A UL White Paper

The Life Cycle of Materials in Mobile Phones

How New Phone Technology Affects the Environment

In just 30 years, mobile telephony has grown into a major global industry, with an estimated 5 billion users around the world (compared with a total world population of just under 7 billion people). While new subscriber growth has slowed somewhat in recent years, product turnover remains high, with over 1 billion new mobile phones shipped in 2009 alone. As a result of ever-advancing technology and product obsolescence in this market, it is estimated that some 300,000 mobile phones are sent to the trash every day in the United States alone.

This white paper examines the overall environmental impact of materials used in mobile phones, from the extraction of raw materials and component manufacturing required to produce the latest models, to the appropriate recovery and recycling of these products at end-of-life (EoL). While the scope of this paper is limited to mobile phones, similar materials are used in many other high technology products, including personal computers, portable entertainment players, and other types of information and communications devices. Energy consumption and radio frequency emissions at the product level are outside the scope of this paper.

Regulated Substances and Waste Legislation

The European Commission (EC) is among the most active and aggressive regulators seeking to address the environmental impact of electrical and electronic equipment. Increasing concerns regarding the toxicity of several heavy metals and flame retardants used in electronic equipment led to the Commission's directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment (2002/95/EC, also known as the RoHS Directive), which came into force in European Union (EU) member states in July 2006.

The EU's RoHS Directive regulates specific hazardous substances, with concentrations limited in parts per million (ppm) by the weight of each homogeneous material that can be mechanically separated, as follows:

- Cadmium (Cd) — 0.01% (100 ppm)
- Lead (Pb) — 0.1% (1000 ppm)
- Mercury (Hg) — 0.1% (1000 ppm)
- Hexavalent chromium (Cr(VI)) — 0.1% (1000 ppm)
- Polybrominated diphenyls (PBB) — 0.1% (1000 ppm)
- Polybrominated diphenyl ethers (PBDE) — 0.1% (1000 ppm)

At present, the RoHS Directive affects mobile phones as well as other consumer products. The Directive also includes several dozen exemptions that allow the use of otherwise restricted hazardous materials in certain specified applications.

The impact of the EU's RoHS Directive on the worldwide electronics industry has been significant. At the tactical level, the regulation has required development of new solders and new soldering process for manufacturing printed wiring board (PWB) assemblies, the selection of alternate materials for solder terminations of components, the qualification of alternate types of flame retardants, and the need to identify replacements for other banned substances. At the strategic level, the implementation of the requirements of the RoHS Directive has required manufacturers to establish new supply chain management procedures, and to develop expertise in specifying and documenting the materials used in electronics hardware.

Further, most consumer product manufacturers have opted not to run separate manufacturing processes for RoHS-compliant and non-compliant products. Instead, they have modified all of their production to comply with RoHS requirements, thereby ensuring that even products shipped to non-EU regions contribute to the worldwide reduction in the use of hazardous materials.

Other nations, including China and South Korea, have followed the EU's lead with similar, but not identical, regulations. In the United States, California has led the way toward increased regulation of hazardous substances in electronic products with the passage of Proposition 65 that imposes strict labeling requirements on products containing any one of hundreds of potentially hazardous materials. All the while, the EU has not stood still, with additional regulations limiting the use of so-called substances of very high concern (SVHC) under its directive on the registration, evaluation, authorization and restriction of chemicals (also known as the REACH Directive), which entered into force in June 2007.

In addition to regulations regarding the use of certain hazardous substances, the EU has also implemented requirements intended to limit the unsafe handling of electronic waste, including improper disposal, "landfilling" and unregulated incineration. The EU's directive covering electrical and electronic equipment waste (2002/96/EC, also known as the WEEE Directive) was enacted in July 2006. The WEEE Directive establishes targets for collection of EoL products and for material recovery and recycling, and limits the quantity of plastics and other materials that can be incinerated for energy recovery. Beyond the EU, some 23 states in the United States presently have some form of proposed or enacted legislation requiring the collection, recovery and recycling of various electronics products.

But, while the above regulations are intended to reduce the overall use of hazardous materials and to divert those actually used from improper waste disposal, it is not clear whether the requirements are based on a holistic assessment of the positive and negative aspects of materials used in electronics.

