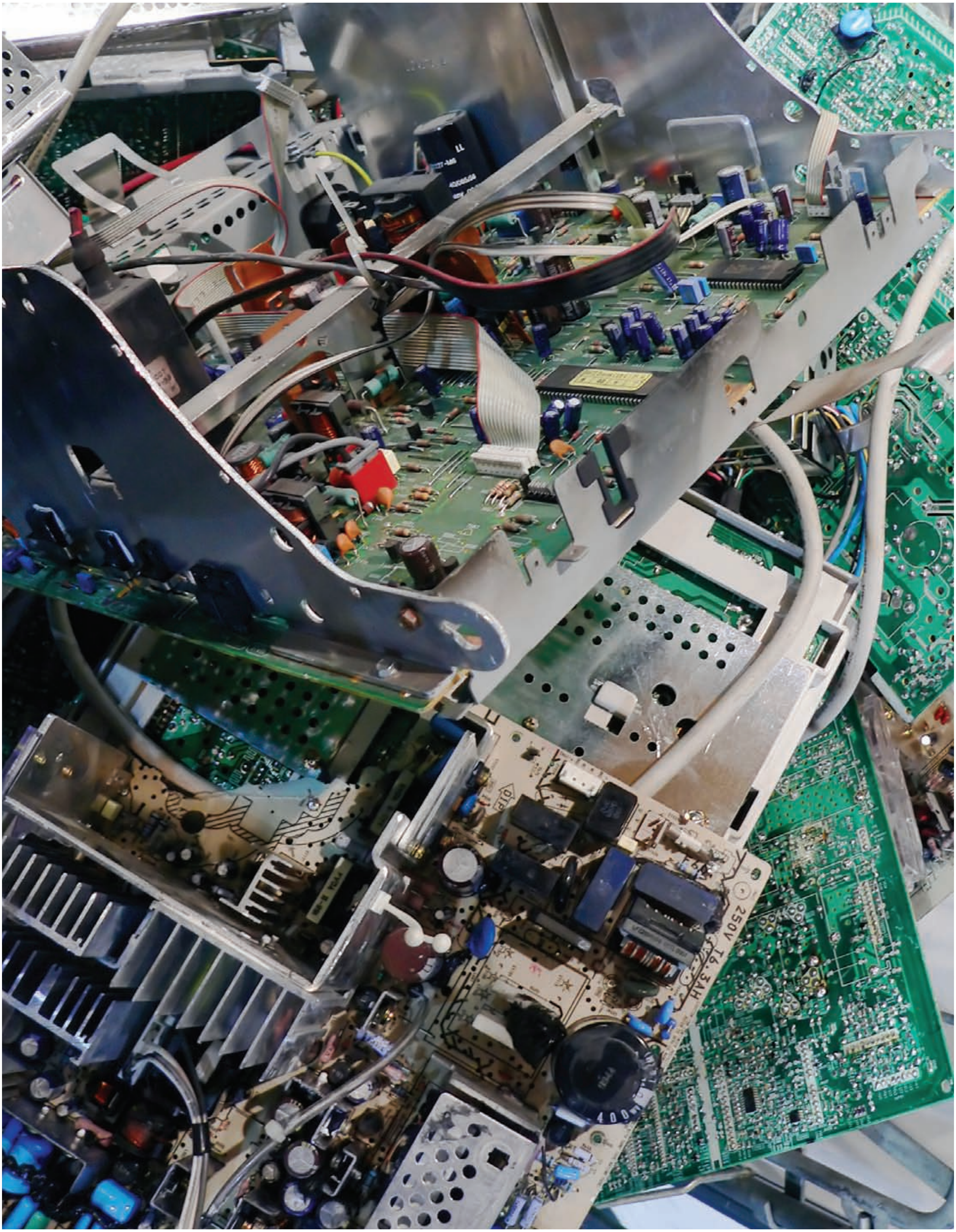


ISTOCKPHOTOS

The gadget scrap heap

As we constantly upgrade and replace our numerous electronic devices, the rubbish tip of forgotten, out-of-date equipment continues to grow. Maria Burke investigates the environmental impact and scientific salvaging of our e-waste

