Analysis of hazardous substances in a HCL laptop computer

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Summary

There is growing awareness of the use of hazardous chemicals in consumer goods, particularly with regard to the rapidly growing sector of electrical and electronic equipment, including computers. Some computers can contain heavy metals and other hazardous chemicals as constituents of their internal components, casings and external wiring. The ongoing manufacture of products incorporating such chemicals has the potential to impact on the environment and human health as a result of their manufacture, use and disposal.

In both the European Union (EU) and China, legislation has been recently introduced to control the use of certain hazardous chemicals in electrical products. In India there is currently no such legislation for this sector.

This study was conducted by Greenpeace to investigate the presence of certain hazardous substances in a laptop computer manufactured and sold in India. The HCL laptop computer (model AX 00014) was purchased in Bangalore, India in August 2006, and the presence of certain hazardous substances was investigated in a wide variety of internal and external components. The specific hazardous substances investigated in this study include;

- The heavy metals; lead, mercury, cadmium and hexavalent chrome (chromium (VI))
- Bromine content, indicative of brominated flame retardants (BFRs)
- PVC (polyvinyl chloride)
- Phthalates esters (phthalates)

The testing included analysis of 27 individual materials and components (using X-ray microanalysis or 'EDAX') to determine the amounts of lead, mercury and cadmium, and the element bromine (as an indication of the presence of brominated compounds) in the surface layers of the materials. In addition, electrical solder from 10 locations within the laptops were analysed for the levels of lead, and 11 metallic materials were analysed for the presence of hexavalent chromium (VI). Furthermore, plastic coatings of 8 separate wires and cables (internal wires, internal ribbon cables and external cables) were analysed for the presence of the plastic PVC. 1 of these 8 plastic coatings, and 1 other material, were also analysed for phthalates - chemicals widely used as plasticisers (softeners) in plastics.

The testing of the various components found a range of hazardous chemicals within the laptop;

- **Lead**, a highly toxic heavy metal, was identified in 4 of the 10 electrical solders tested, with concentrations in the range 32-48% by weight.
- **Bromine** (an indicator of the possible presence of brominated compounds used as **BFRs**) was detected in almost half of the materials tested (13 out of 27), at surface concentrations ranging from 0.24 to 9.9 % by weight. The highest level of bromine was found in the socket on the motherboard to which the external battery connects.
- A wide range of materials contained bromine, both internal components (some printed circuit boards, the cooling fan, a chip, electrical insulating material, as well as internal plastic sockets for ribbon cables, a pin connector and the external battery) and external components (a mouse button and the external battery casing).
- **PVC** was present in the plastic coatings of all 6 of the wires and cables tested (both internal and external).

- **Phthalates** were present in the outer plastic coating of the cable between the dc power transformer and the laptop, with a very high total concentration of 18% - almost a fifth of the total weight of the material.
- **Hexavalent chromium (VI)** was not found in any of the internal metallic materials that were tested

High **bromine** content is likely to be due to the use of a brominated flame retardant (**BFR**) formulation, though the testing method is unable to identify the types of brominated flame-retardants present. There is potentially a very wide range of brominated chemicals that can be used as BFRs, some of which have known toxic properties, and some are highly persistent in the environment and able to bioaccumulate (build up in animals and humans). In whatever form the bromine is present, impacts can result at the product's end of life during some disposal or recycling operations.

Although **PVC** does not have directly toxicity in the same way lead, this plastic does presents its own waste management problems. Furthermore, the use of PVC in certain applications requires that other chemicals be added to the plastic - such as phthalates**,** to plasticise (soften) the PVC. The plastic coating material that contained very high levels of phthalates also contained the plastic PVC. Substitution of PVC with an alternative material that does not require the addition of plasticisers would have eliminated the need for phthalates in this material.

Many **phthalates** are toxic to wildlife and humans. These chemicals are not chemically bound to the plastic, but are able to migrate out of the material over time. This can result in significant losses to the environment during the lifetime of the products, and again following disposal.

Although this study covered a diverse range of components within the HCL laptop, it was not feasible to test every individual component. Even where a chemical is absent from all the samples analysed, it is possible that the laptop is not entirely free of that chemical. Furthermore, this study investigated only one specific HCL model (AX 00014), and the results may not reflect the use of certain chemicals in the HCL brand as a whole. These issues highlight the great difficulties in verifying that any individual product, or brand as a whole, is entirely free of a specific chemical.

This study demonstrates the presence of hazardous chemicals in a popular brand of laptop computer manufactured and sold in India. The placing on the market of this HCL laptop would be illegal in some countries and regions that have legislation to regulate this sector, such as the EU and China. There is clearly a need for measures in India to prohibit the use of such chemicals in electrical and electronic goods in order to prevent human exposure and environmental contamination during manufacture, use and disposal/recycling of these goods.

Regulations in other countries could act as models for the development of similarly protective legal controls in India, though as they stand, even the laws in force in the EU and China do not restrict the use of all hazardous substances that may be present in electrical/electronic equipment. As this study has demonstrated, some such products do contain additional hazardous substances to those currently covered under these laws (e.g. PVC and phthalates). Any legislation seeking to protect human health and the environment by restricting the use of hazardous chemicals in products must ultimately address all uses of known or potentially hazardous substances.

