Ubiquitous Media, Rare Earths - The environmental footprint of digital media and what to do about it

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ABSTRACT: The language of 'immaterial', 'weightless' and 'virtual' digital media inflects discussions from business models to aesthetics, cultural analysis to democratic politics. But digital media are none of these things. The raw materials, manufacture, use and recycling of digital tools all have significant impacts on the people who work in these sectors and on the natural environment. Loss of species and habitats, energy use, pollution, labour and living conditions are all implicated in the physical infrastructure of computing, and are likely to become more so for reasons which include the rise of the BRICK countries, migration to cloud computing, virtualisation technologies and the integration of mobile and telecoms networks. Recent developments in software studies need to be supplemented with a move into hardware studies. At the same time, the apocalyptic tone common to some strands of Green politics and many aspects of critical theory need to be reoriented towards bulding solutions to these potential limits to growth. Once we recognise that there is a problem, we can begin to consider whether the appropriate solutions are technical, economic, political or cultural.

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For much of the 20th century, cathode ray tubes (CRTs) were the fundamental unit of both television and computer displays. The CRT is a glass tube with, at one end an emitter of negatively-charged electrons (the cathode) and at the other a positively-charged anode which attracts the beam of electrons (the cathode ray) to a flattened area covered with phosphorescent materials which light up when struck by the particles. A magnetic coil or electrostatic system focuses the electron beam, and a second magnetic deflector yoke directs their flight towards the desired destination on the screen. In colour CRTs, three electron guns fire beams towards phosphors which glow red, green or blue, separated from one another by a mask. The technology, which derived from both vacuum tubes (perfected in the 1850s) and cathode rays (demonstrated in the 1870s), was first employed with the goal of visual display in the Braun Tube, the CRT oscilloscope demonstrated by Karl Ferdinand Braun in 1897. CRT oscilloscopes, like CRT radar screens, use phosphors which tend to keep their glow for some time after being struck by an electron.

The phosphors in television, computer, ATM and video game CRTs have a shorter illumination, fading swiftly to allow the next image to differ from the one before. They use innovations pioneered by Vladimir Dzworykin in the Westinghouse and RCA laboratories in the 1920s, where he had fled the Russian Revolution. The central innovation, probably introduced by Dzworykin's mentor Boris Rosing, was the scanning of images prior to transmission. Here the difference from the oscilloscope is critical: unlike oscilloscope and radar screens, TV and computer CRT displays are formed as grids of phosphors organised in a cartesian X-Y surface (like graph paper) called a raster display. The electron gun responds to incoming signals by modulating its beams as they perform regular scanning of the whole screen area from left to right and from top to bottom. The level of charge as the beam strikes a given square on the grid determines the 'luma' or brightness signal, with a correspondingly brighter reaction from the phosphor targeted at that specific address on the screen. Oscilloscope and radar screens, in which the intensity of the charge is kept constant, steer the electron beam directly on the X and Y axes using magnetic plates seated inside the electron gun. This allows arbitrary movement in response to incoming signals from various electronic instruments like microphones and radar telescopes. This was the type of screen used in Ivan Sutherland's Sketchpad, an invention to which we will return. This first application of the CRT has been abandoned in television and subsequently (and perhaps consequently) in computer technologies, where signals such as component or composite video and RGB are organised to match the raster grid.

