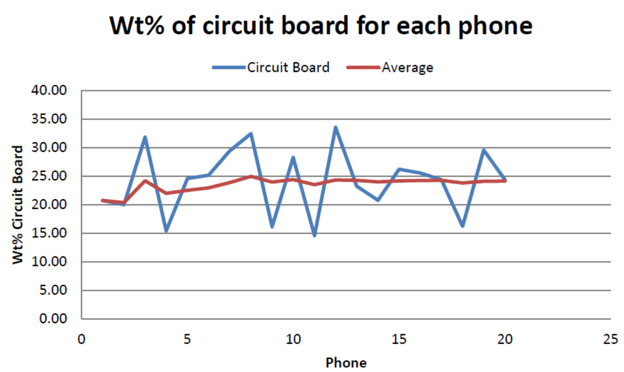

Figure 4: Weight percentage of circuit board per phone.

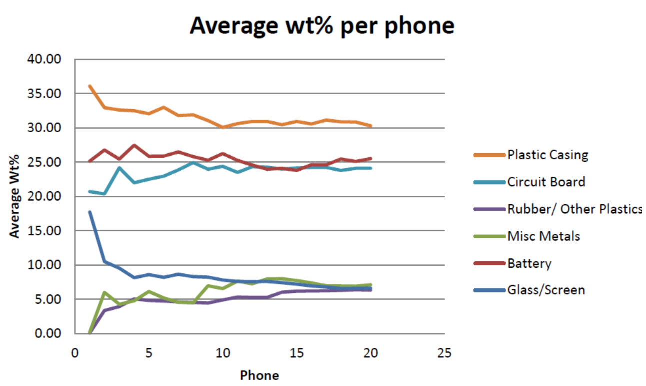

Figure 5: The average weight percentage for each category.

Flip phones also contain more plastic components; some of the flip phones have two screens, which mean more glass content. Touchscreen smartphones contain more glass as the screens are generally bigger. The QWERTY keyboard phones are very similar to bar design phones except that they feature with more buttons and larger screens. Figure 6 shows the average weight percentage of each material group for different categories of phone studied in this paper. As it can be seen from Figure 6b, the QWERTY keyboard phone has the highest weight percentage of the circuit board and the phones with an external antenna have the lowest weight percentage of the circuit board. The battery is the least desirable category for a phone. As shown in Figure 6c, phones with an external antenna on average have the highest weight percentage of battery. These phones generally were the oldest type of phone.