This white paper examines the various materials commonly found in mobile phones from a lifecycle perspective, including the extraction of raw materials, manufacturing of components, final handset assembly, product in use, and recovery and recycling of component materials at the product's EoL. The paper also identifies and evaluates alternative materials available to designers, service providers, retailers, users and other stakeholders.

Metals Overview

From a high-level perspective, mobile phones are generally comprised of approximately 40% metals and 40% plastics by weight, with the remainder made up of glass and/or ceramic and other miscellaneous materials. The major metals content of mobile phones has been analyzed since the initial growth of the industry, and updates continue to become available. Data from earlier generation phones (pre-1997) is shown in Table 1.

TABLE 1: METALS CONTENT OF EARLY MOBILE PHONES (ECTEL 1997)

Major Metals Content of Mobile Phones	
Copper (Cu)	49.0%
Zinc (Zn)	21.8%
Iron (Fe)	11.6%
Nickel (Ni)	6.5%
Aluminum (Al)	5.5%
Lead (Pb)	1.9%
Tin (Sn)	1.7%
Silver (Ag)	1.5%
Chromium (Cr)	0.5%
Gold (Au)	0.1%
Palladium (Pd)	trace

The conversion of mobile phone design and production to comply with RoHS-type requirements has noticeably reduced the content of lead in subsequent generations of products as well as the size, mass and use of structural metals. However, copper has remained the dominant mass of any metal in these devices.

In a more recent study, a variety of metals were identified according to their use within several main functional component categories (see Table 2). Although the percentage of composition was not published in this study, the list nonetheless provides useful guidance as an overall materials content menu by component type, which will be further discussed in the Metals Content of **Main Components section**.

Another recent report details the use of metals in mobile handsets by percentage and economic value. The data is shown in Table 3.

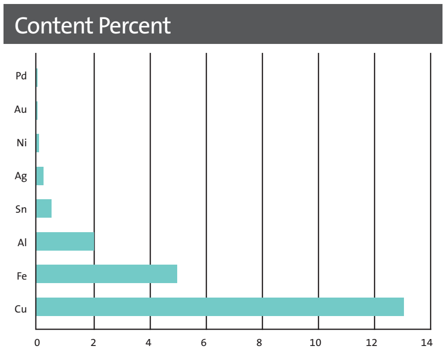
TABLE 2: MAIN ELEMENTS BY FUNCTIONAL COMPONENT (TAKAHASHI 2008)

Type of Part	Elements Detected
Circuit Board	Au, Ag, As Ba, Bi, Cr, Cu, Ga, Mn, Ni, Pb, Pd, Pt, Si, Sn, Ta, Ti, Zn, Zr
Flexible Substrate	Au, Ag, Cu, Pt
Liquid Crystal Display	Au, Ag, As, Ba, Ca, Cu, In, Ni, Sb, Si, Sn
Motor	Au, Ag, Cu, Pt
Camera	Au, Cu, Ni
Speaker/Microphone	Cu, Mn, Zn

A graphical analysis of this data is shown in Figure 1. From this analysis, one might conclude that mainly copper, iron and aluminum are top priority materials.

However, this approach provides neither a complete nor correctly weighted result. It is widely known, for example, that while precious metals, including gold, silver and palladium, constitute a small percentage of the device's total mass, precious metal recovery is a significant factor in life cycle management (Sullivan 2006). Thus, a more inclusive analysis of metal content is warranted.

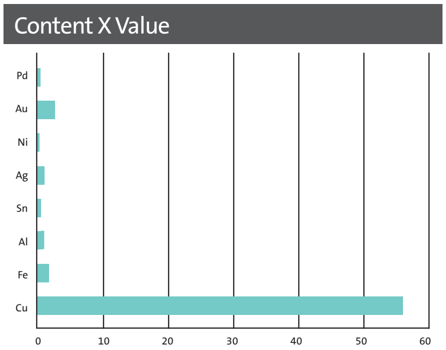
FIGURE 1: PHONE-LEVEL METAL CONTENT (PERCENTAGE) FROM TABLE 3



Metals Content with Value Weighting

In addition to percentage composition data, Table 3 also provides a value ratio for each metal. This factor can be used to weight each metal according to commercial considerations, a relevant factor from a metals recycling point of view. The products of the content percentages and value ratios are depicted in Figure 2. While copper remains dominant, ferrous and aluminum fractions are reduced in importance, and the weighting of gold predictably increases, since precious metals recovery dominates the EoL phase of mobile phones.