The materials involved in CRTs are expensive and many of them toxic and potentially dangerous to dispose of. Colour CRTs require up to 32,000 volts in the screen anode (though monochrome sets use much lower voltages): the energy requirements of such devices are intense. Since the voltage/brightness connection means that unilluminated phosphors require no charge, bright images such as the typical white of a computer word-processing package require higher degrees of energy than darker images (the avowed reason for Google's *Blackle* experiment, which reproduced Google's search pages reversed out to reduce power usage: see http://www.blackle.com/). The glass tube is under extreme pressure – implosion as a result of the vacuum can send fragments ricocheting at lethal speeds – requiring very strong glass in substantial quantities, and often metal reinforcing bands, also under extreme tension. Recycling these components can be a risky process. The glass itself is leaded to minimise the radiation risks associated with both the high energies of the cathode ray, which generates X-rays on impact with the screen, and ions generated as a by-product of running the electron beam. This lead in the glass, the often toxic phosphors which line the screen, and the frequent use of barium in the electron gun assembly, add to the toxicity of the recycling process. Legislation in the USA and the EU prevents throwing CRTs into landfill, but cannot legislate for the recycling villages of Southern China[1] and West Africa where most Northern hemisphere electronic equipment ends up. The Basel Action Network[2] estimated that in 2005 approximately 400,000 junk computers were arriving in Lagos alone.

Liquid Crystal Displays (LCDs) pose similar problems, although their power usage is much lower than CRTs, which they have largely displaced in the computer market. Overtaking CRT sales in 2004, LCDs were projected to sell 50 million units worldwide in 2008, and to double in total by 2011. Found in digital watches, mobile phones, laptops and increasingly in flat-screen TV and monitor screens, waste LCDs are one of the fastest growing recycling problems of recent years, with increases in end-of-life statistics projected at 16 to 25 per cent every five years. The LCD backlights are the most serious pollution hazard, as they contain significant quantities of mercury. The perfluorocompounds used in the crystals themselves have a far higher greenhouse effect than carbon dioxide: up to 22,000 times

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[1] Basel Action Network, Exporting Harm: The High-Tech Trashing of Asia, http://www.ban.org/E-waste/technotrashfinalcomp.pdf, 2002

[2] Basel Action Network, The Digital Dump: Exporting High-Tech Re-use and Abuse to Africa, http://www.ban.org/BANreports/10-24-05/index.htm, 2005

higher on the global warming potential (GWP) index[3]. While the mercury can be recovered in de-manufacturing processes (so long as manufacturers, mainly based in China, Korea and Japan, abide by regulations established in key markets like the EU), the crystals are typically incinerated. The manufacturers association has established high-heat incinerators, backed up with alkaline scrubbers to react with remaining perfluorocompounds, but these too use very significant amounts of energy (though Sharp have established a 'green-powered' recycling plant in 2008). Many appliances are dumped when the screens have relatively minor failures: recyclers can frequently repair and reuse them. But many will find their way into the recycling industry, where the mercury and cadmium from the integral batteries, the indium-tin oxides used in electrodes, and the unpredictable breakdown products of the organic compounds used through the assembly, from polarisation and orientation layers to screen coatings all contribute to the hazards. The problem is exacerbated by the economics of waste recovery, which suggest that the most cost-effective method is manual disassembly[4]. Despite disputes over the toxicity of the components on LCDs, there is general agreement that they are poorly biodegradable, and potentially significant water contaminants.

The ubiquity of LCDs in mobiles places them alongside other dangerous rare earths like selenium and germanium, pointing to a further material problem: the limit to the availability of these materials, essential to the production of chips and batteries. The levels of penetration of personal devices in the West is not sustainable across the rapidly developing markets of India and China, let alone the remaining portion of global population living in the underdeveloped world. The screens in mp3 players and digital cameras, and the other components associated with them, pose not only recycling and recovery problems but suggest that without radical change in their design, there will not be enough raw material to reproduce the West's expectation of multiple, individually owned and used devices for each member of the population. The strategic importance of rare earths has sparked fears that China, which produces 95% of the world's lanthanides, may be introducing export controls, placing its electronics industries in a powerful position to dominate 21st century manufacturing, either through domestic firms, or by forcing transnationals to move their manufacturing to China in order to access the necessary raw materials. Though global reserves include 42 per cent outside China's borders, refining capacity is limited, extraction costs are often higher, and in some instances, as with Arafura, an Australian rare earths mining company, China has moved to purchase significant shares[5]. The possibility of trade wars to compare with those currently being fought over access to oil may loom for the high tech industries, and indeed for green