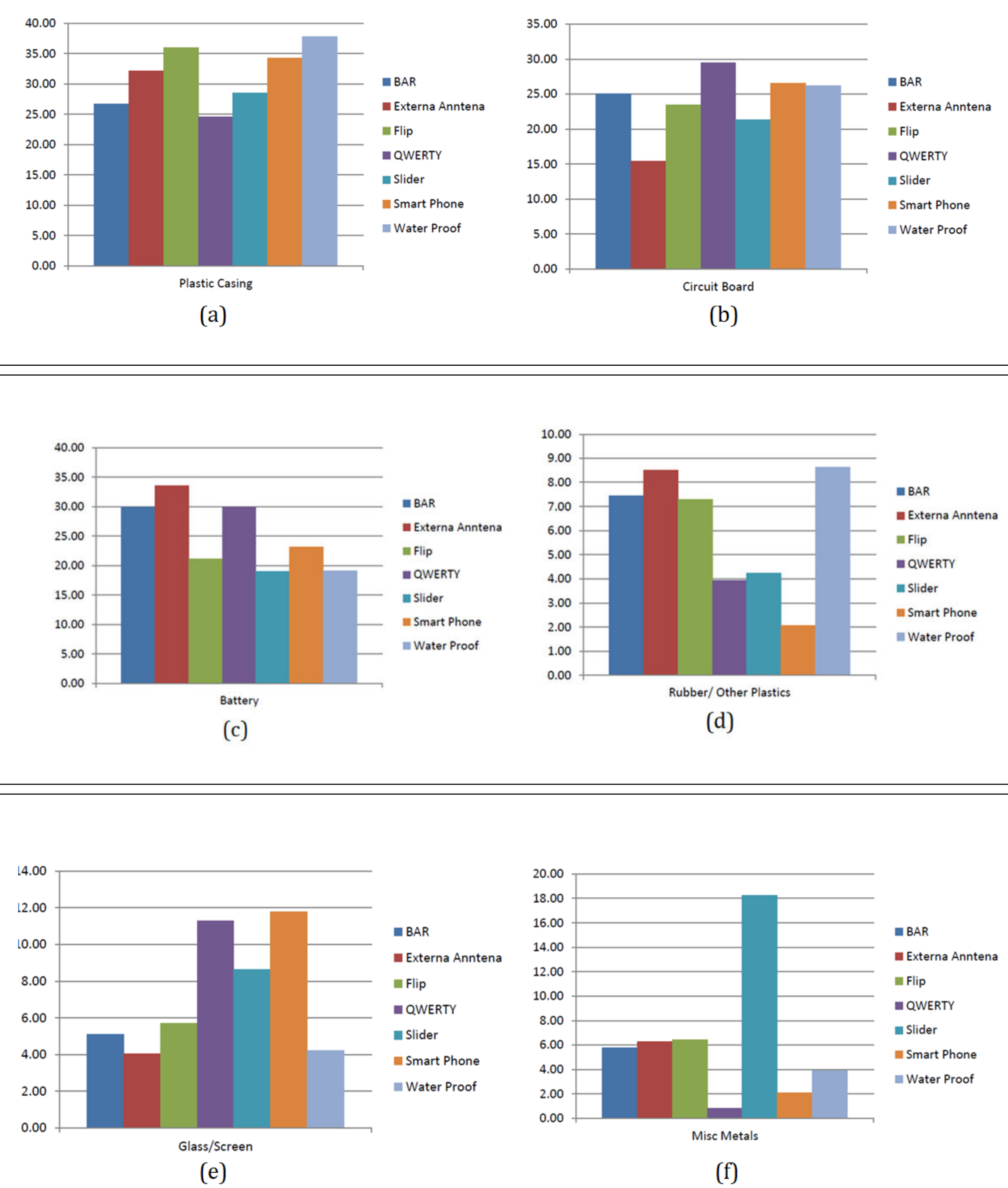

Figure 6: Average weight percentages of (a) plastic casing, (b) circuit board, (c) battery, (d) rubber/other plastic, (e) glass and (f) miscellaneous metals for studied type of phone QWERTY keyboard phones also have high battery weight percentage.

As expected, water and shockproof phones have a high rubber and plastic content. External antenna phones also have a high weight percentage in this category. Smartphones have the lowest internal plastic and rubber content followed by sliders and QWERTY keyboard phones. As shown in Figure 6f, sliders and flip phones have by far the highest average miscellaneous metals content. QWERTY keyboard phones have higher glass/screen weight percentage than the average as shown in Figure 6e. Smartphones, however, have the highest average weight percentage with 11.78%. External antenna phones have the lowest average of glass content with only 4.04% weight percent. This demonstrates the trend of the increase in screen sizes with time as smartphones have screens with almost three times of the size of the older phones. From the data presented in Figure 6, it can be concluded that QWERTY keyboard phones are the most desirable type of phone for precious metal recycling as the weight percentage of the circuit board is fairly higher than the other models, in addition the plastic casing, rubber content and the percentage of the miscellaneous metal are comparatively low. Smartphones are an attractive prospect as the circuit board makes up a significant percentage of the phone and plastics and rubber make up only a small percentage.

In this study the circuit board was reduced using hand tools including scissors, pliers and a Stanley knife. Each board was broken into a variety of sizes depending on the ease with which it could be dismantled, while still allowing each different circuit board to be a variety of sizes. The largest pieces were around 5 cm^2 and the smallest 1 cm^2. During this process further removal of unwanted materials was possible. The majority of this material was unwanted metals that are used to protect parts of the circuit board. When the circuit board was being broken, these protective casings fell off and were discarded. This meant that the total weight of the circuit board was reduced from 529.83 g to 461.52 g. Of the 68.31 g of materials lost, 65.72 g of unwanted material was removed and 2.59 g of potentially useful material was lost during the dismantling process.

Smelting

Before the smelting taken place, the PCBs and copper rod were cut into different sizes (1-5 cm). PCBs were sorted by age and split into three groups to determine the order for the smelting process. The first group consisted of five circuit boards manufactured between 1995 and 2001, with a total weight of 140.23 g (sample 2). The second group consisted of eight circuit boards manufactured between 2005 and 2008, with a total weight of 160.86 g (sample 3). The third group, consisting of seven circuit boards manufactured between 2008 and 2011 with a total weight of 160.43 g (sample 4). Table 2 presents the phones brand used in the experiments.