Introduction

There is growing awareness of the use of hazardous chemicals in consumer goods, particularly with regard to electrical and electronic equipment, including computers. Concerns exist over the potential for chemical exposures, and impacts on the environment, during the manufacture, use and disposal of such products. The potential for impacts due to the use of hazardous chemicals is likely to rise as the production of such goods continues to increase worldwide, while in many cases the lifespan of the products is decreasing. This is reflected in the already large, and rapidly increasing, amounts of electronic waste (e-waste) arising from this sector.

Some electrical products, including computers, can contain heavy metals and other hazardous chemicals as constituents of their internal components, casings and external wiring. A recent investigation by Greenpeace found a range of hazardous chemicals in laptop computers for sale in Europe in 2006[1]. Furthermore, Greenpeace recently demonstrated workplace and environmental contamination in India[2] from the recycling and disposal of old electrical/electronic equipment containing such chemicals.

In some countries and regions, legislation[3] has been recently introduced to control the use of certain hazardous chemicals in electrical products. In India there is currently no such legislation for this sector.

This study was conducted by Greenpeace to gain information on the presence of certain hazardous substances in a typical laptop computer manufactured and sold within India (HCL model AX 00014). The presence or absence of these substances was investigated in a wide variety of internal and external components (casing, touch mouse pads, cables, circuit boards, chips, connectors, insulators, etc.). The specific substances investigated in this study include;

- The heavy metals; lead, mercury, cadmium and hexavalent chrome (chromium (VI))
- Bromine content, indicative the presence of of brominated flame retardants (BFRs)[4]
- PVC (polyvinyl chloride)
- Phthalates esters

The range of substances included in this study were based in part on substances controlled under recently introduced legislation in the EU and China which restrict specific hazardous chemicals in electrical equipment; the EU RoHS Directive and similar Chinese legislation (see below). In addition, this study included a survey of plastic coatings of cables and wiring for the presence or

[1] Brigden, K. & Santillo, D. (2006) Determining the presence of hazardous substances in five brands of laptop computers. Greenpeace Research Laboratories Technical Note 05/2006; www.greenpeace.to/publications

[2] Brigden, K., Labunska, I., Santillo, D. & Allsopp, M. (2005) Recycling of electronic wastes in China and India: Workplace and environmental contamination. www.greenpeace.org/international/press/reports/recycling-of-electronic-waste

[3] EU: Directive 2002/95/EC of the European Parliament and the Council, 27 January 2003, on the restriction of the use of certain hazardous substances in electrical and electronic equipment. Official Journal L037, 13/02/2003: 19-23. http://ec.europa.eu/environment/waste/weee_index.htm. Chinese legislation: Administration on the Control of Pollution Caused by Electronic Information Products. www.mii.gov.cn/art/2006/03/02/art_524_7343.html (Chinese); www.chinarohs.com (unofficial English translation)

[4] The level of bromine was determined in components, as this can indicate the presence of brominated flame-retardants (BFRs). Where bromine was found, however, the study did not investigate the individual BFR chemicals present.

absence of the plastic PVC. Two of these plastic coatings were analysed for phthalate esters (phthalates), chemicals widely used as plasticisers (softeners) in plastics.

The investigation was not intended as a test for compliance with the European RoHS Directive or the equivalent Chinese legislation; rather those substances controlled under pieces of these legislation were used to inform the choice of hazardous substances investigated in this product.

The EU's RoHS Directive and equivalent Chinese legislation [3]

The European Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment, or the RoHS Directive (Directive 2002/95), entered into force on July 1st 2006. The Directive prohibits, with certain exemption, the placing on the market within the EU of such equipment if it contains more than regulated amounts of lead, mercury, cadmium and hexavalent chrome (chromium (VI)), or of the two types of brominated flame retardants, namely polybrominated biphenyls (PBBs) and polybrominated diphenyl ethers (PBDEs, other than the decabrominated congener BDE-209). Limit values are set at 0.1% by mass of homogenous materials for all but cadmium, for which the limit is 0.01%. The stated purpose of the Directive includes, *inter alia* "to contribute to the protection of human health and the environmentally sound recovery and disposal of waste electrical and electronic equipment".

The equivalent Chinese legislation, the 'Administration on the control of pollution caused by electronic information products' entered into force on March 1st 2007. This legislation addresses the same chemicals controlled under the EU RoHS directive, but also includes 'other toxic and hazardous substances or elements as specified by the State' though to date (March 2007) no additional substances or elements have been specifically listed under this law. Additional differences exist between the EU and Chinese legislations.

