RoHS: five years later

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Are electronics any "greener" than before RoHS? It is a fair question to ask. With the advent of RoHS on July 1, 2006, and more recently REACH, one might be inclined to answer that it *is* greener than it was. We will take a look at this question in several different ways, to discover the actual positive and negative effects of RoHS in both first world and developing countries

Let's start this investigation into RoHS by examining something independent of this directive: the increased function of electronics.

There has probably never been an industry that has continuously delivered increasing performance while using fewer materials and less energy than electronics. Consider a comparison to the automobile industry. Your father's (or grandfather's) 1947 Chevy would take you on the 100-mile trip from Utica, NY, to Cornell University in about 3 hours. It would use about 6 gallons of gasoline. Today, a 2011 diesel Chevy Cruze can make that same trip on better roads in about 2 hours, using less than 3 gallons of fuel. Time and gas mileage increased 30-50% in about 65 years for the same basic function: getting you there.

Now, let's make a comparison to electronics. In 1947, the ENIAC computer was two years old; it was in service until 1955. It boasted 19,000 vacuum tubes and something like 1 kilobit of memory. It used 200kW of electricity, enough to supply hundreds of homes. Today, a modern laptop computer has about 2.5 billion transistors (each transistor is roughly equal to a vacuum tube in its contribution to computation power) and 4 gigabits of memory, so it is approximately 100,000 to 1 million times more powerful. It has all of this power, yet it consumes only about 1 two-thousandth (100 watts/200kW) of the power of the ENIAC. So, for the amount of power used for similar calculation ability, today's laptop delivers about 1 billion times more calculations per watt of power.

In 65 years, the automobile has delivered incrementally more function per energy used, while the computer and, by association electronics have delivered exponentially more function per energy or materials used. So electronics, per function, is a very "green" technology. This position assumes that "green" means that electronics deliver more and more function using less and less "stuff." But what about the materials in electronics? Has RoHS added to electronics' greenness?

Materials in electronics

RoHS effectively banned lead, mercury, hexavalent chromium, cadmium, and two flame retardant chemicals: polybrominated biphenyls (PBB) and polybrominated diphenyl ether (PBDE), from electronics, except for a few exempted products and applications. With its sister recycling law, WEEE, the intent of RoHS was to make the European Union's environment safer. I know of no study or analysis that supports this RoHS hope. If enforced, WEEE does improve "greenness," as about 85% of products must be recycled. Unfortunately, electron-

Figure 1 – A 1947 Chevy and 2011 Chevy Cruze

Figure 2 – The ENIAC computer and iPhone. The iPhone has about 10,000 times the computing power

ics that don't get recycled and end up in a landfill are not likely to pollute the landfill any less, but, RoHS does make recycling safer for the recyclers. Many are unaware that safer and easier recycling is the prime purpose of RoHS. Safer recycling is one of the three pillars of the green mantra: "Reduce, Reuse, Recycle." Many still argue, however, that non-RoHS compliant products could and have been safely recycled with proper pre-cautions, so why put the electronics world through the pain of RoHS? I find this argument compelling.

To answer this question, we should ask, "Does RoHS help anyone else?" Some colleagues have estimated that about 50-80% of electronic product waste is shipped to third-world countries and "recycled" illegally. This practice ignores the 1992 Basel Convention that forbids transportation of hazardous waste between countries, especially from first-world to third-world countries. In reality, many of our electronics products are "recycled" as shown in Figures 3 and 4. The man extracting the solder from old circuit boards will use the same pan later in the day to cook his dinner. The boy in Figure 4 can only get money from the metal merchant if the insulation is burned off the copper wire. The burning process will often produce toxic gases. These figures are from the National Geographic article, "High Tech Trash". CBS also presented an investigation on the Chinese city of Guiyu. The people there not only work with toxic materials, the entire town is contaminated, so they also live in toxic materials. RoHS-compliant products will make these types of illegal recycling safer for these people and their environment.

Negative effects of RoHS?

Electronics, by its increased function, miniaturization, and energy efficiency, is by its very nature a green industry. Although the intent of RoHS may not make first-world countries greener and safer, it will undoubtedly help the epidemic of unsafe recycling in third-world countries.

However, some people claim that RoHS makes the environment worse because more tin and silver is used in lead-free solders. They argue that the increased use of these metals creates mining pollution and has driven the price of these metals sky-high. In addition, the higher melting temperatures of lead-free solder require reflow soldering temperatures to be higher, thus using more electricity. Let's examine these claims.

Approximately 90,000 tons of solder are used in electronics, with about 80,000 tons used in wave soldering and 10,000 tons in SMT soldering. It is important to remember that electronics solder is a subset of all solder. All solder (alloys for brazing pipes, etc.) uses about 190,000 tons of tin. Solder is the single largest user of tin (Figure 5).