Sample 1				
Copper				
Sample 2				
Nokia	3100	Bar	2000	21.20 g
Philips	Fizz	Ext. Antenna	1995	54.99 g
Sample 3				
LG	KP202	Flip	2007	13.59 g
Motorola	V3x	Flip	2005	17.66 g
Sony Ericsson	K800i	Bar	2006	18.86 g
Sample 4				
Nokia	Nokia	Nokia	Nokia	Nokia
2220	2220	2220	2220	2220

Table 2: Phone brands used in different samples.

The planned smelting process involved smelting of 1kg of a copper rod into the furnace as the test sample, once copper is melted the temperature measured and the first sample was taken. At the second stage of the experiment, sample 2 placed into the furnace with the temperature set in 1200°C. The third sample inserted into the furnace after 20 min (The time duration for sample taking was set to be 20 min). Sample 1 contained only the copper. This is for comparison. According to the manufacturer, this sample contains 99.9% copper, 0.005% Lead, 0.001% Bismuth and 0.094% others impurities. Sample 2 contained the copper and circuit boards (consisted of five circuit boards of phones manufactured between 1995 and 2001), with a total weight of 140.23 g. The comparisons from this sample with sample 1 gave an indication of the material content of mobile phones manufactured between 1995 and 2000. Using the average percentage of materials in a circuit board as found by Kasper et al. [20] and shown in Table 1 the sample is expected to contain the metals shown in Table 3. Also shown is the actual metals found in the sample through the ICP-AES analysis.

Material	Expected (Sample 2)	Result (Sample 2)	Expected (Sample 3)	Result (Sample 3)
Copper	95.56%	99.70%	93.02%	98.80%
Aluminum	0.05%	0.14%	0.07%	0.60%
Lead	0.09%	0.01%	0.14%	0.01%
Iron	0.30%	0.02%	0.48%	0.39%
Tin	0.18%	0.01%	0.29%	0.01%
Nickel	0.18%	0.07%	0.29%	0.10%
Zinc	0.15%	0%	0.23%	0%
Silver	0.00%	0.02%	0.01%	0.04%
Gold	0.01%	0%	0.01%	0.01%
Bismuth	0.09%	0%	0.09%	0%
Other	3.39%	0.03%	5.38%	0.02%

Table 3: Materials expected to be found in Sample 2 and sample 3.

Sample 3 contained copper rod and eight circuit boards of phones manufactured between 2005 and 2008, with a total weight of 160.86 g. The comparison between the two samples gave an indication of the material content of mobile phones manufactured between 2005 and 2008. Using the average percentage of materials in a circuit board as found by Kasper et al. [20] and shown in Table 1 the sample is expected to contain the metals shown in Table 3. Also shown is the actual metals found in the sample through the ICP-AES analysis.

Material	Expected	Result
Copper	91.39%	96.80%
Aluminum	0.09%	0.40%
Lead	0.17%	0.01%
Iron	0.59%	2.48%
Tin	0.36%	0.02%
Nickel	0.35%	0.18%

Zinc	0.29%	0.01%
Silver	0.01%	0.04%
Gold	0.01%	0.03%
Bismuth	0.09%	0%
Other	6.65%	0.02%

Table 4: Materials expected to be found in sample 4.

The outcome of the analysis presented promising results. It was shown that the amount of gold and silver continued to increase as more PCBs added to the smelting mixture. Table 5 shows the elements found in the tested samples by percentage and weight. It was also found that arsenic; phosphorus, chromium, palladium, and platinum were present in negligible amounts as to not appear in the analysis (less than 0.005%).

Element	Sample 1	g	Sample 2	g	Sample 3	g	Sample 4	g
	%		%		%		%	
Cu	99.9	999	99.7	1043.981	98.8	1050.392	96.8	1045.982
Al	-	-	0.143	1.484	0.6	6.379	0.4	4.322
Sn	-	-	0.005	0.052	0.011	0.117	0.023	0.249
Mn	-	-	-	-	0.028	0.298	0.013	0.14
Ni	-	-	0.069	0.716	0.095	1.01	0.18	1.945
Pb	-	-	0.011	0.114	0.005	0.053	0.008	0.086
Zn	-	-	-	-	-	-	0.007	0.076
Fe	-	-	0.018	0.187	0.393	4.178	2.48	26.798
Ag	0.006	0.06	0.02	0.208	0.038	0.404	0.04	0.432
Au	-	-	-	-	0.011	0.117	0.026	0.281

Table 5: Elements found in sample by percentage and weight.

