Abstract

The electronics manufacturing industry has been experiencing a fast-changing landscape with recent legislations targeting the supply chains for the 3TG minerals: tin, tantalum, tungsten, and gold mined from the Democratic Republic of Congo. These minerals exhibit unique properties that are crucial to their role in the manufacturing process and functionality of many electronic products such as computers, cell phones, and printers. This work focuses on using a bottom up model to quantify conflict mineral content within LaserJet printers and uses a market analysis to compare the conflict mineral composition between various IT products in order to obtain a measurement of impact the conflict minerals have in their respective IT product. On the global scale, the model estimates the market share of tin, tungsten, tantalum, and gold in printers to be 1.44%, 0.083%, 0.017%, and 16.5%, respectively. These results indicate a strong potential and improvement for the development of redefined materials selection processes for manufacturers of IT products in using alternative solutions or substitute materials. Current work in this field shows that it is imperative for future work to focus on decreasing the market share of these conflict minerals and shifting manufacturing focus to developing new conflict-free electronic products.
Table of Contents

Abstract .................................................................................................................................................. 2
Table of Contents .............................................................................................................................. 3
List of Figures ..................................................................................................................................... 4
Acknowledgements .......................................................................................................................... 5
1. Introduction ................................................................................................................................... 6
   1.1 Growing pressures on an evolving electronics industry ......................................................... 6
   1.2 Present legislation .................................................................................................................... 7
   1.3 What are conflict minerals? ..................................................................................................... 8
2. Materials overview: Tantalum, Tin, Tungsten, and Gold .............................................................. 10
   2.1 Tantalum ...............................................................................................................................................
   2.2 Tin ............................................................................................................................................................
   2.3 Tungsten ................................................................................................................................................
   2.4 Gold ........................................................................................................................................................
   2.5 Materials use in the IT industry ...................................................................................................... 12
3. Methodology: the "bottom up" approach model ................................................................................. 13
   3.1 Tin ............................................................................................................................................................
   3.2 Tungsten ................................................................................................................................................
   3.3 Tantalum ...............................................................................................................................................
   3.4 Gold ........................................................................................................................................................
   3.5 Printer Market Analysis and Comparison ................................................................................. 16
4. Results ................................................................................................................................................ 18
5. Discussion .......................................................................................................................................... 24
   5.1 Substitutions Analysis ................................................................................................................... 25
       5.1.1 Tin ....................................................................................................................................................
       5.1.2 Tantalum ......................................................................................................................................
       5.1.3 Tungsten .....................................................................................................................................
       5.1.4 Gold ..........................................................................................................................................
6. Conclusion .......................................................................................................................................... 30
7. Future Work ......................................................................................................................................... 32
References ............................................................................................................................................ 33
List of Figures

Figure 1. Estimated average amount of time, tantalum, tungsten, and gold per printer...18
Figure 2. Estimated amount of minerals in various electronic products from previous work.................................................................20
Figure 3. Global LaserJet printer market scaling and consumption analysis.................................21
Figure 4. Scaled global amounts and market shares by amounts per product compared with previous work.........................................................22
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1. Introduction

1.1 Growing pressures on an evolving electronics industry

The global electronics industry is one of the fastest growing industries in today's market. Large multinational consumer electronic companies have emerged giving to more dynamic outsourcing relationships. While growing electronic companies try to stay ahead of the competition with new insight into innovation across the value chain, they will also need to cope with the increasing regulatory needs for their materials\[1\]. To meet the demands of a rapidly changing market, electronic companies will need a holistic view of how change in their industry, as well as in their value-chain, impacts their business. Manufacturers will need to increase flexibility and adaptability to quickly accommodate changing markets and move into new ones, or leave less profitable ones.