The UN Environment Programme estimates that the world generates 20–50 million tonnes of 'e-waste' each year and amounts are rising three times faster than other forms of municipal waste. It's a problem fuelled by expanding markets and increasingly speedy product innovations, such as the switch from analog to digital technologies. Europe's solution to its burgeoning e-waste mountain is a new EU directive. Since first agreed back in February 2003, it has been gradually rolled out across Europe and, from 1 July 2007, UK manufacturers will be expected to comply with the new rules. The aim of the *Waste Electrical and Electronic Equipment (WEEE) Directive*[1] is to reduce the amount of e-waste going to landfill, and to increase re-use and recycling.

From 1 July, consumers will be expected to take all old electrical and electronic equipment to collection points, where the waste will be transferred to licensed treatment facilities for recycling and disposal. The directive sets targets for recovery and recycling for different categories of waste (see box, p46). Equipment manufacturers and retailers or importers must pay for collection and treatment of these goods. Many UK companies have subcontracted these responsibilities.

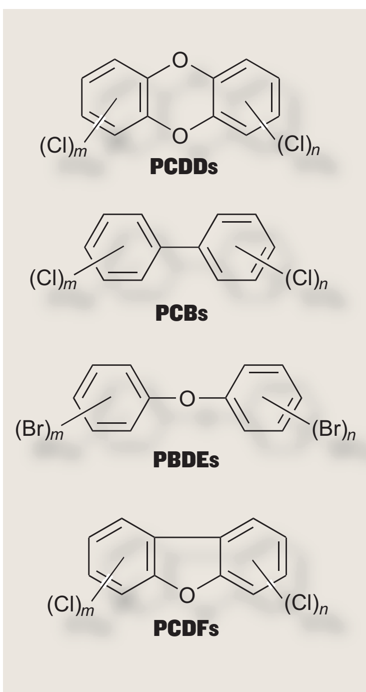
Toxic issue

WEEE regulates a complex mixture of e-waste materials and components, many of which are highly toxic, such as lead, cadmium, mercury, arsenic, and hexavalent chromium/chromium(VI).

Landfilling presents significant contamination concerns as toxins can leach into groundwater and soil. These include brominated flame retardants (BFRs) found in TVs, circuit boards, connectors and cables; polychlorinated biphenyls (PCBs) found in transformers and capacitors; and lead, which is found in cathode ray tubes and circuit boards, and other heavy metals in LCD monitors and other devices.

The US Environmental Protection Agency (EPA) estimates that lead comprises four per cent by weight of all discarded electronics. Timothy Townsend's team at the University of Florida recently showed that lead leached from waste electronic devices at concentrations greater than its regulatory toxicity limit (5mg/L).[2] They also found that smaller devices, such as mobile phones and remote controls, tended to leach higher concentrations of lead than larger devices, such as computers. 'Larger devices contain more ferrous metals which affect the reducing conditions,' explains Townsend. 'If there's lots of steel in there, it will 'leave' first, rather than the lead.'

Lead in landfills would dissolve in leachate, the water that forms at the bottom, says Townsend. 'If the landfill is unlined, then it could seep out into groundwater. If the landfill is lined, the lead will stay



Persistent organic pollutants (POPs) are released when e-waste is incinerated

In short

- **The UN Environment programme estimates that the world generates 20–50 million tonnes of electronic and electrical waste each year**
- **The EU's Waste Electrical and Electronic Equipment (WEEE) directive aims to reduce landfill of e-waste and increase reuse and recycling**
- **Exported e-waste is creating a growing environmental problem in the developing world**
- **Modern recycling techniques can utilise e-waste as a source of precious metals**

BASEL ACTION NETWORK

People make a living salvaging e-waste, exposing themselves to health risks

‘Wastes generated by every stage of the recycling process were contaminated with toxic heavy metals and persistent organic pollutants’

in the leachate that is discharged into a treatment plant. Sometimes lead can precipitate out of solution as lead sulfide, for example. Then it will stay at bottom of a landfill. But it is dangerous regardless of the form it’s in.’