As shown in Table 5, the percentage of copper decreased through samples 1 to 4, however, the weight of the copper presented still increased in sample 2 and 3. This is due to the copper becoming diluted as more material is added. The elements found in the circuit board of phones manufactured between 1995 and 2000 can be seen in sample 2, Table 5. These data show that other than copper, the most prevalent element found in these phones was aluminum. Sample 2 contained 0.143% aluminum (1.48 g of the 76.19 g of circuit board). This number then increased in sample 3 by 0.457%. This equates to around 6.76 g of aluminum in the three phones, but the level then reduced in sample 4. This reduction could be due to oxidization of the aluminum. Based on Ellingham Diagram [21], 1200°C has the lowest Gibbs free energy ($\Delta G°$) and hence some aluminum may have oxidized. This explains the drop of aluminum between the 3rd and 4th samples. Manganese also has a relatively low value for $\Delta G°$ as shown in Figure 7. Manganese was only found to be present in the third and fourth samples. This indicates that it was most abundantly used in mobile phones manufactured between 2005 and 2007. The manganese then may have oxidized; this explains the drop in the value of manganese between the third and fourth samples. As Nickel continues to increase through every sample it is unlikely that a significant amount of Nickel oxidized. Therefore, it is also unlikely that any metal requiring more energy to oxidize would have oxidized significantly. The metals on the graph that fit this description are lead and copper. Zinc was found in samples 4 but not in any other sample. This indicated that zinc was only present in Nokia mobile phones manufactured between 2009 and 2010 and touchscreen smartphones. However, as shown in Table 6 the vapour temperature at a pressure of 100 kPa (close to atmospheric pressure) is 921°C. This indicated that any zinc that was in the other phones could have vaporized before the samples were taken as the molten copper was above 1150°C for the duration of the test.

Element		Vapour temperature at 100 kPa	Vapour temperature at ~ 1200 °C
Ag	Silver	2160°C	0.01 kPa (1140°C)
Al	Aluminium	2517°C	0.001 kPa (1209°C)
As	Arsenic	601°C	-
Au	Gold	2805°C	0.001 kPa (1373°C)
Cr	Chromium	2669°C	0.001 kPa (1383°C)
Cu	Copper	2563°C	0.001 kPa (1236°C)
Fe	Iron	2859°C	0.001 kPa (1455°C)
Mn	Manganese	2060°C	0.1 kPa (1220°C)
Ni	Nickel	2911°C	0.001 kPa(1510°C)
P	Phosphorus	431°C	-
Pb	Lead	1754°C	1 kPa (1139°C)
Pd	Palladium	2961°C	0.001 kPa (1448°C)
Pt	Platinum	3821°C	0.001 kPa(2057°C)
Sb	Antimony	1585°C	10 kPa (1218°C)
Sn	Tin	2620°C	1 kPa (1220°C)
Zn	Zinc	921°C	-

Table 6: Vapour temperatures at 100 kpa and 1200 °C of elements tested in analysis.

The level of gold and silver increased as more circuit boards were added to the mixture. This can be seen in the difference between samples 1 and 2 (Ag 0.006% and 0.02%), samples 2 and 3 (Ag 0.02% and 0.038%, Au >0.005% and 0.011%) and samples 3 and 4 (Ag 0.038% and 0.040%, Au 0.011% and 0.026%) as presented in Table 6. Figure 7 shows the phase diagram for copper and gold. From this, it can be seen that gold is completely miscible with copper and the gold content increased from sample 3 to sample 4. As shown in Table 7, at close to atmospheric pressure (100 kPa) arsenic and phosphorus vaporize in a furnace operating at 1200°C. This explained the absence of arsenic and phosphorus from the samples, although neither of the elements was expected to be present. Palladium and platinum have extremely high vaporizing temperatures (2961°C and 3821°C respectively).