Recently, the electronics supply chain has been a fast-changing landscape as a result of the initiatives and actions taking place to address the consumption of conflict minerals. In general, chemical and manufacturing industries have been subject to strict resource use issues. Between materials criticality and sustainability, conflict minerals, materials cost, and legislations, manufacturers and consumers around the world are required to know what materials are in our products and what are the risks associated with using those materials. Some companies such as HP and Intel have developed strategies and alternative solutions in order to address the legislative pressure around materials selection and supply chain transparency.
1.2 Present legislation

In the chemical industry, a variety of legislations with widespread impact have been implemented to help regulate the consumption and use of certain materials. In particular, a landmark piece of legislation known as Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH) limits the use of toxic substances in the manufacturing stage of a product\[2\]. Other notable initiatives are the Toxic Control Act 1976 and the California Green Chemistry Initiative\[3\]. As a result of these regulations, chemical companies must now concern themselves with which chemicals and substances that both their suppliers and consumers use and emit when using their products. As a result, regulations such as REACH have driven raw material transparency requirements to a higher level of regulatory attention in the market. It is believed that over time, as companies become equilibrated with REACH standards, a safer environment will be fairly easy to maintain\[3\].

Therefore, this belief has been carried through other industries such as the electronics industry as seen in the Restriction or Use of Hazardous Substances Directive in Electrical and Electronic Equipment (RoHS) and the Waste Electrical and Electronic Equipment Directive (WEEE)\[4, 5\]. Setting recycling and recovery targets for companies and their electrical products are emphasized by WEEE and are aimed to address the problem of large amounts of toxic e-waste. In these legislative initiatives, manufacturers, importers, and distributors are forced to understand the requirements placed on them in order to ensure compliance.
1.3 What are conflict minerals?

Conflict minerals, in the scope of this thesis, describe elements originating from the Democratic Republic of Congo (DRC) that are processed into common electronic components such as tin, tantalum, tungsten, and gold. In many cases, the global consumption and processing of these materials are linked with financing civil conflict in the DRC region. This connection was noted in 2001 when the United Nations began to link the exploitation and use of conflict minerals in global consumer electronic products such as laptops, cell phones, televisions, and printers\[6\]. Since then, laws and provisions have been passed to require U.S. Securities and Exchange Commission reporting companies to disclose their use of conflict minerals\[7\].

In the DRC, armed militias and the Congolese army are waging a decade-long war fueled largely by the trade in minerals that are used in cell phones, laptops, televisions, and other electronic products. As one of the deadliest conflicts since World War II, the violence in DRC becomes an accountability issue for all of us as electronic products suppliers and consumers. Revenues from mining these minerals, along with corruption and government tensions, add to the widespread severity of military violence and abused labor rights\[8,9\]. A number of the everyday electronic products people use contains valuable minerals that ultimately pay for the military weapons for the DRC militia. Thus, this leads to both a supplier and consumer obligation to follow up and ensure that company purchases and supply chain are not perpetuating the conflict. Recently, the U.S. Congress passed legislation as part of the Dodd-Frank Wall Street Reform and Consumer Protection Act, which requires U.S. companies who are involved in the DRC minerals
trade to publicly declare the actions they are taking to ensure their business does not support the armed militias who profit from the DRC's instability\[^{10}\].

Notably, the Wall Street Reform and Consumer Protection Act which became effective on July 21, 2010 discourages the use of conflict minerals from the covered region including gold, tantalum, tungsten, and tin. These metals were produced from the mines in the Eastern region of the DRC and surrounding countries, which are controlled by non-government military groups, or unlawful military factions. Local DRC military groups profit from the illegal mining of these materials and lead to human rights abuses, environmental travesties, and theft from the country's citizens\[^{11}\].

Materials selection and declaration is becoming a critical step in the supply chain of companies in the electronics product industry. The DRC region has material industries for tin, tantalum, tungsten, and gold, which have a large economic and social effect in DRC. Literature, previous, and current work about materials substitution for these minerals have shown great potential for alleviating the conflict in DRC, but is first dependent on knowing the current state of the consumption of these minerals in certain electronic products via a bottom-up approach. If conflict minerals are able to be quantified in today's electronic products, companies will be able to identify their current conflict minerals usage levels and being to think about alternative solutions to these minerals. By modeling and quantifying conflict minerals in printers, this analysis adds to the current work and allows for the investigation of how IT companies can find substitute solutions for material selection in their supply chain.
2. Materials overview: Tantalum, Tin, Tungsten, and Gold

This section provides background information for the four covered materials as discussed in order to understand the key properties of each element and how their properties play a role in today's electronic products.