FIGURE 2: CONTENT (PERCENT) TIMES VALUE WEIGHTING OF PHONE-LEVEL METAL CONTENT



Another important life cycle consideration is the energy required to extract metals from their respective ores, which is illustrated in Figure 3. From an energy perspective, precious metals gold, silver and palladium exceed the impact of copper. In addition, the energy content of plastics is also significant. Although not prominent in Figure 3, glass has been noted in other sources as having a significant energy footprint, due to the high melt temperatures that are required during manufacturing.

Neither tin nor nickel are significant from a recovery value or energy perspective and will not be considered priority materials here. However, nickel must still be considered from an external, user contact perspective (see **External Surfaces** section).

Therefore, from a phone-level standpoint, major metals of interest are:

- Copper
- Gold
- Silver
- Palladium
- Ferrous metals, e.g., steels and stainless steels
- Aluminum

Metals in these products are considered a valuable resource, and the data clearly supports the need for recovery of EoL products and the recycling and reuse of these metals (Sullivan 2006). The unwanted end result would be for high volumes of such products ending up in a landfill, where some of the metals, including copper, nickel, antimony, lead and zinc could leach out (Lincoln 2007).

Metals Content of Main Components

Another useful way to approach material content is from a functional point of view, based on an analysis of the main components. One such breakdown is shown in Table 4, where the six priority metals that have already been identified from bulk product analysis have been highlighted.

Highlighted elements are those identified as priority metals in this paper.

Several observations can be drawn from this data, including the following points:

- Certain components contain metals not found to be significant at the handset level
- Other metals significant at the handset level may not appear in selected components.

Among the restricted substances identified in the EU's RoHS Directive, only lead and chromium were identified in this data. (Note: Some common exemptions apply to lead, e.g., in glass frit of chip components or machinable brass and aluminum. With regard to chromium, only its hexavalent form (Cr(VI)) is restricted, while chromium metal is allowed and may be found in stainless steels.

Clearly, non-metals are missing from the data based on chemical analysis. Notably absent are the light metal beryllium; the halogens, i.e., fluorine, chlorine, bromine, iodine, astatine; phosphorous; and all organic (carbon-based) compounds. Halogens may contribute to EoL concerns due to dioxin and furan formation when improperly incinerated. Beryllium in beryllia or copper beryllium alloys should be minimized from a dust inhalation perspective

Metals — Future Trends

In other studies, the dominant components in the life cycle of a mobile phone are PWBs, liquid crystal displays (LCDs) and integrated circuits (ICs). ICs are typically mounted on a PWB, so that a bare PWB, or substrate, which has not yet been populated with components or soldered as an assembly, is a subset of the PWB category that is often presented in the literature to mean the assembly of PWB plus soldered components.

The rest of the metals listed in Table 4 remain available for ongoing environmental study. It may be useful to comment here on where and why they might be used:

- *Antimony* (Sb): Antimony oxides are synergists for brominated flame retardants (BFR)
- *Arsenic* (As): Could be found in specialty glass of displays. GaAs is also used in semiconductors
- *Barium* (Ba): Ceramic capacitors are typically based on barium titanate

FIGURE 3: ENERGY CONSUMED IN RAW MATERIAL EXTRACTION (YU 2010)