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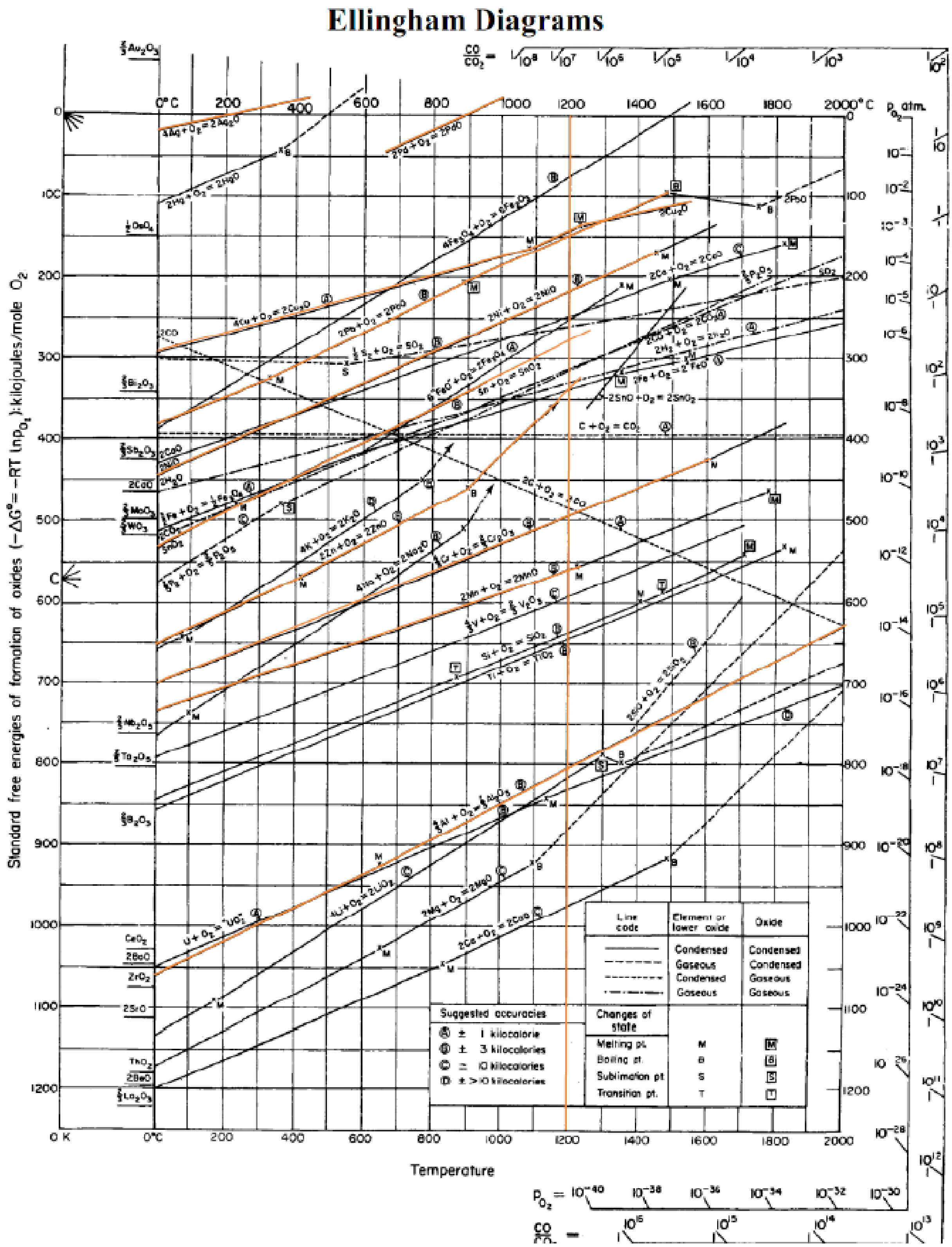

Figure 7: Ellingham Diagram with relevant elements in orange [21].

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This indicated that the absence of these materials was not due to vaporization and perhaps could mean that any material that is present in the circuit boards did not melt and mix with the copper but has been captured in the slag. Although the study by Kasper et al. [20] has not found any of these metals, due to the value of these metals further investigation into their presence in the slag should be done. Chromium may also have not mixed with the copper as it has a melting point of 1907°C. However, chromium was not expected to be present in the samples. This is shown in Table 7, which compares the percentage of materials expected to be found in the copper mixture as found by Kasper et al. [20] with the materials found in the copper mixture through analysis carried out in this study. As it can be seen from Table 7, the experimental results showed significantly higher values for copper than what was estimated by Kasper et al. [20], and as a result, the values for every other element are lower than what was expected. A possible reason is that Kasper's study was done by burning the circuit board and testing the remaining ashes. In this work, however, the circuit boards were smelted first and the samples of the resulting metals were analyzed and reported. The smelting route involved high-temperature processing which affected the circuit boards as discussed above. The materials also require time to reach an equilibrium state and for the mixture to become homogeneous.