Incineration of e-waste also produces potentially hazardous by-products, mainly dioxins, furans and polycyclic aromatic hydrocarbons, caused by burning PVC plastic and wire insulation. Materials containing PVC are precursors to polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs). These are classified as persistent organic pollutants (POPs) under the Stockholm Convention, a global treaty drawn up to protect human health and the environment. To make matters worse, according to researchers from Tohoku University in Japan, copper acts as a catalyst for the formation of PCDD/Fs during the combustion of PVC. So burning all that PVC-insulated copper wiring, may lead to even higher emissions of PCDD/Fs.

There is growing evidence that polybrominated diphenyl ethers (PBDEs) may cause liver and thyroid damage and impair brain development. They are also bioaccumulative, having been found in human breast milk and some foods, such as salmon and butter. Animal studies on PCDD/Fs have shown them to cause various types of cancers including liver, skin, lung, thyroid, tongue, and hard palate. In humans, several studies have linked them to an increased incidence of soft-tissue sarcoma.

Other persistent toxic substances released by incineration include PBDEs, which are used as flame retardants. In computers, for example, penta-BDE, octa-BDE, and deca-BDE appear in printed circuit boards, plastics (computer casing), cables, and components such as connectors. Due to health risks, penta-BDE and octa-BDE have been banned within the EU since August 2004 and are being phased out in several states of the US from 2006.

A team from the Hong Kong Baptist University recently reported findings from a village in southeastern China, which has been heavily involved in dismantling e-waste for the past decade.[3] They found that open burning of plastic chip and cables produced levels of PBDEs in combustion residues that were some of the highest found in any environmental medium – more than 16 000 times higher than those found in soil samples in a distant reservoir that served as a control site. High levels of PBDEs were also found in soils from an acid-leaching site, where workers use a mixture of nitric acid and hydrochloric acid to recover precious metals from shredded printed circuit boards. Open burning and acid-leaching also produced the highest levels of PCDD/Fs.

A 2005 Greenpeace study of industrial units and dump sites in China and India produced more evidence of environmental contamination. It found that the

Recovery and recycling targets set by the WEEE directive for different categories of waste

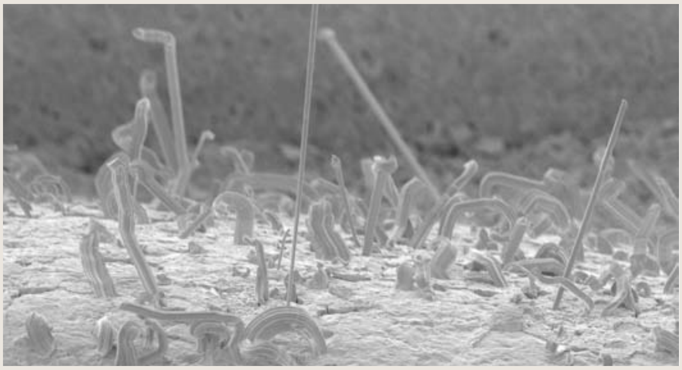
Category description		Recovery % by average weight per appliance	Recycling % by average weight per appliance
Category 1	Fridges and freezers	80	75
	Large household appliances	80	75
Category 2	Small household appliances	70	50
Category 3	IT and communications equipment – CRTs (ie PC monitors)	75	65
	IT and communications equipment – other	75	65
Category 4	Consumer equipment – CRTs (ie televisions)	75	65
	Consumer equipment – other	75	65
Category 5	Lighting equipment	70	50
Category 6	Electronic tools	70	50
Category 7	Toys, leisure and sports equipment	70	50
Category 8	Medical equipment	t-b-a	t-b-a
Category 9	Monitoring and control equipment	70	50
Category 10	Vending machines	80	75