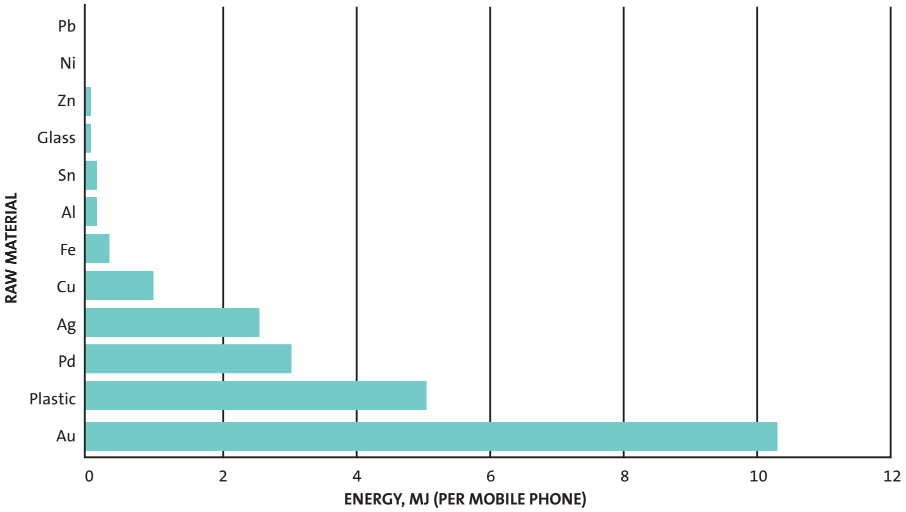


TABLE 3: METAL CONTENT AND VALUE RATIO AT PHONE LEVEL (YU 2010)

Element	Cu	Al	Fe	Ni	Pb	Sn	Ag	Au	Pd
Content (%)	13.0	2.0	5.0	0.1	0.3	0.5	0.1	0.0	0.0
Value Ratio (%)	4.3	0.3	0.2	0.1	0.0	0.6	3.9	78.9	11.8

- *Bismuth* (Bi): Its presence is not expected and is not listed in other comprehensive data for populated electronic PWBs (Legarth 1996, p. 35). Bismuth could possibly be a trace metal in Pb-based solder
- *Calcium* (Ca): Glasses are known to contain CaO (Legarth, 1996, p. 28)
- *Chromium* (Cr): Chromium seems anomalous on PWBs, but is known to be present in stainless steels, and in thin films for corrosion protection of steel, e.g., Cr(III)
- *Gallium* (Ga): High performance semiconductors may be based on GaAs
- *Indium* (In): Used in displays as an optically transparent conductor, indium tin oxide (ITO)
- *Manganese* (Mn): Manganese is not often found in electronics except as an internal layer in tantalum capacitors
- *Nickel* (Ni): Nickel is often used as an internal barrier layer to prevent intermetallic growth in component terminations, and is a constituent of stainless steels
- *Lead* (Pb): Banned under RoHS-type requirements. May be present in exempt applications, e.g., glass or ceramics
- *Platinum* (Pt): While platinum has been listed in some other reports (Legarth 1996, p. 35), its related noble metal, palladium, which is used in some termination systems, is found more often
- *Silicon* (Si): Silicon dioxide is the major constituent of glass, used in fibers woven in rigid PWBs, reinforcements for plastics, and lenses for displays. Silicon is also the major substrate in ICs and other semiconductors. Silicon is an abundant resource in sand, and it may be recovered in a glass fraction during recycling, but there are no known ways to recover any of the significant energy content of a functional semiconductor at the material level.
- *Tantalum* (Ta): Used in tantalum capacitors.
- *Tin* (Sn): Tin is common in component terminations and is the major metal in solders.
- *Titanium* (Ti): TiO2 is a white pigment, which may be attributed to markings on a PWB or component. Titanium could also be found on external surfaces in plastics, paints or markings. Titanium is also a major element in the alloy NiTi (nitinol), a shape memory material, which has been used for external antenna wires
- *Zinc* (Zn): Zinc is used in various brasses alloyed with copper
- *Zirconium* (Zr): Zirconium is not widely found in electronics, and its presence here is not explained

Metals — Energy Footprint

The energy footprint of major components parallels their materials impacts. Figure 5 shows that silicon and GaAs semiconductors contribute more to energy impact than the remaining electronic parts, followed by LCD and ceramic devices. In comparison, the contribution of final phone assembly is small.

Plastics

Two major classes of plastics, thermoplastics and thermosets, are relevant to mobile handsets and all types of electronic devices. The carbon backbone is not detected in routine metals analysis, so a bill of material or disassembly is required to obtain product-specific detail.