Materials and methods

The HCL laptop computer (model AX 00014) was purchased by Greenpeace in Bangalore, India, in August 2006. The laptop was dismantled at the Greenpeace Research Laboratories in the UK, taking all possible steps to avoid contamination of materials (including the use of analyte-free materials and antistatic devices in a controlled laboratory environment). A range of different analyses were thereafter carried out on individual components and materials:

- 10 individual samples of electrical solder were separated from different components within the laptop (e.g. motherboard) and subsequently analysed for their lead content by atomic emission spectroscopy (AES).
- 11 distinct internal metallic components were analysed for the presence of hexavalent chromium (VI) using a diphenylcarbazide colorimetric method.
- 27 individual materials and components were selected for X-ray microanalysis (EDAX), an analytical technique that allows the detection and quantification (as percent by mass) of major elements in the surface layers of the material analysed. This technique was used to identify the presence or absence of the metals cadmium (Cd), mercury (Hg) and lead (Pb), as well as the element bromine (Br) to give an indication of the presence of organobromine compounds (including brominated polymeric materials) used as flame retardants.

- 2 of the materials analysed by EDAX (internal ribbon cables), and a further 6 additional materials (coating of internal wires and external cables), were selected for analysis to show the presence or absence of PVC in the insulating plastic coatings of these wire and cable samples.
- 1 of the 8 plastic coating materials tested for PVC, and one other material (a ribbon cable), were further analysed for a range of phthalates

In making the sample selections, every effort was made to include examples of as many as possible of the diverse materials and components present within the laptop. A schematic of the components separated and the analyses carried out is presented in Figure 1. A full list of the materials and components, along with the results of their analyses, is provided in Tables 1-5. The analyses of the solder samples for their lead content, and of the metallic components for the presence of hexavalent chromium (VI) were carried out at the Greenpeace Research Laboratories. Those materials for analysis by EDAX, and those for PVC and phthalate content were forwarded to the laboratories of Eurofins Environmental A/S in Galten, Denmark, for analysis. Further details of all the individual analytical methods employed are given below.

Lead content in solder

Each sample was accurately weighed, and to each was added concentrated hydrochloric acid (1ml). After standing for 12 hours, concentrated hydrochloric acid (0.5 ml) and concentrated nitric acid (0.5 ml) were added, and the solution left until all sample material had dissolved. Deionised water was added to make a final volume of 10ml, and the solution analysed by ICP atomic emission spectrometry (AES).

Hexavalent chromium (Cr VI)

The analysis was carried out in accordance with method IEC 62321/1CD, 111/24/CD-method 9[5]. To the surface of each sample, was added 0.2 ml of the testing solution (0.4 g of 1,5-diphenylcarbazide, 20 ml acetone, 20 ml ethanol, 20 ml orthophosphoric acid solution and 20 ml of demineralised water). The presence of hexavalent chromium was indicated by the formation of a red-violet colour. In each case, the method was applied in turn to 1) untreated surface, 2) surface finely abraded to remove any reduced chromate surface, but not remove the whole chromate layer, 3) surface vigorously abraded to exposure deeper layers.

X-ray microanalysis (EDAX)

The sample for analysis was placed in the Energy Dispersive X-Ray Fluorescence (EDAX) instrument at room temperature, and analysed for the surface concentrations of bromine (Br), cadmium (Cd), lead (Pb) and mercury (Hg). This technique does not provide data on the presence or absence of chlorine (Cl), therefore cannot indicate the presence or absence of PVC.

PVC

Each sample was tested for the presence of the element chlorine (an indicator of PVC) using the Beilstein test. For those samples testing positive for chlorine, the presence of PVC was confirmed using Fourier Transform Infrared (FT-IR) analysis.

[5] International Electrotechnical Commission (IEC) Test for the presence of hexavalent chromium (Cr VI) in colorless and colored chromate coating on metallic samples. Procedures for the determination of levels of six regulated substances (lead, mercury, hexavalent chromium, polybrominated biphenyls, polybrominated biphenyl ether) in electrotechnical products IEC 62321