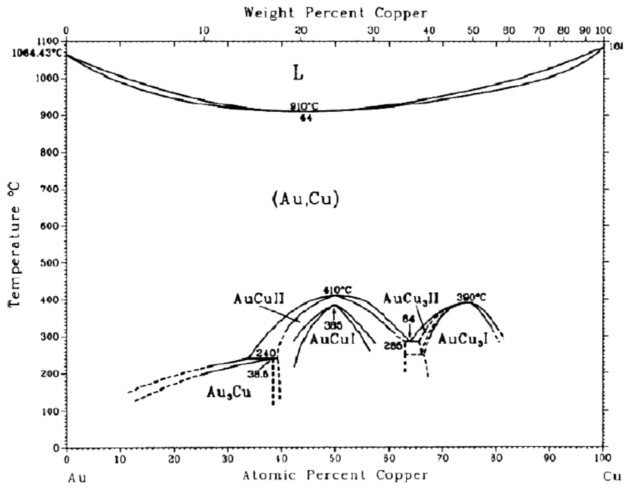

Figure 8: Au-Cu phase diagram [22].

This time varies for all materials [22]. It is possible that the time required for the copper mixture to reach a state of equilibrium was not reached and that the samples taken were not a complete representation of all the materials present. Another possible reason could be the fact that the circuit boards from other studies ex, [23] differ and are not as diverse in range as those used in this project.

	Sample 2		Sample 3		Sample 4	
Element	**Expt.**	**Result**	**Expt.**	**Result**	**Expt.**	**Result**
Copper	95.56%	99.70%	93.02%	98.80%	91.39%	96.80%
Aluminium	0.05%	0.14%	0.07%	0.60%	0.09%	0.40%
Lead	0.09%	0.01%	0.14%	0.01%	0.17%	0.01%
Iron	0.30%	0.02%	0.48%	0.39%	0.59%	2.48%
Tin	0.18%	0.01%	0.29%	0.01%	0.36%	0.02%
Nickle	0.18%	0.07%	0.29%	0.10%	0.35%	0.18%
Zinc	0.15%	0%	0.23%	0%	0.29%	0.01%
Silver	0.00%	0.02%	0.01%	0.04%	0.01%	0.04%
Gold	0.01%	0%	0.01%	0.01%	0.01%	0.03%
Bismuth	0.09%	0%	0.089	0%	0.09%	0%
Manganes e	0%	0%	0%	0.03%	0%	0.01%
Antimony	0%	0%	0%	0%	0%	0%
Other	3.39%	0.03%	5.38%	0.02%	6.65%	0.02%

Table 7: Expected element percentage versus analysis results.

Conclusion

A feasibility study conducted to assess the possibility of recycling precious metals out of waste mobile phones' PCBs through a city based induction smelting plant for the city of Sydney. Twenty phones tested in this study varied in age, type, and manufacturer. The process used manual disassembly of printed circuit boards in consideration of the different composition ratios in different fractions. In this study, the PCBs cut into pieces up to 5 cm^2 and placed into the smelter with copper of a known purity. The melting temperature set to be 1200°C .The comparison between different mobile PCBs samples manufactured in different time periods presented an indication of the material content of different mobile's PCBs. From the analysis of the collected phones, the following conclusions can be drawn:

- Water and shockproof phones have a high rubber and plastic content. Smartphones have the lowest internal plastic and rubber content followed by sliders and QWERTY keyboard phones.
- Sliders and flip phones have the highest average miscellaneous metals content. QWERTY keyboard phones have higher glass/screen weight percentage than the average figure and external antenna phones have the lowest average of glass content.
- QWERTY keyboard and smartphones are the most desirable type of phone for precious metal recycling as the weight percentage of their circuit board is higher than other models.

The experimental results can be summarized as follows:

The level of gold, silver, iron, nickel and tin increased with adding more circuit boards to molten copper mixture. A thick slag formed on the surface of the copper mixture which made it difficult to continue to add more circuit boards. This is an area for future study.

The most prevalent element found in the circuit board of phones other than copper, is aluminum. The weight percentage of aluminum increased with adding more circuit boards to the molten copper then decreased which could be due to the oxidization of the aluminum at the later stages of the smelting.

The absence of arsenic and phosphorus from the samples close to the atmospheric pressure could be explained by vaporizing them in a furnace operating at 1200°C. Palladium and platinum on the other hand have higher vaporizing temperatures which indicated that the absence of these materials was not due to vaporization but trapping into the slag.

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