2.1 Tantalum

Tantalum is a refractory metal that has a high melting point with shape memory properties, and is highly resistant to corrosion by acids. It is a good conductor of heat and electricity, which provides as great properties to apply in capacitors. Tantalum oxide films on the surface of a metal permit current to flow unidirectional path. To extract tantalum, the primary mineral tantalite is needed. Leading tantalum producers are Rwanda and the DRC. In the scope of this thesis, the primary uses of tantalum are capacitors and wires[12].

2.2 Tin

Tin is a non-magnetic metal that is relatively resistant to corrosion, malleable, ductile, and durable. Tin requires fairly low maintenance, which leads tin to be the preferred material for alloying and coating other metals through a soldering process. When looking at practical applications, tin content in solders can range between 5% and 98% by weight, which correlates proportionally to the solder (tensile and sheer) strength. The primary mineral source for tin is cassiterite, produced mainly by China and Indonesia[13]. Tin soldering can lead to different alloying properties in any given
electronic product and thus limits the options for possible tin substitutions in soldering processes.

2.3 Tungsten

With a high melting point, the lowest expansion coefficient for metals, high hardness to carbon ratio, tungsten dominates the performance factor for what is needed in high temperature applications. Scheelite and wolframite are the main minerals extracted to obtain tungsten. Of the world’s tungsten reserves, over 90% are outside the US. Of these resources, nearly half are found in China (the world’s largest tungsten consumer). Western world supply of tungsten is very limited and a large amount of tungsten is recovered through recycling scrap tungsten products, particularly in the U.S.\textsuperscript{14}.

Due to its high melting point and low vapor pressure, tungsten is used in high temperature contexts such as light bulb filaments and other electronic applications and products as well. Although the primary use for tungsten is in hard metals for industrial drilling and cutting, its secondary use for tungsten is in electronics. Tungsten is ideal for critical temperature resistant electrical components due to the wear and temperature resistant properties and electrical conductivity. Tungsten’s unique properties limit possible options for substitution elements as discussed in Section 5.1.3.

2.4 Gold

As a relatively chemically stable metal when in contact with air and moisture, gold makes a good protective coating on other more reactive metals. Sheets of gold are good
for infrared shields since gold is a good thermal and electrical conductor while reflecting infrared radiation as well. Electronic applications represent a significant amount of the United States’ annual gold consumption. However, the market for gold is dominated by the top 10 gold producing countries that produce over 60% of the global production for gold. However, no single country dominates global production. Currently, China leads production and consumption\textsuperscript{[15,16]}.

2.5 Materials use in the IT industry

Industrial electronic materials include those of steel metals used in consumer electronic equipment as well as other types of consumer products. Uniqueness of materials used is necessary for desired functionality and performance levels\textsuperscript{[17]}.

In most electronics, the main components are integrated circuit chips, conductive materials, packaging materials, insulation materials, ceramics, optics, and semiconductors. Different types and amounts of each component are used depending on the electronic product. For example, a LaserJet printer and a tablet might not use the same amount of capacitors as printers are generally much larger and serve a different function. The types of categories for electronic products vary widely since different products can serve very different purposes and functions, even though they may use the same material in its manufacturing process. Therefore, analyses through various different electronic products is necessary to accurately understand and quantify the amount of conflict minerals used in each category of product.
3. Methodology: the “bottom up” approach model

In order to understand the impact of conflict materials in today’s electronic products, the work of this thesis focuses on quantifying the amount of conflict minerals (tin, tantalum, tungsten, and gold) in printers that will add to current work.