Common Thermoplastics

Since many major housing parts are being marked with ISO 11469 codes, e.g., >PC+ABS<, it is often possible to disassemble and inspect samples to identify their composition in cases

TABLE 4: COMPONENT-LEVEL METALS CONTENT (TAKAHASHI 2008)

[†] Elements are those identified as priority metals in this paper.

Metal	Au[†]	Ag[†]	As	Ba	Bi	Ca	Cr	Cu[†]	Ga	In	Mn	Ni	Pb	Pt	Si	Sb	Sn	Ta	Ti	Zn	Zr	Al[†]	Fe[†]	Pd[†]
PWB	•	•	•	•	•		•	•	•		•	•	•	•	•		•	•	•	•	•			
Flex	•	•						•						•										
LCD	•	•	•	•		•		•		•		•			•	•	•							
Camera	•							•				•												
Audio components								•			•									•				

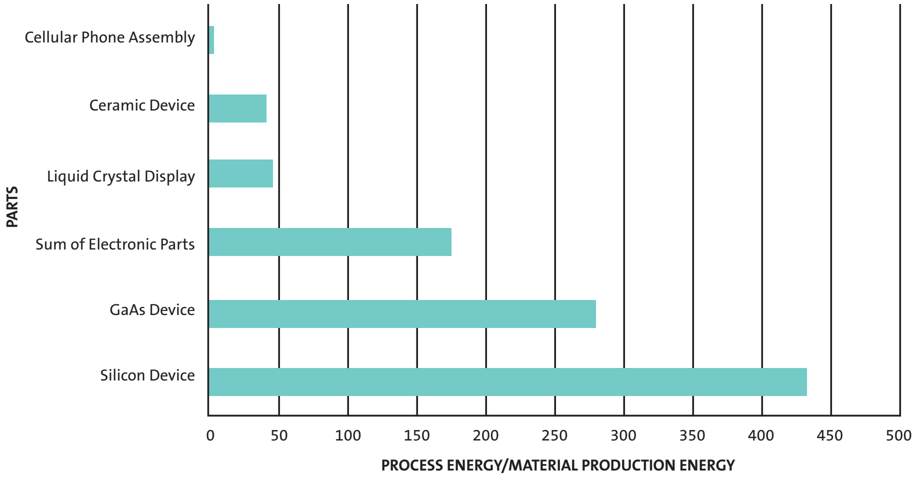
where a supplier bill of material is not available. Polycarbonate (PC), acrylonitrile butadiene styrene (ABS) and blends of these two materials are commonly, though not exclusively, used for housings. These basic polymers may further contain varying levels of glass fibers to improve mechanical stiffness. Commercial thermoplastics also always contain additives for better flow and processing, heat and UV protectants, other stabilizers, and inorganic or organic colorants.

In contrast to flexible plastics like PVC, plasticizers like phthalates are not expected to be present in engineering thermoplastics. While flame retardant grades are available, industry practice tends to limit their use to housings of external power supplies and not the housings of mobile handsets themselves. Numerous other base plastics and blends may also be found, e.g., copolymers of PC and siloxane.

The handset manufacturer has the additional options of metalizing, painting and, in the case of ABS-containing resins, plating the surface to achieve cosmetic requirements. Clear thermoplastics like PC or polymethylmethacrylate (PMMA) may also be found, usually with suitable coating layers for anti-abrasion, anti-smudging or optical properties (see **External Surfaces** section).

In addition to the major resins used in housings, a vast number of other polymers may be used, each with their own specific mechanical properties depending on their intended function. These materials may require further investigation on a case-by-case basis.

FIGURE 4: ENERGY REQUIRED TO PRODUCE MAIN COMPONENTS (YAMAGUCHI 2003)



Recycling Thermoplastics

Thermoplastics can be collected, reground and molded into new parts, subject to limitations on source control, contamination, separation of desired grades and colors, and degradation of mechanical properties versus virgin resin. The recycling of engineering thermoplastics may enjoy more widespread success as recycling volume increases and the practice of using recycled content reinforces life cycle thinking.