FIGURES FROM WWW.DEFRA.CO.UK

Electronics with a conscience

'Environmentally conscious electronics' has been taken up by the US-based International Electronics Manufacturing Initiative (INEMI), a consortium of approximately 70 electronics manufacturers and suppliers. A major strand of its work in this area has been developing lead-free solutions. After years of research to replace lead solders used in assembling printed circuit boards, it recommended two tin-rich alloys mixed with silver and copper. But work is continuing as the recommended alloys raise the melting point by as much as forty degrees, impacting on other steps in the assembly process.

Another ongoing project is looking at tin whiskers.



Lead is added to tin plating to prevent the growth of tin whiskers

NASA

Manufacturers use tin plating as a surface coating for the leads on electronic components and, for decades, small amounts of lead have been added to the tin to prevent the growth of whiskers, or needle-like protrusions. If whiskers grow too long, they can cause electrical shorts, disrupt moving parts or affect performance. It's been difficult for designers to come up with Pb-free, tin-plated finishes so INEMI is working to devise tests for predicting tin whiskers, and modelling efforts to understand why they form and how to control them.

'While there are naysayers still out there, the change to lead-free electronics will happen,' says David Bergman, vice president of standards, technology and international relations at IPC, the US association of connecting electronics industries. 'Companies in Japan and Europe have already accepted this inevitable conclusion and several US manufacturers have gone on record with their plans.'

wastes generated by every stage of the recycling process were contaminated with a range of toxic heavy metals and persistent organic pollutants and that these contaminants were reaching surrounding soils and water courses.

Dumping the problem

Environmental contamination from this primitive recycling is becoming a huge problem for developing countries, says Jim Puckett of environmental NGO the Basel Action Network (Ban). 'While some items are re-used, the junk can be dumped without cost or liability,' he says. 'Dumping and burning is the norm, even in the official landfills, and there are plenty of 'unofficial' dumps.' In many countries, he adds, growing numbers of people earn a living from salvaging e-waste, often exposing themselves to health risks.

It's not yet clear how the environment and human health are affected by this growing industry, but evidence is building that there is need for concern. The statistics are certainly compelling. UNEP says that about 80 per cent of computer e-waste is being exported to Asia, and 90 per cent of these exports have been sent to China as illegal imports for 'recycling'.

Careful, controlled recycling of e-waste is a different issue. In the UK, considerable effort is going into devising safe methods of recycling that allow re-use of e-waste components. At present, it is relatively straightforward to extract ferrous and non-ferrous metals from e-waste, says Gerrard Fisher of the Waste & Resources Action Programme (Wrap), a UK government-funded organisation that promotes recycling. There are several approaches available for recycling glass that may contain compounds of lead, boron and phosphorus. The main challenge lies in dealing with the plastics that are left behind after the metals and glass have been extracted.

'The UK will have to deal with 300 000 tonnes of plastic per year when WEEE kicks in'

Plastic packaging

The UK currently recycles about 10 000–15 000 tonnes of plastic waste per year, but it will have to deal with around 300 000 tonnes when the WEEE directive kicks in, says Roger Morton of Axion, a plastics recycling company. E-waste contains a mixture of different plastics, making it difficult to recycle. These plastics are often contaminated with heavy metals or BFRs (about 30 per cent of plastics in a TV will contain BFRs). Currently, recycling companies split the plastics into those containing BFRs and those that don't. 'While the non-BFR fraction can be recycled and reused, usually the only option is to landfill the BFR fraction,' says Morton.