Each material underwent a thorough analysis to determine upper bound estimates as accurately as possible. Based on the recent work\cite{18}, a bottom up approach was adopted to estimate the amount of mineral per printer. Tear down reports were obtained. A qualitative estimate of the accuracy of this quantification was based on comparison with other products in the electronics industry of similar size and functionality. The tear down data contained detailed information of all the electronic components for 60 printers, including the quantity of each component within the product. The relevant data was used to quantity minerals involved capacitors, resistors, and integrated circuits for all 60 printers and then averaged to obtain final results.

3.1 Tin

Since tin is mainly used in solder as both an electrical and chemical connector between printed circuit boards and various components, the average amount of solder paste was calculated per printer in which tin content was a certain percentage (89% - conflict paper) of the solder paste. Previous work has incorporated the use of surface mounted technology in solder, flux, and other agents that are applied to the printed circuit board via a stencil. Upon solidification, the pattern solder paste forms a strong bond between the circuit board and the different components.
Mathematically, it was necessary to calculate the amount of solder paste used per component in order to calculate the amount of tin in the product. This was depend on the determined the landing surface area and multiplying by the thickness of the stencil used in surface mounted components (0.16mm used in conflict minerals paper as a high estimate). The model used in previous work is:\[^{18}\]:

$$Tin \ (g) = \sum_{n=1}^{Q} A_n \cdot T_n \cdot \rho_{Sn} \cdot C_n$$  \hspace{1cm} Eqn. 1$$

Where $A$ is the area of the component land pattern, $T$ is the stencil thickness, $\rho_{Sn}$ is the density of tin, and $C$ is the percent tin content of the solder paste. This calculation was repeated for all relevant components for each printer. From there, the average amount of tin per general printer was calculated and graphed.

### 3.2 Tungsten

Although tungsten has two primary uses in electronic products (vibration motors an integrated circuits), it was not apparent that printers contain vibration motors in their teardown reports. Therefore, only the data for integrated circuits of tungsten was used to estimate the quantity of tungsten. The size of the integrated circuit die area and thickness of tungsten layer were determined and multiplied by the number of connecting metal layers, which was assumed to be 8 layers as the upper bound estimated. Other assumptions used in the conflict paper was that the die to package relationship is 0.8:1 and a safety factor of 3 would be used to account for the die yield during the chemical vapor deposition process of its manufacturing. The model used is below:
\[ Tungsten (g) = \sum_{n=1}^{x} (A_n \times 0.8) \times T \times L \times \rho_w \times 3 \quad \text{Eqn. 2} \]

where \( A \) is the IC package area, \( T \) is the layer thickness, \( L \) is the number of layers, and \( \rho_w \) is the density of tungsten. This calculation was repeated for all relevant components for each printer. From there, the average amount of tungsten per general printer was calculated and graphed.

### 3.3 Tantalum

Mainly used in the production of capacitors as a dielectric voltage layer for the capacitor, tantalum was quantified using the volumetric efficiency\[^{18}\] of the capacitor as a measure of its capacitance and voltage. Additionally, a tantalum wire is used as an electrical contact to the lead frame. However, this was not accounted for in this calculation as it did not appear in the teardown report, thus the calculated tantalum amount is a lower estimate.

\[ Tantalum (g) = \sum_{n=1}^{Q} \frac{C_n \times V_n}{\mu F V / g_n} \quad \text{Eqn. 3} \]

where \( Q \) is the total number of tantalum capacitors, \( C \) is the capacitance, \( V \) is the voltage rating and \( \mu F V / g \) is the volumetric efficiency of the tantalum powder used. This calculation was repeated for all capacitor components in each printer.

Another component found to contain tantalum were tantalum films in the integrated circuits with a thickness \( T \) of 65nm. This was accounted for in the estimated tin calculation using the model:
\[ Tantalum (g) = \sum_{n=1}^{k} (A_n \times 0.8) \times T \times L \times \rho_w \times p_{Ta} \quad Eqn. 4 \]

Where \( A \) is the IC package area, \( T \) is the layer thickness, \( L \) is the number of layers, and \( \rho_{Ta} \) is the density of tantalum, and \( p_{Ta} \) is the percent tantalum content by volume. From there, the average amount of tantalum per general printer was calculated and graphed.