There have been dissenting opinions on the economic and environmental validity of spending resources to recycle plastics, which may represent only a minor fraction of a handset's overall environmental footprint. One such view is presented in Figure 5.

According to this data, the main economic impacts are in the LCD and the populated PWB (including ICs), a view that agrees with the known energy footprint of these assemblies discussed earlier in this paper. For consumer plastics (consumer plastics are defined as those with Society of the Plastics Industry (SPI) recycling codes 1 through 6; engineering resins like PC are lumped under code #7, Other), it is not unusual to see a financial loss, though the impact needs to be more thoroughly reviewed to fully understand environmental benefits of recycling versus energy recovery. Data appears to be rather limited regarding the recycling of engineering thermoplastics.

In addition, engineering plastics recycling today is not necessarily a closed loop. Resins from EoL electronic products may not feed back into new electronic products. Some approaches rely upon collection of items such as consumer water bottles that can be ground and incorporated in an engineering resin. An alternate approach is chemical conversion of a consumer resin like polyethylene terephthalate (PET) to another base chemical feedstock that can then be used to manufacture PET and other engineering resins.

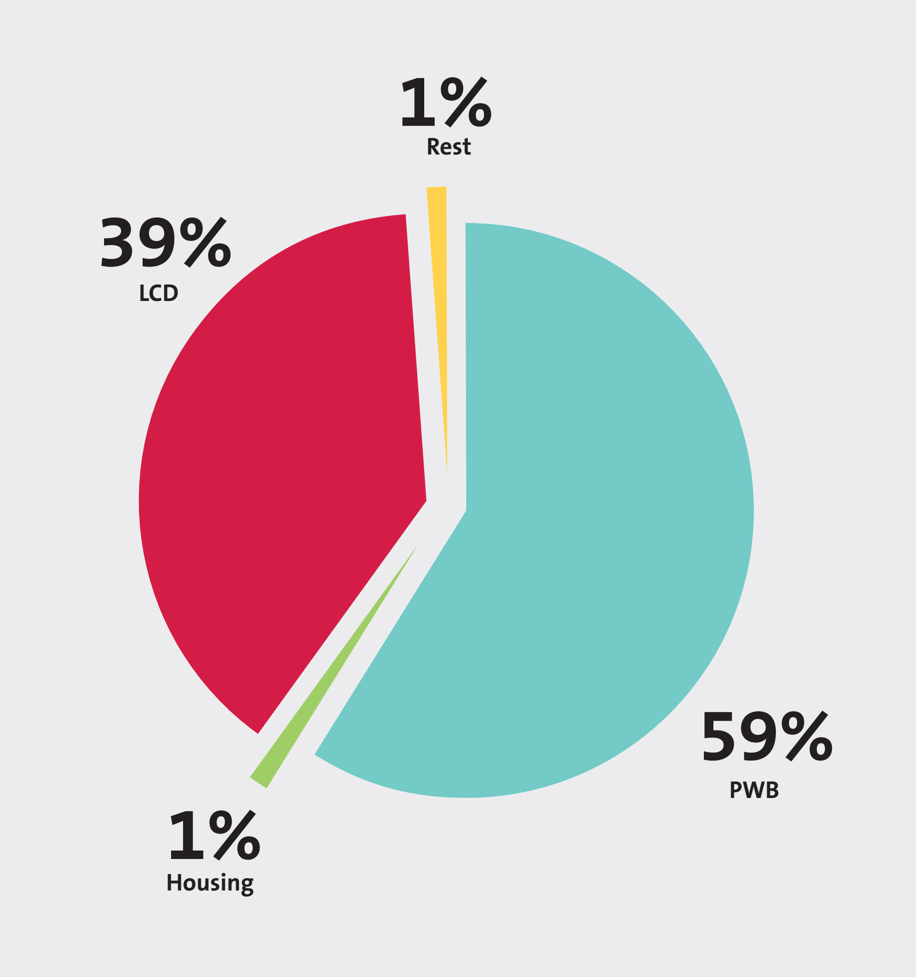
Despite the perceived limits of plastic recycling, it seems intuitive that most types of recycled plastics would save on energy, compared with manufacturing virgin resin from petrochemicals. UL Environment continues to seek additional data that would identify these benefits.