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[3] Avtar S Matharu and Yanbing Wu, 'Liquid Crystal Displays: from devices to recycling' in Electronic Waste Management, Issues in Environmental Science and Technology eds R E Hester and R M Harrison(Cambridge: RSC Publishing, 2008) 180-211

[4] B Kopacek, 'ReLCD: Recycling and Re-use of LCD Panels' in Proceedings of the 19th Waste Management Conference of the IWMSA (WasteCon2008). 6 – 10th October 2008. Durban, South Africa.; http://ewasteguide.info/Kopacek_2008a_WasteCon,

[5] The Australian, 'China builds rare-earth metal monopoly', March 9, 2009, http://m.theaustralian.com.au/business/WorldBusinessNews/fi24471.htm

technologies: hybrid cars require up to two kilograms of rare earths for their batteries alone.

architecture

It is clear that our 'immaterial' culture is highly material, especially when we consider its ecological footprint in raw materials, in use and at end-of-life. Without delving into the manufacturing process, which would require another chapter, suffice it to point out that Dell Computers, a large but otherwise typical US computer brand, use up to 98 OEM/ODM (original equipment manufacturer/ original design manufacturer) sources to produce their equipment, the vast majority in developing countries or in export-friendly free-trade zones like the notorious *maquiladoras* of the Tijuana US-Mexico border country, where pay and conditions are far below developed nation standards. Screens are a typical OEM/ODM item, installed without the manufacturers' name attached, and only sometimes branded by an on-seller. For example the disc drive in my MacBook Pro is credited to Matsushita, who almost certainly have outsourced its manufacturing offshore, while the memory manufacturer is listed as "0x127F000000000000" and the LCD has no vendor or manufacturer named in any form. As is typical of information capitalism, key brands like Apple, Matsushita and Sony (who provide my batteries) do not manufacture components themselves, and frequently do not even own the assembly plants where the final products come together. Instead they concentrate on the core business of intellectual property: trademarking the brand, patenting hardware and copyrighting interlinked software and content. Although corporate research and development is now also often outsourced, for example to India in the software industry, or to increasingly corporatised universities in the materials science field, core trade secrets and the development of core innovations will typically be the one area of corporate concern to be kept as close as possible to the centre of operations. PRINT: We should not forget that fundamentally, in a capitalist economy, print is an advertising medium. Let's look at some statistics: "Businesses in North America spend $65+ billion per year on print media advertising. The average office worker generates 2 pounds of paper waste per day. Paper and printing related expenditures typically represent 15 to 30 percent of every corporate dollar spent, exclusive of labor", according to the Institute for Sustainable Communication (http://www.sustainablecommunication.org/).

LEDs

Gallium is a vital component. Though its major use is in LEDs, new uses in solar power cells suggest it may become a strategic metal in the same way that germanium has. The major source is bauxite, the aluminium ore. Unfortunately, not all bauxite deposits have much gallium: the richest sources, and the biggest suppliers to the US LED fabrication market, are China and Ukraine, though the US Geological Survey reports increasing imvestment in recycling from scrap, since even the most promising US bauxite deposits do not have economically recoverable gallium (Jaskula 2009). The LED is, like all advanced technologies, deeply embroiled in the globalisation process and the new terms of struggle, in the era of free trade, for strategic advantage, especially as major governments plan for the post-oil economy. Similarly, even the minute amounts of gallium, indium and arsenic used in doping semiconductor parts are rare enough to need to be recovered, and their toxicity is a critical factor in the global trade in waste and its ultimately social impact in the recycling villages of Southern China and West Africa (Basel Action Network 2002, 2005).