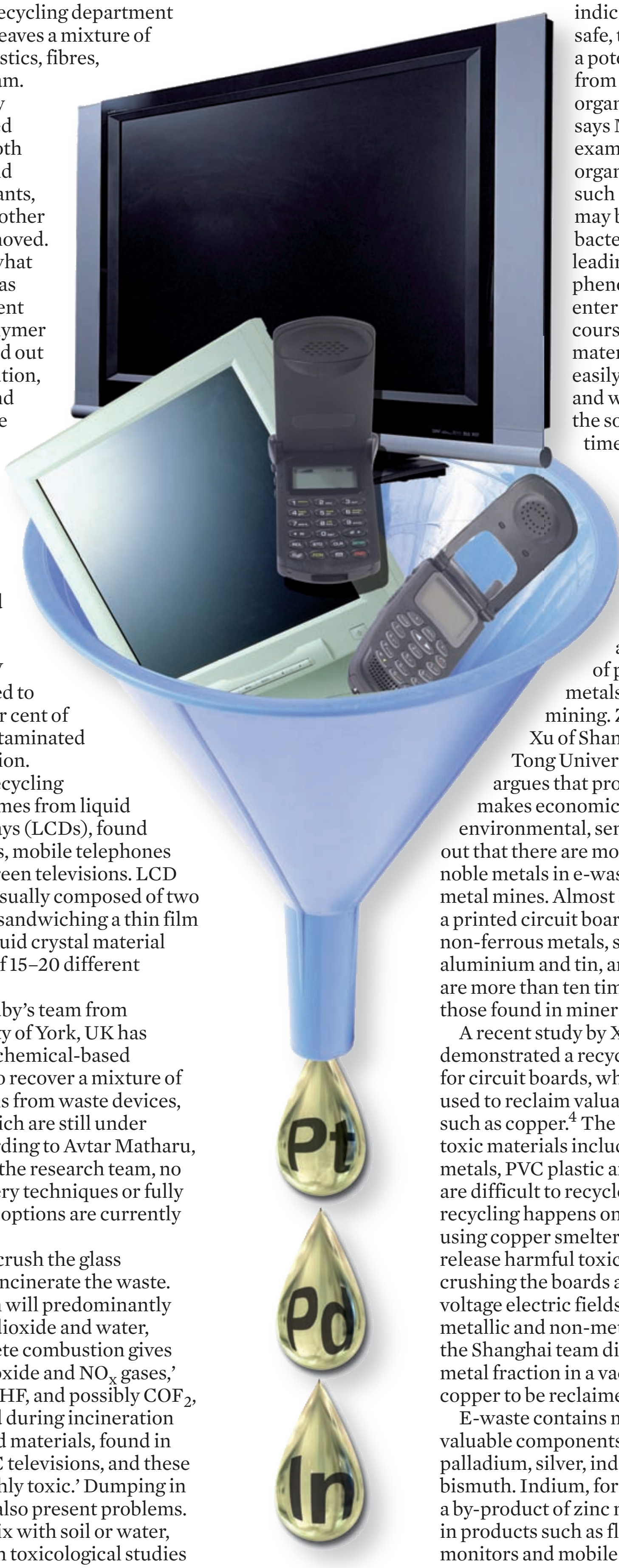
Wrap asked Morton to review and test out the most workable solutions for recovering polymers from e-waste. 'The most cost-effective, safest and commercially viable option' for dealing with BFR-contaminated plastics was the CreaSolv process, developed by the Fraunhofer Institute for Process Engineering and Packaging (IVV) in Freising, Germany.

First, appliances are broken up in a giant mill; then the metals and circuit boards are separated out, explains Andreas Mäurer, head of

Television sets containing tens of different compounds are a recycling challenge

CORBIS

HAMISH KIDD / SCOTT OLLINGTON



the plastics recycling department at IVV. This leaves a mixture of shredded plastics, fibres, wood and foam. A proprietary solvent is used to dissolve both the plastic and its contaminants, allowing the other bits to be removed. Then using what he describes as 'a clever solvent trick', the polymer is precipitated out from the solution, leaving behind the BFRs. 'We are able to isolate high-grade polymers that are re-useable, and concentrated BFRs,' says Mäurer. In tests, the IVV team managed to recycle 95 per cent of the BFR-contaminated plastics fraction.