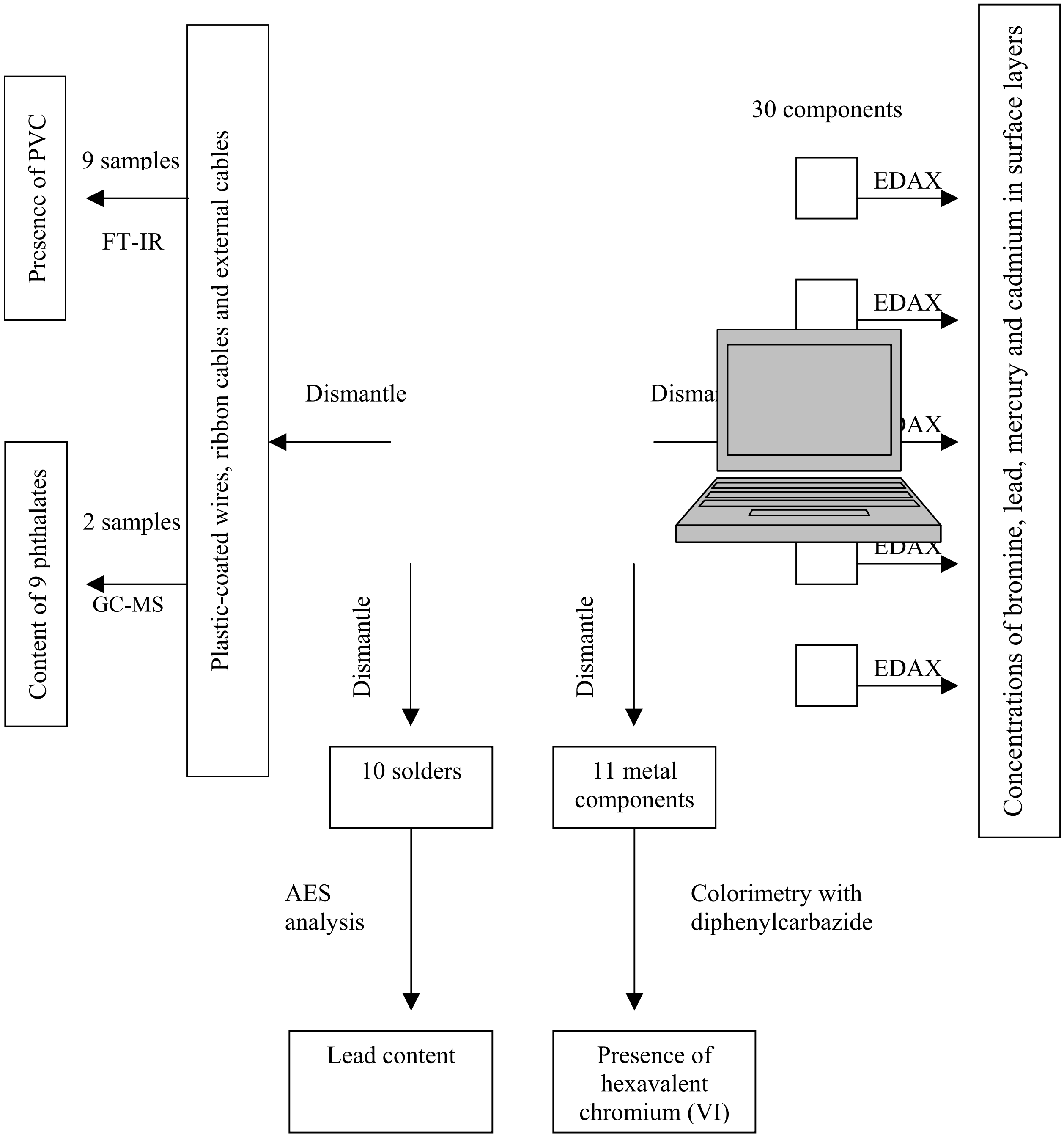

Figure 1. Dismantling of the laptop's components and their analysis

Phthalates

A portion of each sample was extracted into dichloromethane, with the addition of internal standards for quality control purposes. The extract was analysed using capillary gas chromatography coupled with a mass spectrometer (GC-MS) for the identification and quantification of 9 phthalates; di-n-butylphthalate (DBP), butylbenzylphthalate (BBP), diethylhexylphthalate (DEHP), di-n-octylphthalate (DOP), dimethylphthalate (DMP), diethylphthalate (DEP), di-iso-butylphthalate (DiBP), di-isononylphthalate isomers (DiNP), di-isodecylphthalate isomers (DiDP). Unlike the other phthalates listed, both DiNP and DiDP are not individual chemicals but are groups of very closely related chemicals (isomers).

Results and discussion

The results from the different types of testing carried out on the selected components from the HCL laptop are discussed in the following sections. It is important to note that these data relate only to those materials and components tested, which were a fraction of the total number of materials and components within the laptop. The absence of a certain chemical in all samples does not indicate that the laptop is entirely free of that chemical.

Lead content in electrical solder

The levels of lead in the 10 samples of electrical solder are presented in Table 1. Lead was present in 4 samples, with concentrations in the range 32-48% by weight. The samples that contained lead were three solders used on the motherboard (to join a USB socket connector, solder pads on the motherboard, and connection to the pins of small semiconductor chip) as well as connection of a component to a separate orange coloured circuit board.

Sample #	Component	Lead (%)
S1	circuit board of DVD drive; solder pad	<0.1
S2	circuit board of DVD drive; to small component	<0.1
S3	circuit board of DVD drive; to connector socket	<0.1
S4	motherboard; connector to USB socket	48
S5	motherboard; solder pad	47
S6	circuit board below mouse touchpad; solder pad	<0.1
S7	circuit board below mouse touchpad; to ribbon cable socket	<0.1
S8	small orange circuit board; to attached component	41
S9	hard drive circuit board; solder pad	<0.1
S10	motherboard; to pins of small chip	32

Table 1. Lead content of electrical solder samples, as a percentage (%) by weight.

The levels of lead in all 4 samples indicate the intentional use of lead in these materials. The levels far exceed trace levels that could potentially be present as a result of the unintentional trace contamination of solder with lead. Lead based solders have historically been widely used in electrical solders (commonly an alloy of tin and lead; 63% tin to 37% lead), though this material has increasingly been substituted in recent years with lead-free alternatives[6]. This change to lead-free solders is largely a result of legislation in some countries, particularly the EU RoHS Directive, impacting more broadly on a globalised industry. Although not applicable to the HCL laptop sold in India, such regulations set a limit far lower than the levels found in these samples (e.g. the EU RoHS Directive[3] set a limit of 0.1% lead, with certain exceptions).