(It should be noted that epoxy is also classified as hazardous waste in many jurisdictions). The common use of sapphire as a substrate in LED fabrication is probably less significant in recycling terms, but it is worth recalling that for the last decade, the world's largest producer of sapphires is no longer Australia but Madagascar, linking LED technology back to the economics of underdevelopment (Duffy 2005), and the suspicion that there may be some link to the 2009 coup in the Indian Ocean island state.

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Statistics are the stock in trade of environmental politics, but they are poor guides when it comes to taking action, not least because of the problem of comparing unlike things. Like digital and analog media. Despite everything, we still believe with at least half our brains that digital media are fundamentally weightless. One calculation suggests that when you add the number of electrons travelling through it, 'The weight of the Internet adds up to just about 0.2 millionths of an ounce' (http://discovermagazine.com/2007/jun/how-much-does-the-internet-weigh). That is certainly one way of looking at it. Another would be to add together the weight of all the computers, servers, mobiles, cables, satellites and routers that make up the technical infrastructure. That is a lot of oil-derived plastic. It's also a lot of metals.

Only minute quantities of minerals are required to build a single chip, but when chip manufacture soars into the billions, the amounts become significant. Perhaps the most infamous is **coltan**, a vital component for mobile phone chips, mined extensively in war-ravaged eastern Congo and Rwanda, where impoverished miners have taken to hunting for bush meat in order to survive: that's mountain gorillas. Or **lanthanides**, the rare earths required for both LCD screens and the batteries for hybrid cars. China, whose public strategy for recovery from the global financial crisis includes moves into high-tech and eco-friendly product manufacture, recently secured significant shares in Arafura, an Australian mining company, to help bolster its global dominance in the rare earths field The Australian, 'China builds rare-earth metal monopoly', March 9, 2009). Then there are sapphires, slivers of which are the favoured based for LEDs, which provide not only large screens but the backlights for laptops. Madagascar recently overtook Australia as the main source, and though retrieving them is considerably less dangerous than other developing world mining operations, they are treated as conflict gems because of the ongoing civil war in the country, and tie them to the international criminal economy.

The mercury-tainted tailings from gold mines, another element vital to digital devices, is only part of the story. The number of toxic materials needed to make the 220 billion silicon chips manufactured annually is staggering: highly corrosive hydrochloric acid; metals such as arsenic, cadmium, and lead; volatile solvents like methyl chloroform, benzene, acetone, and trichloroethylene (TCE); and a number of super toxic gases. And then there are the workers. In the sweatshops of the US-Mexican border where many of our computers and mobiles are assembled, "Under NAFTA, maquiladora employment increased by 54% in Ciudad Juárez, spurring significant population growth. Yet Juárez still has no waste treatment facility to treat sewage produced by the 1.3 million people who now live there." (http://www.corpwatch.org/article.php?id=1528). The relation between environmental and human exploitation and degradation extends to manufacturing.

At the point of consumption, the power use of the internet is intense. Researchers at Stanford found that total power used by servers represented about 1.2% of total US energy use in 2005. Earlier figures from 2000 indicated that office network equipment consumed a further 2%, a figure which is likely to have risen dramatically from the total of 74 terawatt hours over the intervening decade. Globally, the figures can roughly be multiplied by ten. This doesn't include such eminently 'doh' moments as Google's construction of a server farm 250 miles from the nearest hydro plant, with the associated dramatic wastage of power between generator and use. Nor does it include the significant domestic uses of internet, here most of the media-rich files are downloaded and played back.

And then there is the problem of recycling. The Basel Action Network, which monitors infringements of the basel protocols o the export of hazardous waste, reported in 2005 that of 500 40-foot containers shipped to Lagos each month, as much as 75% of the imports were “junk” and not economically repairable or marketable (http://www.ban.org/BANreports/10-24-05/). In the recycling villages of southern Guandong province, child cancer rates are among the highest in the world. The source isn't clear, because of the range of culprits. The glass from cathode ray tubes, now being dumped in huge quantities as they are replaced with groovier LCD and plasma screens, are coated in phosphors, but no-one knows what they have become over their thousands of hours of high-energy irradiation. Likewise the ionised plasma gases in phosphor coated cells which illuminate plasma screens are a totally unknown quantity. certainly the plastic coating from wires, typically burnt off to retrieve the valuable metals, contain toxic and climate-changing PCBs. And on. And on.