Tin is the base material for almost all solders. If tin-lead solder were used, approximately 57,000 tons of tin (90,000 x 63% tin) would be used each year, with lead-free solder about 88,000 tons (90,000 x 98% tin). This is an apparent increase of about 30,000 MT of tin used each year. An interesting thing to consider, however, is that lead-free solder is about 14% lighter than tin-lead solder, and solder use in wave soldering (wave soldering uses almost 90% of electronic solder) is measured by volume not weight (i.e. assuming approximately the same fillet size); about half of this increase should be cancelled out. This is all a bit confusing, however, so it may be best just to look at tin use. According to the United States Geological Survey (USGS), about 300,000 tons of tin are consumed each year. Figure 6 is a graph of world tin production at mines per year. The amount of refined tin used each year in the US is shown in Figure 7. Looking at these graphs, it is hard to say that the amount of tin used has gone up since RoHS. It would appear that tin use is likely more affected by the

Figure 3 – Recycling electronic metals in New Delhi

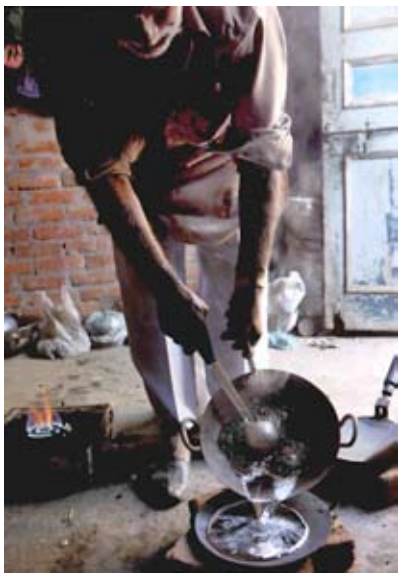

Figure 4 – The metal merchant will only take the wire with no insulation

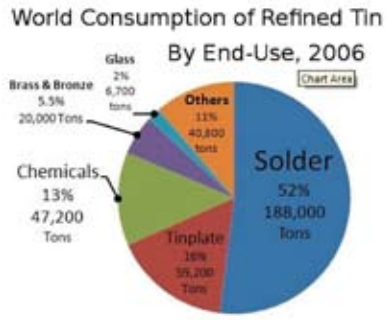

Figure 5 – Solder is the largest end user of tin (http://en.wikipedia.org/wiki/File:TinConsChart.jpg)

economy and that it is really difficult to see an effect from RoHS's July 2006 enactment.

Most wave soldering solders have low or no silver. About 3% of the 10,000 tons of SMT solder, or 300 MTs of silver, are used in electronics. This is about 1.5% of the 22,000 MTs of silver produced each year. Silver use in electronics does not make anyone's list of top silver usage.

Electronics solder use since RoHS has not caused tin use to increase, nor is it a significant factor in silver use. Therefore, it is highly unlikely that electronics use of tin or silver has been a prime driver in their stunning price increases in 2011.

An obvious disadvantage of lead-free electronics soldering assembly is that the reflow oven must be hotter, and therefore, will use more electricity (versus 63Sn37Pb soldering). This is true because the melting point of lead-free solders is around 225°C, while eutectic tin-lead solder is 183°C. But is the extra amount of electricity significant? Brian O'Leary claims that a typical SMT oven uses $7K of electricity a year at $0.072/kilowatt hour (kWh), or about 100,000 kWh. That number strikes me as about right, as a household uses about 5,000-20,000 kWh per year.

In the late 1990s, I participated in a study that estimated that there were 35,000 SMT lines in the world. At a 3% growth rate, that would be about 50,000 lines now. So, worldwide SMT reflow oven use would be about $5x10^9$ kWh (50,000 ovens x 100,000 kWh/per year) worldwide.

With most reflow oven heat loss due to convection, the increase in energy use would be approximately proportional to the difference between the oven temperature and the room temperature (25°C). An oven processing tin-lead solder would run at about 210°C, versus a lead-free oven at 250°C. The added energy for a lead-free oven would be about (250°-25°)/(210°-25°), or about 22% more. If all assembly lines in the world were SMT, the added energy use would be about 0.22 x $5x10^9$ kWh = $1x10^9$ kWh. The cost of this extra electricity would be about $100 million (US) at $0.10/kWh. The electronics industry generates about $1.5 trillion in sales. This added cost would be about 0.0067% of sales. Since world electrical use is about 150,000 $x10^9$ kWh per year, this increase is about 1/150,000 of all of the electrical use or 0.00067%.

Although more electricity is used, the increase is not significant to the value of the electronics sold or the total world use of electricity.

Where does all of this information and discussion lead us? There are at least three conclusions:

- By its very nature, electronics is a "green" industry in that it continues to provide more and more function and service while using fewer materials and less energy.
- Although RoHS does not necessarily make the citizens or the environment of developed countries safer, it will have an overwhelming positive effect on the large number of places in developing countries that are unsafely recycling electronics.
- There is little evidence that the implementation of lead-free soldering has measurably increased the use of tin, silver or electricity.

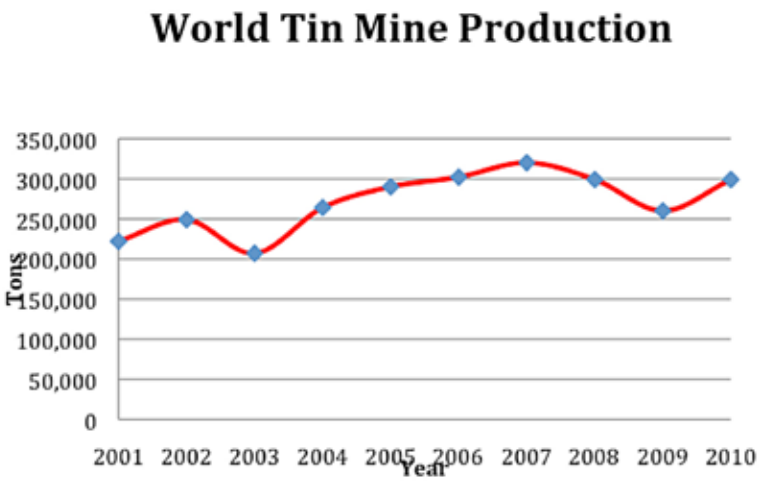

Figure 6 – World tin production at mines

Figure 7 – US consumption of tin has decreased since RoHS was enacted