Recycling of electrical/electronic equipment that contains lead can result in contamination of the workplace and surrounding environment with this highly toxic metal, as demonstrated in our earlier study[2] of e-waste recycling yards in India and China.

Lead (Pb) has been widely used as a major component of solders in electronic goods[6]. Lead is highly toxic to humans, as well as to animals and plants. It can build up in the body through repeated exposure and have irreversible effects on the nervous system, particularly the developing nervous system in children. Exposure can also have effects on the heart, kidneys and brain. For many effects there is no known safe level of exposure[7].

Hexavalent chromium (Cr VI)

Qualitative colorimetric analysis of 11 internal metallic components from the HCL laptop did not detect hexavalent chromium (VI) in any sample. This analysis is able to detect the presence of hexavalent chromium at levels far below 0.1% by weight. Details of the components tested are presented in Table 2.

Sample #	Component	Hexavalent chromium (✓/ X)
Cr1	keyboard metal plate	X
Cr2	mouse touchpad; plate below circuit board	X
Cr3	removable plate over hard drive on back casing	X
Cr4	hard drive case (back plate)	X
Cr5	hard drive case (main body)	X
Cr6	case of internal cooling fan	X
Cr7	DVD drive; external case	X
Cr8	plate inside rear casing	X
Cr9	internal metal housing	X
Cr10	internal metal housing	X
Cr11	internal metal housing	X

Table 2. Presence or absence of hexavalent chromium (Cr VI) in the surfaces of internal metallic components; ✓ indicates Cr VI was detected, X indicates Cr VI was not detected

[6] Lau, J.H., Wong, C.P., Lee, N.C. & Ricky Lee, S.W. (2003) Electronics Manufacturing with Lead-Free, Halogen-Free & Conductive-Adhesive materials. McGraw-Hill ISBN:0-07-138624-6. Geibig, J.R., Socolof, M.L. (2005) Solders in Electronics: A Life-Cycle Assessment. US EPA 744-R-05-001

[7] Spivey, A. (2007) The weight of lead, effects add up in adults. Environmental Health Perspectives 115(1): A30-A36

X-ray microanalyses (EDAX)

Bromine was detected in approximately half of the materials tested by EDAX (13 out of 27 samples), at surface concentrations ranging from 0.24 to 9.9 % by weight. A wide range of materials contained bromine, both internal components (some printed circuit boards, the cooling fan, a chip, electrical insulating material, as well as internal plastic sockets for ribbon cables, a pin connector and the external battery) and external components (a mouse button and the external battery casing). The highest bromine content of all the components analysed was 9.9% surface bromine by weight in the socket on the motherboard to which the external battery connects.

Bromine was not detected (above 0.1%) in some other circuit boards, internal plastic sockets and connectors, and external buttons, nor was it detected in any of the external plastic casing materials tested. None of the components tested by EDAX contained cadmium, lead or mercury at surface levels above the detection limits of 0.01% for cadmium and 0.05% for lead and mercury. The results of the EDAX testing are presented in Table 3 below.

Sample #	Component	Bromine (%)	Cadmium (%)	Mercury (%)	Lead (%)
1	Mouse touchpad	nd	nd	nd	nd
2	Mouse button (left)	**2.9**	nd	nd	nd
3	Keyboard space bar	nd	nd	nd	nd
4	Screen surface	nd	nd	nd	nd
5	External casing surrounding mouse touchpad & buttons	nd	nd	nd	nd
6	Ribbon cable (internal); connected to keyboard	nd	nd	nd	nd
7	External casing: plastic casing surrounding screen	nd	nd	nd	nd
8	External casing: outside top casing (reverse of screen)	nd	nd	nd	nd
9	External casing: plastic casing inside battery compartment	nd	nd	nd	nd
10	cooling fan (internal)	**4.3**	nd	nd	nd
11	Electrical insulation sheet	**1.9**	nd	nd	nd
12	Circuit board, base board; motherboard	**1.9**	nd	nd	nd
13	Circuit board, base board; memory chips	**2.1**	nd	nd	nd
14	Circuit board, base board; hard drive	**0.24**	nd	nd	nd
15	Circuit board, base board; larger circuit board under mouse touchpad	**0.86**	nd	nd	nd
16	Circuit board, base board; DVD drive	nd	nd	nd	nd
17	Circuit board, base board; orange circuit board	nd	nd	nd	nd
18	Socket on motherboard for external battery	**9.9**	nd	nd	nd
19	External battery casing	**1.5**	nd	nd	nd
20	Ribbon cable to mouse touchpad large circuit board	**2.3**	nd	nd	nd
21	Ribbon cable to mouse touchpad small circuit board	**2.3**	nd	nd	nd
22	Plastic socket for pin connector, on motherboard (see #25)	**6.9**	nd	nd	nd
23	Plastic socket for memory chip circuit board	nd	nd	nd	nd
24	Plastic connector socket for DVD drive	nd	nd	nd	nd
25	Plastic pin connector, fitting into #22	nd	nd	nd	nd
26	External power transformer plastic casing	nd	nd	nd	nd
27	Surface of main chip on motherboard	**0.72**	nd	nd	nd

Table 3. Results of X-ray microanalysis (EDAX) testing. nd; not detected above method detection limits; bromine (0.1%), cadmium (0.01%), mercury (0.05%), lead (0.05%)

Although EDAX provides a reliable and quantitative method for determining the total bromine content of the surface layers of a material, it does not yield information on the chemical form in which the bromine is present. High bromine content is likely to result from the use of a brominated flame retardant formulation, though the method is unable to identify the types of brominated flame-retardants present.