### 3.4 Gold

Gold is most commonly used in electronic products as connectors and contacts for ports in circuit boards, semiconductors, and other electronic components. Therefore, estimates for gold quantities were based on the number of gold plated connectors obtained from the teardown reports. As indicated in the conflict minerals paper, the gold coating thickness was assumed to be an upper end value of 0.76 \( \mu m \). The assumed method is as follows:

\[ Gold = \sum_{n=1}^{Q} A_n \times T_n \times \rho_{Au} \times N_n \quad Eqn. 5 \]

Where \( A \) is the area of the contacts, \( T \) is the thickness of the contacts, \( \rho_{Au} \) is the density of gold, and \( N \) is the number of contacts per connector.

### 3.5 Printer Market Analysis and Comparison

After the amount of each mineral was quantified in each printer, a market analysis was conducted for printers to determine their role in the electronics industry and to identify any leverage the electronics industry could have on the supply chain for its
minerals. The market share comparison was compared between each product using the results of previous literary work[18].
4. Results

The amount of tin, tantalum, tungsten, and gold determined for the data set of printers is shown in Figure 1. It is important to note that the assumptions made, overall, created an underestimate total amount due to the consideration of select components and estimations that had to be made when data was not explicit in the teardown reports. More detail on this underestimate will be provided below.

Figure 1. Estimated average amount of tin, tantalum, tungsten, and gold per printer.

In Figure 1, the data shows that printers contain an average of 40.8 g of tin per printer. Since the printers that were analyzed were mostly for office use according to their printer IDs, it is not surprising that there are numerous circuit boards in printers with components that would require a large amount of solder. The tin value is also an underestimate as not every single component was accounted for. The analysis neglected
switches, oscillators and other relatively smaller components because the tin content in their solder area was very small. Therefore, only the main components were analyzed: resistors, transistors, capacitors, ICs, ports, and contacts. There was a very small trace of tantalum in the printers when calculating for tantalum films using the die size area of the integrated circuits. Additionally, tantalum capacitors are most common in mobile phones and electronic hand-held devices, particularly as a component in vibration motors, which printers do not usually have. As more initiatives are being taken to break away from the use tantalum capacitors, it may not be surprising if printer production has achieved a zero consumption value for tantalum. The tungsten amount is relatively high when compared to that of other products as seen in Figure 2, which describes the amount of tin, tantalum, tungsten, and gold in other electronic products. When we compare gold amounts in Figure 1 with Figure 2, the amount of gold in printers is much higher than that of the other products. This result can be seen as parallel with tin because since there is a higher surface area of circuit boards, there are most likely more ports and connectors connecting various component that require gold coatings.

The estimated amounts in Figure 2 of each material vary as expected depending on the product based on the previous work. The amount of tantalum is cell phones is very low compared to that of other products, which can be due to the decreasing use of tantalum capacitors in the industry and the limited used of tantalum capacitors in printers (which are mainly used for vibration motors in cell phones). Tungsten is high in cell phones relative to the other products since cell phones tend to become hot when in use for long periods of time. Tin levels are similar for the larger IT products analyzed.
Gold levels are highest in printers as it may be that printers have more components with ports and connectors than any of the products analyzed.

![Graph showing the amount of minerals in various electronic products from previous work](image)

**Figure 2.** Estimated amount of minerals in various electronic products from previous work\(^{18}\)

The scaling of the LaserJet printers in Figure 3 shows the market breakdown for the conflict minerals in printers. A noticeably high market share for printers is the consumption of gold in at 16.5% of the total production in 2012 measured by global shipment. The total global shipments (31.7 million shipped units) of LaserJet printers in 2013 was roughly estimated using the 2013 fourth quarter statistic and converting that
to an annual shipment statistic my multiplying by 4 totaling 126.8 million global shipped LaserJet printers\[19\].