Another recycling challenge comes from liquid crystal displays (LCDs), found in calculators, mobile telephones and wide-screen televisions. LCD screens are usually composed of two glass sheets, sandwiching a thin film of viscous liquid crystal material – a mixture of 15–20 different compounds.

John Goodby's team from the University of York, UK has developed a chemical-based technology to recover a mixture of liquid crystals from waste devices, details of which are still under wraps. According to Avtar Matharu, a member of the research team, no viable recovery techniques or fully safe disposal options are currently available.

Recyclers crush the glass screens and incinerate the waste. 'Incineration will predominantly give carbon dioxide and water, but incomplete combustion gives carbon monoxide and NO_x gases,' he explains. 'HF, and possibly COF_2, are produced during incineration of fluorinated materials, found in high-spec LC televisions, and these gases are highly toxic.' Dumping in landfill may also present problems. 'LCs don't mix with soil or water, and, although toxicological studies indicate LCs are safe, there is always a potential hazard from man-made organic compounds,' says Matharu. 'For example, landfill of organic substances, such as esters, may be prone to bacterial hydrolysis leading to precursor phenols which may enter the water course. Fluorinated materials do not easily biodegrade and will remain in the soil for a long time.'

High value junk

But it's not all toxic waste: this mound of e-waste plastics could provide a source of precious metals to rival mining. Zhenming Xu of Shanghai Jiao Tong University in China argues that proper recycling makes economic, as well as environmental, sense. He points out that there are more rare and noble metals in e-waste than in metal mines. Almost 30 per cent of a printed circuit board consists of non-ferrous metals, such as copper, aluminium and tin, and these metals are more than ten times purer than those found in minerals.

A recent study by Xu demonstrated a recycling technique for circuit boards, which can be used to reclaim valuable metals, such as copper.[4] The boards contain toxic materials including heavy metals, PVC plastic and BFRs and are difficult to recycle. Currently, recycling happens on a small scale using copper smelters, which can release harmful toxic fumes. After crushing the boards and using high-voltage electric fields to separate metallic and non-metallic materials, the Shanghai team distilled the metal fraction in a vacuum, allowing copper to be reclaimed.

E-waste contains many other valuable components, like gold, palladium, silver, indium and bismuth. Indium, for example, is a by-product of zinc mining used in products such as flat-screen monitors and mobile phones. In the past five years, indium's price has increased six-fold, making it more expensive than silver, reports Ruediger Kuehr of the United Nations University. Although mine reserves are limited, indium recycling only happens in a few plants in Belgium, Japan and the US.

'The large price spikes for all these special elements that rely on production of metals, such as zinc, copper, lead or platinum, underline the need for efficient recycling loops to recover them from old products,' says Kuehr. 'This requires hi-tech processes, but it's vital to do it.'

Kuehr is involved in a new global public-private initiative called Solving the e-waste problem (Step) based in Bonn, Germany.[5] Step was launched in March to standardise recycling processes, extend the life of products and markets for their reuse, and harmonise world legislative and policy approaches to e-waste. Its members include manufacturers, such as Hewlett-Packard, Dell and Ericsson, and UN, governmental, NGO and academic institutions.

Many manufacturers are also looking to develop 'clean' products with longer life-spans, which are safe and easy to repair, upgrade and recycle. One driving force is the EU directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS), which came into force last July.

Kevin Brigden of the Greenpeace Laboratories at Exeter University believes that this directive has had a far-reaching impact on industry. Some manufacturers have pledged to produce 'greener PCs' with fewer harmful ingredients, agrees Ban's Jim Puckett (see 'Electronics with a conscience, p47). 'So far, Europe has led the way in this regard with RoHS: even though it was considerably watered down, it sent the right message. We have been told by industry insiders that a 'toxic-free' computer could be achieved as early as 2015. This is the ultimate solution to the crisis.'

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