There is potentially a very wide range of brominated chemicals that can be used as brominated flame retardants (BFRs). Commonly used examples include polybrominated diphenyl ethers (PBDEs) and tetrabromobisphenol A (TBBPA), as well as brominated polymeric and oligomeric materials.

PVC

The results of the testing of 8 plastic components for the presence of the plastic PVC are presented in Table 4. Of these materials, 2 samples (20 and 21) were also analysed by EDAX as discussed above. Furthermore, 1 of the 8 samples (samples 32), and one other sample (sample 6) were also analysed quantitatively for the presence of 9 phthalate esters.

Of the materials subject to PVC analysis, all 6 of the plastic coatings of internal and external wires and cables tested positive for PVC. The plastic of the 2 ribbon cables did not contain PVC.

Sample #	Component	PVC
6[(b)]	Ribbon cable connected to keyboard	-
20[(a)]	Ribbon cable connected to mouse touchpad large circuit board	nd
21[(a)]	Ribbon cable to mouse touchpad small circuit board	nd
28	Plastic coating of internal power wire to screen	PVC
29	Plastic coating of internal wire to fan	PVC
30	Plastic coating of internal wire to speaker	PVC
31	Plastic coating of internal wire to internal BIOS battery	PVC
32[(b)]	Outer plastic coating of external cable from dc power transformer to laptop	PVC
33	Inner plastic coating of external cable from dc power transformer to laptop	PVC

Table 4. Samples analysed for PVC and phthalate content; results of the analysis for PVC content; nd - not detected; PVC - presence of PVC confirmed. (a) also analysed by EDAX; (b) also analysed for phthalate content. Sample 6 was analysed for phthalates but not for PVC.

Although PVC does not have directly toxicity in the same way as chemical such as lead, PVC does presents its own waste management problems by acting as a source of organic-bound chlorine to the waste stream, as well as raising additional concerns at other points in its lifecycle. Furthermore, the use of PVC in certain applications requires the use of additive chemicals, such as phthalate esters (phthalates) used as plasticisers (softeners).

Phthalates

The concentrations of the nine phthalates quantified in the two plastic materials are given in Table 5. In addition to the two laptop components (samples 6 and 32), one of the purpose-made storage bags used to store and transport all samples was also analysed for phthalate content. For this material, no phthalates were detected above method detection limits.

One of the samples, the outer plastic coating of the external cable between the dc power transformer and the laptop (sample 32), contained five different phthalates. This included a mixture of di-isononylphthalate isomers (DiNP) and di-isodecylphthalate isomers (DiDP) at a total concentration of 180000 mg/kg (18%), or almost a fifth of the total weight of the material

As noted above, the phthalates DiNP and DiDP are not individual chemicals. Each one is a group of very closely related chemicals, or isomers, with the same overall molecular formula but slightly different structures. The chemical similarity of DiNP and DiDP, combined with the large numbers of individual isomers present in each formulation, inevitably leads to a degree of overlap between the two during analysis when high overall concentrations are present. Consequently, complete separation of DiNP and DiDP congeners was not possible for sample 32, though data indicated that the mixture was predominantly DiNP.

Phthalate	**sample 6 (a) mg/kg**	**sample 32 (b) mg/kg**	**storage bag mg/kg**
Di-n-butylphthalate (DBP)	< 20	52	< 20
Butylbenzylphthalate(BBP)	< 20	< 20	< 20
Diethylhexylphthalate (DEHP)	< 20	3400	< 20
Di-n-octylphthalate (DOP)	< 20	< 20	< 20
Dimethylphthalate (DMP)	< 20	< 20	< 20
Diethylphthalate (DEP)	< 20	< 20	< 20
Di-iso-butylphthalate (DiBP)	< 20	250	< 20
Di-isononylphthalate Isomers (DiNP)	100	180000*	< 80
Di-isodecylphthalate Isomers (DiDP)	<90	*	< 80

*Table 5. Concentrations of nine phthalates in the plastic components, in mg/kg. (a) ribbon cable connected to keyboard; (b) outer plastic coating of external cable between dc power transformer and laptop. * for sample 32, summed data is given for diisononylphthalates (DiNP) and diisodecylphthalates (DiDP).*

The coating of the external cable (sample 32) also contained three other phthalates, though at far lower levels. Diethylhexylphthalate (DEHP) was present at 3400 mg/kg (0.34%), di-iso-butylphthalate (DiBP) at 250mg/kg (0.025%), and di-n-butylphthalate (DBP) at 52 mg/kg (0.0052%). The level of DEHP suggests it may have been intentionally added to the material, or at least was present due to substantial DEHP contamination of the DiNP/DiDP formulations intentionally added to the material. The far lower levels of DiBP and DBP suggest that these two phthalates may well be present from unintentional trace contamination, rather than having been added intentionally.