![Table showing LaserJet printer market scaling and consumption analysis](image)

**Figure 3. Global LaserJet printer market scaling and consumption analysis**

In comparison to the other products in Figure 4, the LaserJet printer market ranks lower than the laptop, desktop, display, and smart phone markets, and approximately the same as cell tablets. Recent predictions expect a strong surge in the LaserJet printer market due to the increase in office buildings with new startups and companies. By looking at Figure 3 and Figure 4, the portion of conflict minerals in printers can be compared with those in other products. It is observed that the printers have the highest mineral total of gold and the lowest for tantalum, with tungsten close behind.

This does not seem too surprising as there are many ports and connectors on components within large-scale office printers that might be a large reason for high prices of these types of printers. Further support may be required to conclude that there is a small trace of tantalum in the analyzed printers.
Previous work and literary research has analyzed different electronic products and the estimated respective global market shares and breakdowns for each conflict mineral consumed in the world as seen in Figure 4.

<table>
<thead>
<tr>
<th></th>
<th>Average 2011/2012</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Global shipments (millions)</td>
</tr>
<tr>
<td>Laptop</td>
<td>203</td>
</tr>
<tr>
<td>Desktop</td>
<td>148.3</td>
</tr>
<tr>
<td>Server</td>
<td>7.413</td>
</tr>
<tr>
<td>Display</td>
<td>180</td>
</tr>
<tr>
<td>Smart Phone</td>
<td>722.4</td>
</tr>
<tr>
<td>Tablet</td>
<td>128</td>
</tr>
<tr>
<td>Laserjet Printer</td>
<td>126.8</td>
</tr>
<tr>
<td><strong>Total mass (tons)</strong></td>
<td><strong>8,753</strong></td>
</tr>
<tr>
<td><strong>Total market (tons)</strong></td>
<td><strong>359500</strong></td>
</tr>
<tr>
<td><strong>Percent of market (2012)</strong></td>
<td><strong>2.4%</strong></td>
</tr>
</tbody>
</table>

*Figure 4. Scaled global amounts and market shares by amounts per product compared with previous work*

The results from Figure 4 present challenging estimates to the manufacturing waste of these products and how much of the mineral used is scraped. Capacitor manufacturing leads to unknown waste levels depending on the manufacturer's efficiency. For gold, the waste level assumption is low because the cost of gold is very high. Additionally, recycling levels for these minerals is variable as it is difficult to know how much of the market is recycled mineral and how much is mined mineral. Since the
bottom up approach is an as-used model, an analysis of material waste and recycling would lead a different work stream and provides an avenue for further complementary work to be done.
5. Discussion

The bottom up approach model was implemented and verified in estimating the amount of tin, tantalum, tungsten, and gold in various models of HP printers. A few limitations of the bottom-up approach model is that for the scope of this thesis, a number of smaller components were not accounted for and thus provides a larger possibility that the mineral quantities obtained are underestimates. Additionally, several assumptions were made in the calculation of quantity such as fixed density of solder and thickness layers, which were assumed at the higher end of the range. Since this analysis only covers HP LaserJet printers and adds to the previous work\cite{18}, the global shipment market analysis for LaserJet printers was determined using an estimated total shipment of Laserjets in 2012 and dividing by the average price of an office printer to obtain a quantity value. It's important to note that for the purposes of comparison, the global shipment data for products in Figure 2 were taken from 2011 and 2012 statistics while the global shipment data for printers was taken from 2013 data. The estimated global shipments number could lead to inaccurate market share estimations, particularly since the materials industry is relatively flexible and changes in materials supply happen often from year to year.

As the LaserJet printers industry grows at 9.7% per year\cite{20} the diminishing use of conflict minerals will hopefully be seen. From a manufacturing standpoint, it is possible for manufacturers to source electronic 3TA materials from conflict-free regions. Recently, there has been a major concern for product performance if substitute materials are used and consumer demand will be dramatically affected.
5.1 Substitutions Analysis

Possible substitutions in the use of conflict minerals lead to limited applications, economic penalties, and compromised material properties.