Thermosetting Plastics

Epoxies are used in rigid PWBs, laminated in layers with glass weave reinforcement, with copper photopatterned, and chemically etched and plated to form interconnects. PWBs in mobile phones also often contain one or more layers of resin-coated copper high density interconnect (HDI). Custom grades of epoxies are also used in molding component packages such as semiconductors, tantalum capacitors and so forth. In these applications, flame retardants are almost always used, thus warranting attention on the potential environmental issues from the use of halogens, including chlorine and bromine.

One of the most commonly used flame retardants in electronics PWBs and component packages is tetrabromobisphenol A (TBBPA). This compound is chemically reacted into the backbone of epoxies so that it is no longer present as an individual chemical species to help reduce its release and exposure to the environment. Still, additional studies are indicated regarding TBBPA's limited biodegradeability and its toxic effects on aquatic organisms. (Rosenblum 2011).

FIGURE 5: ENVIRONMENTAL IMPACT OF CELLULAR PHONE PARTS (BOKS 2000)



Unlike thermoplastics, which can be recycled and remelted into new applications, epoxies generally are not recyclable. It is currently accepted that the epoxy may be used for energy recovery in the pretreatment ("roasting") of PWBs, including assembled PWBs; however, the glass is destined to end up as a slag. Some work has been done to recycle epoxy and glass as inert filler for various applications.

Bio-Based Plastics

Besides recovery and recycling, another emerging approach to improving materials sustainability involves renewable biological sources. Many of these new materials are just being commercially introduced. Some of the feedstocks being developed for basic chemicals include corn, soybeans, or sugar cane. Non-foodstuff sources, like castor beans and kenaf, and cellulose and lignin from forest products, are also under development.

Bio-based materials may either replace traditional petrochemicals for making an existing type of plastic or may become the building blocks for creating new types of plastic. More research is required to better understand the energy footprint of bio-based materials and to validate their overall sustainability. However, the current consensus is that bio-based materials generally contribute to sustainability.

External Surfaces

So far, this paper has examined the mobile phone from a functional perspective. While the use phase does not use or generate materials (excluding the chemical reactions within batteries), the main use phase materials issue to be addressed is skin contact by the user. With the exception of external nickel, which may cause allergic dermatitis, no additional concerns regarding skin contact with external surfaces have been identified to date. However, the following areas are included here for sake of completeness.

Metals

Because a cell phone is a radio transmitter and receiver, the use of external metals is necessarily limited to prevent the degradation of antenna performance. Aluminum alloys are most commonly used due to their light weight.

Anodizing

As a preferred method of finishing aluminum, anodizing is an electrolytic process in which aluminum is treated in a bath of an oxidizing agent (strong acid) to which colorants may also be added. Thus, the surface contains aluminum oxides, imparting a hard, ceramic-like finish with entrapped pigments providing the desired color.

Magnesium and its alloys have been used on a much more limited basis. (Note that magnesium was not listed in any of the references cited in the previous section on metals.) Finishing tends to be problematic for magnesium, but painting and anodizing are possible (see the **Paint** section). Since its use appears to be rare and the external surface will be addressed elsewhere, magnesium is not of significance at this time.

Steels and stainless steels may find limited use in either finished or unfinished form. Their externally available nickel content may be tested per the methods identified in EN 1811 and EN 12472 for allergic dermatitis, but these materials do not generally release excess nickel in use.

Plastics

As discussed in the **Common Thermoplastics** section, plastics may be of numerous chemical families and contain additives as well, though most often the top surface is decorated.

Glass

Glass use is on the rise, especially with touch screen handsets. Aluminosilicate glass is most common, with chemical strengthening applied to exchange sodium with potassium within the outer portions of the glass structure itself. Bare glass is not likely to be the final external surface, since various clear coatings are applied to address reflections, smudging and other user concerns. These coatings may consist of a variety of silicone or fluorosilicone polymers, although detailed formulations are usually proprietary. However, such coatings may wear off, leaving exposed glass.