The internal ribbon cable (sample 6) contained diisononylphthalate isomers (DiNP), though only at a trace level, indicating that this chemical had almost certainly not been added intentionally to this material. The possibility that this cable contained other, non-phthalate plasticisers cannot be determined from the analyses performed in the current study. As noted above, this material did not contain the plastic PVC.

The sample with very high levels of phthalates (the external cable sample 32, described above) also tested positive for the plastic PVC, as may have been expected from the high phthalate content. Where flexibility is required, such as is the case in cabling, the use of PVC requires the addition of a plasticiser (softener), such as a phthalate. Use of an alternative material to PVC that does not have this requirement would have eliminated the need for the use of phthalates in this material.

Phthalates that are incorporated into plastic materials are not chemically bound to the plastic, but are able to migrate out of the material over time. This can result in substantial losses to the environment during the lifetime of products, and again following disposal. Therefore, it is of particular concern that very high levels of phthalates were found in an external component of the laptop (the plastic coating of the cable from the dc power transformer, sample 32).

The predominant phthalate identified in this material, DiNP, has potential toxicity to reproductive systems in mammals[9], and potential toxicity to other organs. Other phthalates present at lower levels in this material have even greater toxicity. For example, both DEHP and DBP are known to be toxic to reproduction, capable of causing changes to both male and female reproductive systems in mammals[9].

Phthalates are not currently included in the European RoHS directive that restricts the use of certain other hazardous substances in electrical and electronic products does not cover phthalates. However, due to concerns over human exposure to toxic and potentially toxic chemicals, the use of certain phthalates is restricted in toys and childcare articles within the European Union[8]. This Directive bans the sale of toys and childcare articles that include plastic containing more than 0.1 % by weight of phthalates including DiNP and DiDP (for products that can be placed in the mouth by children), as well as those with more than 0.1 % of DEHP or DBP (for all such products).

Phthalates are widely used as plasticizers (softeners) in plastics, especially PVC (e.g. in cables and other flexible components), though many other industrial uses exist. Many phthalates are toxic to wildlife and humans, often through their metabolites (chemicals to which they breakdown in the body). **DEHP**, a widely used phthalate, is a known to be toxic to reproduction, capable of causing changes to both male and female reproductive systems in mammals (e.g. development of the testes in early life[9]). Other phthalates (e.g. **DBP** and **BBP**) also exert reproductive toxicity[9]. Both **DEHP** and **DBP** are classified as "toxic to reproduction" within the EU[8]. There is also evidence of the reproductive toxicity of **DINP** [9], and this phthalate can also have effects on the liver and kidneys.

[8] EC (2005) Directive 2005/84/EC of the European Parliament and of the Council of 14 December 2005 amending for the 22nd time Council Directive 76/769/EEC on the approximation of the laws, regulations and administrative provisions of the Member States relating to restrictions on the marketing and use of certain dangerous substances and preparations (phthalates in toys and childcare articles). Official Journal of the European Communities L344, 27.12.2005: 40-43 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2005:344:0040:0043:EN:PDF

[9] Park, J.D., Habeebu, S.S.M. & Klaassen, C.D. (2002) Testicular toxicity of di-(2-ethylhexyl)phthalate in young Sprague-Dawley rats. Toxicology 171: 105-115. Gray, L.E., Ostby, J., Furr, J., Price, M., Veeramachaneni, D.N.R. & Parks, L. (2000) Perinatal exposure to the phthalates DEHP, BBP and DINP, but not DEP, DMP or DOTP, alters sexual differentiation of the male rat. Toxicological Sciences 58(2): 350-365

Conclusions

This study covered a diverse range of components within the HCL laptop, though it was not feasible to test every individual component. It is possible that some components which were not tested contain one or more of the chemicals investigated in this study. Therefore the absence of a chemical in all samples analysed from the laptop does not indicate that it is entirely free of that chemical. Furthermore, the HCL brand includes a range of different products available on the market. The results from this study are applicable to the specific model tested (AX 00014), and may not reflect the use of certain chemicals in the brand as a whole. These issues highlight the great difficulties in verifying that any individual product, or brand as a whole, is entirely free of a specific chemical.

Nevertheless, this study into the presence of hazardous chemicals in one HCL laptop computer has revealed valuable information.