5.1.1 Tin

The electronics industry has been attempting to slowly abandon one of its long-time materials, lead-tin solder. Lead-tin solder has been used to attach electronic components to printed writing boards. However, serious adverse health effects of lead have led to the search for replacement using solders made of alternative alloys and polymer formulations known as electrically conductive adhesives. As a result of RoHS, there has been a greater emphasis for the industry to omit the use of lead in electronics manufacturing. Although lead is not a problem when contained in electronic equipment, it becomes a problem when electronic components are disposed of in landfills leading to lead leakages into sources of drinking water. This risk becomes compounded in countries that receive massive imports of electronic waste, such as China\textsuperscript{21}.

The International Electronics Manufacturing Initiative\textsuperscript{22} (iNEMI) has selected a tin-silver-copper alloy as a replacement alternative for lead-tin solder due to its performance reliability and ease to work with as a replacement. This alloy, know was SAC solder (Sn, Ag, Cu) is very close to lead-tin’s melting point, though still slightly higher which may pose a manufacturing problem in the electronics industry because higher temperatures mean more stress on components and an increase in the manufacturing time required to head and cool the products during the course of their production. Another slight problem that has arisen is that anytime there is a change in materials,
there is a learning curve in using the new materials to diminish manufacturing defects
and product performance. Overall, whereas lead uses might pose a greater public health
concern than SAC solder, the latter uses more energy through its manufacturing lifetime
than when using lead-tin solder. Nevertheless, SAC solder is used commonly today in
many electronic products and their components.

Another alternative to lead-tin solder is the use of ECAs (electrically conductive
adhesives)—polymers such as silicone and polyamide, containing tiny flakes of metal such
as silver. In electronics, these polymers adhere to the printed circuit boards while the
metal flakes conduct electricity. Some advantages to this alternative include high
electrical conductivity due to the presences of silver and low electrical resistance. From a
manufacturing standpoint, ECAs require lower application, melting temperature leading
to quicker manufacturing duration times. Currently, ECAS are available for low power
applications such as LCDs, but are not fully prepared for the marketplace overall, where
greater amounts of current are needed\textsuperscript{[21]}.

5.1.2 Tantalum

Tantalum is commonly used in the production of tantalum capacitors. With a
potential shortage and inevitable price increase in the tantalum market, tantalum
capacitors have received major attention for replacement for substitution. Substitutes
such as aluminum, rhenium, titanium, tungsten, and zirconium, exist for tantalum, but are
usually made at either a performance or economic penalty. The price for tantalum
products is mostly affected by events in the supply and demand for tantalite, as well as
the manufacturing scale and material specification.
Compared to their use throughout the rest of the world, tantalum capacitors have a strong presence in the North American market. Aluminum Capacitors provide abundance and boasted ESR values when it is used as a solid electrolyte polymer. The polymer aluminum capacitors offer 10,000 times better conductivity than the electrolyte found in wet aluminum technology, and 1,000 times more than MnO2 used in tantalum technology. Polymer Aluminum Capacitors also offer stable capacitance against frequency and temperature changes. A Surface Mount Aluminum Electrolytic Capacitor and SP-Caps are available as tantalum replacement options featuring low ESR values, excellent performance, and low cost[11].

5.1.3 Tungsten

Of the world's tungsten reserves, over 90% are outside the US. Of these resources, nearly half are found in China. China is also the world's largest tungsten consumer. A large amount of tungsten is recovered through recycling scrap tungsten products. In the US, recycled tungsten accounts for about 33% of the tungsten consumed. When mixed with carbon, tungsten makes a very strong, resistant material known as tungsten carbide. Due to its high melting point and low vapor pressure, tungsten is used in high temperature contexts such as light bulb filaments and other electronic applications/products as well. Currently, tungsten is the only material for light bulb filaments[23,26].

Tungsten consumption/demand around the world is continuing to increase, and when combined with increased controls by the Chinese government on their domestic tungsten industry, the price of tungsten increase leading to forecasted international
supply shortages of primary tungsten. China has also reduced tungsten exports to the rest of the world. The European Union has categorized tungsten as a “critical raw material” due to concerns over the security of the supply of tungsten. As a result, companies with valuable tungsten resources hold a strategic international position. Potential substitutes for cemented tungsten carbides are cemented carbides with molybdenum, and titanium. In some applications, substitution would result in increased cost of a loss in product performance. At the moment, there is no real satisfactory substitute for key electronic applications\[25\].