Paint

One or more coats of spray-applied paint, e.g., base coats and clear overcoat, are common over both plastic and metal external parts. One major type of paint chemistry is 2K, or 2-component, polyurethane. Variations include thermal or ultraviolet curing, solvent-borne formulations with the emission of volatile organic compounds (VOCs) that may be incinerated on site, high solids/low VOC formulations, and waterborne varieties. Pigments are certain to be present in any type of paint, including inorganics like TiO2 for white, and an extensive list of possible chemicals for other colors.

Plating

Chromium is the most common type of plating for external parts on ferrous metals as well as for wet-plateable plastics containing ABS. In addition to chromic acid, some of the plating chemistries may involve sulfuric acid and palladium, tin and/or copper-based activators. Thus, the presence of chromium and the other metals should be investigated as a potential risk.

There are also widely used nameplates or escutcheons formed by plating electroformed nickel with chromium, adding vacuum-deposited metal, and finishing with a clear top coat of paint. Nickel electroplating itself may also be colored, e.g., “black nickel” for steel fasteners.

Vacuum Metalization

Vacuum metalization can most often be found in mobile handset applications and may be externally applied using a tin-rich source. The resulting film imparts a metallic look that is not dense enough to be electrically conductive. Subsequent overcoatings may include colored or clear paint that may wear off. Hence, the use of vacuum metalization may result in user contact with potentially hazardous materials.

Other Decorations

Practically any of the aforementioned external surfaces may contain artwork or printing applied by various printing processes. Other types of decorations include in-mold lamination and in-mold decoration.

Fabrics and leather may contain azo dyes that are regulated in the EU. EU Directives regulating azo colorants include 2004/21/EC, 2003/3/EC and 2002/61/EC.

Glass

Handsets are trending toward larger displays and toward displays dominated by touch screens. The material most often used is specialty glass. While use of recycled glass (cullet) would offer a reduction in the energy footprint, it is not known whether manufacturers are able to ensure stringent optical and mechanical properties with post-consumer recycled content. More work is needed here to gain a better understanding of the use of post-consumer cullet by manufacturers.

Also needed is a better understanding of the potential for recycled content in glass fiber (fiberglass) to be used as a filler in plastics and the glass weave of PWBs. Energy savings within the glass production process can be awarded through supplier environmental management incentives.

ULE's Standard for Sustainability

UL Environment is working with stakeholders to develop a Standard intended to address sustainability in mobile phones. In its current form, the draft standard, ULE 110 , Interim Sustainability Requirements for Mobile Phones, assesses each product on its use of sustainable materials in its design and construction, selection of materials and use of recycled content as well as efforts to optimize material recovery and recycling at a product's EoL. The Standard assesses the sustainability not just of a product itself, but also accompanying accessories, including the product's power supply and even product packaging. The Standard also addresses larger issues such as the environmental management system used by the manufacturer and toxicological concerns.

ULE 110 employs an achievement matrix that rates each product on several different sustainability categories, including materials, energy use, health and environmental concerns, EoL management, packaging and product manufacturing, and innovation. Each product must earn a minimum number of points to qualify for certification and can qualify for higher certification levels depending on the total points earned. Mobile phones meeting the criteria of the Standard will have demonstrated significant strides toward achieving environmental sustainability.

Conclusions

This paper has reviewed the market trends and regulatory landscape for mobile phones, which have been significant drivers of change in the past few years. The materials content of these products has been analyzed from a life cycle perspective. For each of the main material categories, i.e., metals, plastics, external surfaces and glass, key environmental impacts have been detailed for material selection in product design as well as prospects for a high degree of material reuse and recycling at EoL.

Although small in their overall amount, precious metals are significant by virtue of their limited availability, energy footprint and recovery value. Comments on a comprehensive list of other elements based on the available chemical analysis data have also been provided.

No solution is currently available for recovering the embedded energy in key components like ICs and displays. However, prospects remain open for future optimization of recycled plastics and bio-based plastics, including a closed-loop approach where old products are recycled back into new ones.

For information about the "The Life Cycle of Materials in Mobile Phones" white paper, please contact Research Engineer Roger Franz, UL Environment, at Roger.Franz@ulenvironment.com.

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