The idea of a clean, weightless, immaterial digital realm is entirely bogus. Unfortunately, there are no quick fixes.

For art publishing, there are also some aesthetic problems with the shift to digital, especially when it comes to illustrations. Computer screens typically have a colour gamut – the range of colours they can display – of around 40% of the visible spectrum. In order to squeeze the full spectrum into this restricted palette while keeping the vital colour differences intact, colour management software pushes the colours towards the wavelengths that can be displayed, but does so unevenly across the spectrum. The results are notoriously difficult to predict: different manufacturers use different colour gamuts, so the end result can be radically different when viewed in Windows, Linux or Mac OS.

There's another strategy involved too. Since the colour differences on a display are smaller than they would be in the original artwork, one technical solution has been to boost the illumination available. In the case of professional screens like Apple's Studio Display monitors, the backlighting exceeds 400 candelas per square metre, where a candela is (loosely) the light radiating from a square centimetre of white-hot platinum. Because the combination of LCDs and LEDs in these displays is very energy-efficient, they don't actually melt. But the illumination, which gives the illusion of high resolution and sharply distinct colours, merely foxes the eye, and sacrifices accuracy (print-oriented users turn the brightness control to its lowest setting to get some idea of the likely colours of inks in ordinary light). These anomalies might give some idea of why digital reproductions can be so acid on the eye, or indeed so muddy.

For a journal of record like *Artlink* there have to be some archival issues too. Partly this has to do with colour reproduction, but it is also an issue of storage. There are two problems here. One is that computers are the first machines since Detroit gas-guzzlers to exploit the marketing idea of built-in obsolescence. Each new software release loses backward compatibility (.docx files won't open in the older versions of Word), eventually you have to upgrade to stay in contact . . . And each upgrade ups the demand for processing power, while old technologies like floppy discs and even classic CD-ROMs no longer play on new machines. Archives also archive machines so they can access the old content, but the viability of conserving them fades with each passing year. Unlike paper and ink, machines need replacement parts and maintenance. Today's archive all too soon becomes tomorrow's folder full of unopenable files.

In the grander scale of things, storage is becoming a huge problem. A report from 2008 commissioned by network consultancy EMC estimates that the total amount of information created, captured and replicated in what they call the digital universe (including cameras, X-rays, PVRs and so forth) would grow tenfold between 2006 and 2011, from 180 to 1,800 exabytes (ten to the power of 18 bytes). More intriguingly, the report suggests that, in 2007, the amount of information generated would for the first time outstrip the total available storage, an that that trend would continue for the foreseeable future.

In itself this is not a problem: we mostly do not want our mobile phone calls, e-mails and SMSs filed away for future use. I once worked out that if the entire population of Australia devoted itself exclusively to watching TV, it would only just complete watching the total world output for a year before it had to start all over again. Billions of hours of film and video, billions of files. Electronic repositories of state and public service files will soon be overwhelmed. Cloud computing – which depends on massive server farms and massive energy use to store and cool – is a symptom, not a cure. Information soon will be produced in such quantities that an ever increasing proportion of it will have no home at all.

The choices *Artlink* and other art publishers face are stark. They involve the aesthetic of the printed magazine and of digital displays, the requirement to record and preserve the contemporary art scene for posterity in an era of increasingly ephemeral media, and hard choices about the share publishers have to take in the ecological and sociological circuits of capital and environmental change. These decisions occur in planet-spanning networks of policy, regulation, governance, standardisation, trade, property, toxicology and ecology and involve us in however distant a way with the great themes of poverty and environmental degradation. Whatever solution we go for, it will have to involve a great deal less of something.