5.1.4 Gold

Because gold is chemically stable and conducts electricity so well, it is very important in electronics. Electronic applications represent a significant amount of the United States’ annual gold consumption. Alloys of gold are commonly used in electronics to reduce the amount of gold used while maintaining the positive features of gold. Recycling gold from used electronics will provide only a very small amount of gold; though some do find this venture profitable depending on how much gold is recycled in a certain product and how good one is at recycling gold\[23\].

One low cost alternative to gold in electronics applications is Silver MaxPhase. This newly developed silver metal alloy (patent pending) uses a physical vapor deposition process to coat components. It performs better than gold as an electrical conductor and exhibits comparable wear and corrosion resistance at the fraction of gold’s cost. From a large-scare standpoint, this alternative would lead to sizeable savings and a cost advantage for electrical components such as connectors and contacts. Using Silver
MaxPhase also causes the price of a resource to be more predictable over time in comparison to the constantly fluctuating price of gold of which the electronics manufacturing industry suffers from. Additionally, electrical component suppliers find it difficult to get licenses for gold plating lines because licensing authorities, particularly in China, are not showing interest in approving new licenses due to the potential environmental and health hazards of gold plating. Currently, qualification is underway for computers, industrial, telecom, and other electrical product groups[27].
6. Conclusion

There continues to be high growth in the consumer electronics industry. Many companies, such as Samsung\textsuperscript{[28]} and Intel\textsuperscript{[11]} have taken action in diminishing and preventing the use of conflict minerals in their manufacturing processes and supply chain. In some instances, certain companies are asking their suppliers to provide written documentation stating the materials supplied do not contain conflict minerals originating from the DRC conflict regions or, if the materials do originate within conflict regions, that the relevant mines have been certified as conflict free. Additionally, some materials suppliers may not have up-to-date knowledge of their supply chains that would require them to understand where their materials are coming from. Therefore, it can be expected that this refining process may take a bit of time as mining and smelting activities are multiple steps removed from the manufacture of market ready products\textsuperscript{[22]}.

It is important to note that although consumers are purchasing the electronic products, it is more so the IT company's responsibility to control the regulation of conflict minerals. Company or government regulations should be the players to steer the supply chain of these conflict minerals and move towards substitute materials and solutions. It is possible for consumer electronic products to be conflict minerals free.

On the other hand, it must not go unnoticed that there can be large economic effect for a large scale manufacturer to adopt new principles and manufacturing policies to meet compliance regulations\textsuperscript{[29]}. It can sometimes be very difficult for large These conditions must be properly and strategically to both reduce the transition impact for
manufacturers as well as reduce damage to people and the environment in third world countries such as the DRC. For example, as more manufacturers transition into using lead-free solders, electronic components and produces have provided immediate health benefits to electronics industry workers and factory operations, as well as a decrease in toxic e-waste around the world.

Regardless, the underlying problems within the unstable regions of the DRC will not have been fully resolved. The cause and effect of mining conflicted minerals in the DRC will need to be resolved with stronger intervention to order to ultimate support and sustain and safe environment in developing regions with conflict minerals.
7. Future Work

More research can be done on quantifying newer IT products that have just been released into the market for consumer demand, such as new cell phones, tablets, laptops, etc.. Analyses on newer and current electronic products will reveal which companies have taken action to support the conflict free IT products. It will also show which products are most in need to find alternative solutions to using conflict minerals and which products have progressed the most in redefining their materials selection process in the supply chain.

Additionally, more accurate estimations can be determined in order to validate global shipment numbers and support the calculated market shares for each conflict mineral. It is important to note that market shares can vary widely in the materials market due to mines and smelters opening and closing as well as fast-changing government legislation targeted towards toward IT companies.
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