- Lead was found to be present at high levels in four of the ten electrical solders tested
- Bromine was detected in half of the 27 components tested, at levels up to 9.9% by weight, presumably as a result of the use of brominated organic materials to confer flame retardancy.
- The analytical testing methods used in this study are not able to identify the chemical forms of the bromine in the various components that tested positive for bromine. Many of the brominated chemicals currently, or historically, used as brominated flame-retardants (BFRs) have known toxic properties, and some are highly persistent in the environment and able to bioaccumulate (build up in animals and humans). Furthermore, in whatever form the bromine is present, impacts can result at the product's end of life, particularly as some disposal or recycling operations (e.g incineration, smelting and open burning) can potentially release the bromine in hazardous forms, including hydrogen bromide and brominated dioxins[10]. In the EU and China the use of certain BFRs is specifically restricted in new electrical and electronic equipment[3].
- The presence of PVC coatings was found in all of the 6 plastic coating of internal and external wires and cables tested. The 2 ribbon cables did not contain PVC.
- Phthalates were present at very high levels (18% by weight) within an external component of the laptop (a section of the power cable), posing a risk of significant releases of phthalates from the material during use and disposal. The most abundant phthalates in this material have known toxicity, and in some regions their uses are restricted in toys and childcare articles (though not computers) due to the risk of human exposure. The use of PVC plastic in this flexible material requires the use of chemicals such as phthalates as plasticisers (softeners). Some alternative materials to PVC would not require the use of plasticisers.

The results from this study clearly document the continued presence of hazardous chemicals in a popular brand of laptop computer manufactured and sold in India, and highlight the need for

[10] Stutz, M., Riess, M., Tungare, A.V., Hosseinpour, J., Waechter, G., Rottler, H. (2000) Combustion of Halogen-free Printed Wiring Boards and Analysis of Thermal Degradation Products. Proceedings Electronic Goes Green 2000, 127-132. Leung, A.O.W., Luksemburg, W.J., Wong, A.S., Wong, M.H. (2007) Spatial Distribution of Polybrominated Diphenyl Ethers and Polychlorinated Dibenzo-*p*-dioxins and Dibenzofurans in Soil and Combusted Residue at Guiyu, an Electronic Waste Recycling Site in Southeast China. Environmental Science and Technology Research ASAP; http://pubs3.acs.org/acs/journals/doilookup?in_doi=10.1021/es0625935

measures to prohibit the use of such chemicals in electrical and electronic goods in order to prevent human exposure and environmental contamination during manufacture, use and disposal/recycling of these goods. Substitution of hazardous chemicals is widely achievable either by direct replacement of a toxic chemical with non-hazardous alternatives or through altering product design and materials used to eliminate the need for such chemicals. For example, the substitution of PVC with materials that do not require the use of plasticizers such as phthalates is already a commercially viable option. This would also avoid all the other problems associated with the production and disposal of PVC itself.

Such changes can be achieved either through self imposed commitments by manufacturers and/or national legislation. Experience in the UK and EU relating to other hazardous chemicals has recognised that the implementation of voluntary or negotiated measures is most effective when driven by the promise of future regulation. The placing on the market of this HCL laptop would be illegal in some countries and regions that have legislation regulating this sector, such as the EU and China. These legislative instruments could act as models for the development of similarly protective legal controls in India.

Nevertheless, as they stand, even the laws in force in the EU and China do not restrict the use of all hazardous substances that can be present in electrical/electronic equipment. As this study has demonstrated, such products can contain additional hazardous substances to those currently covered under these laws (e.g. PVC and phthalates). Any legislation seeking to protect human health and the environment by restricting the use of hazardous chemicals in products must ultimately address all uses of known or potentially hazardous substances.

Appendix. Composition of electrical solder samples for the HCL laptop

In addition to the lead content, the samples of electrical solder were also analysed for a wider range of metals and metalloids that have been reported to be potential components of electrical solder alloys.[11] The levels of these metals/metalloids are presented in the table below. All but one sample (03) contained high levels of tin. Other metals present were copper, nickel and silver, generally at levels below 5% by weight. In 3 samples (03, 07 &10) copper was present at higher levels. For no samples were antimony, bismuth, indium or zinc present at levels above method detection limits.

Sample #	Antimony (%)	Bismuth (%)	Copper (%)	Indium (%)	Lead (%)	Nickel (%)	Silver (%)	Tin (%)	Zinc (%)
01	<1	<0.5	1.5	<0.5	<0.1	<0.1	3.9	92	<0.1
02	<1	<0.5	5.9	<0.5	<0.1	0.7	3.9	86	<0.1
03	<1	<0.5	16	<0.5	<0.1	0.7	2.1	<0.5	<0.1
04	<1	<0.5	3.3	<0.5	48	<0.1	<0.1	48	<0.1
05	<1	<0.5	0.4	<0.5	47	<0.1	<0.1	52	<0.1
06	<1	<0.5	0.3	<0.5	<0.1	0.2	4.6	93	<0.1
07	<1	<0.5	62	<0.5	<0.1	2.7	2.3	28	<0.1
08	<1	<0.5	6.4	<0.5	41	<0.1	<0.1	50	<0.1
09	<1	<0.5	1.3	<0.5	<0.1	<0.1	4.3	89	<0.1
10	<1	<0.5	25	<0.5	32	1.3	<0.1	40	<0.1
Detection limit	<1	<0.5	<0.1	<0.5	<0.1	<0.1	<0.1	<0.5	<0.1

Table A1. Levels of certain metals and metalloids in solder samples by percentage weight

[11] Lau, J.H., Wong, C.P., Lee, N.C. & Ricky Lee, S.W. (2003) Electronics Manufacturing with Lead-Free, Halogen-Free & Conductive-Adhesive materials. McGraw-Hill ISBN:0-07-138624-6