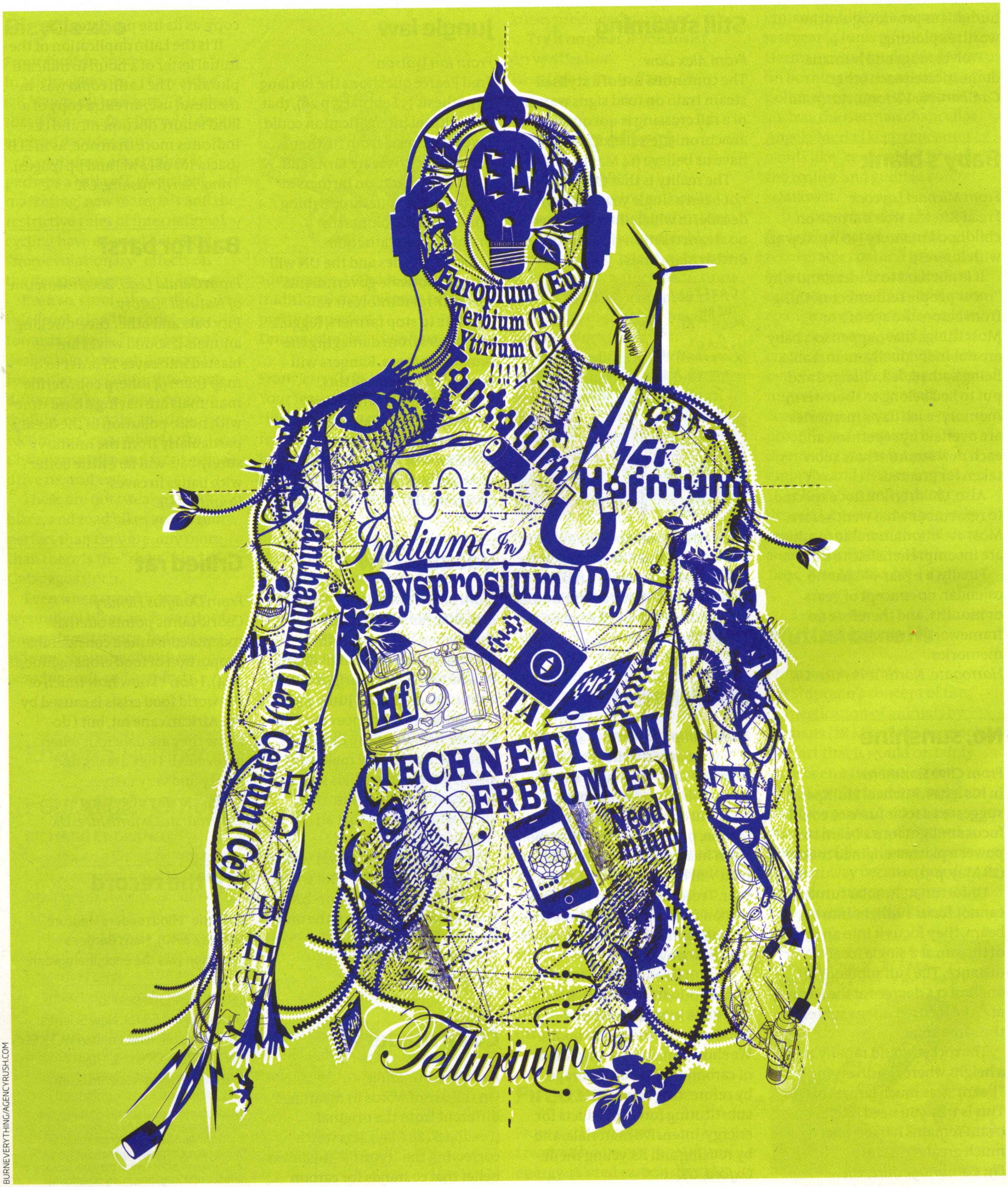


BURNEVERYTHING/AGENCYRUSH.COM

Our modern lives depend on a host of obscure materials – and supplies are running out, says James Mitchell Crow

Unsung elements

AS YOU flick the light switch in your study, an eerie europium glow illuminates your tablet computer, idling on the desk. You unlock it, casually sweeping your finger across its indium-laced touchscreen. Within seconds, pulses of information are pinging along the erbium-paved highways of the internet. Some music to accompany your surfing? No sooner thought than the Beach Boys are wafting through the neodymium magnets of your state-of-the-art headphones.

For many of us, such a scene is mundane reality. We rarely stop to think of the advances in materials that underlie our material advances. Yet almost all our personal gadgets and technological innovations have something in common: they rely on some extremely unfamiliar materials from the nether reaches of the periodic table. Even if you have never heard of the likes of hafnium, erbium or tantalum, chances are there is some not too far from where you are sitting.

You could soon be hearing much more about them, too. Demand for many of these unsung elements is soaring, so much so that it could soon outstrip supply. That's partly down to our insatiable hunger for the latest gadgetry, but increasingly it is also being driven by the green-energy revolution. For every headphone or computer hard-drive that depends on the magnetic properties of neodymium or dysprosium, a wind turbine or motor for an electric car demands even more of the stuff. Similarly, the properties that make indium indispensable for every touchscreen make it a leading light in the next generation of solar cells.

All that means we are heading for a crunch. In its Critical Materials Strategy, published in December last year, the US Department of Energy (DoE) assessed 14 elements of specific importance to clean-energy technologies. It identified six at "critical" risk of supply disruption within the next five years: indium, and five "rare earth" elements, europium, neodymium, terbium, yttrium and dysprosium. It rates a further three – cerium, lanthanum and tellurium – as "near-critical".

What's the fuss?

It's not that these elements aren't there: by and large they make up a few parts per billion of Earth's crust. "We just don't know where they are," says Murray Hitzman, an economic geologist at the Colorado School of Mines in Golden. Traditionally, these elements just haven't been worth that much to us. Such supplies are often isolated as by-products during the mining of materials already used in vast quantities, such as aluminium, zinc and copper. Copper mining, for example, has given us more than enough tellurium, a key component of next-generation solar cells, to cover our present needs – and made it artificially cheap.

"People who are dealing with these new technologies look at the price of tellurium, say, and think, well, this isn't so expensive so what's the fuss?" says Robert Jaffe, a physicist at the Massachusetts Institute of Technology. He chaired a joint committee of the American Physical Society and the Materials Research Society on "Energy Critical Elements" that reported in February this year. The problem, as the report makes clear, is that the economics changes radically when demand for these materials outstrips what we can supply just by the by. "Then suddenly you have to think about mining these elements directly, as primary ores," says Jaffe. That raises the cost dramatically – presuming we even know where to dig.

An element's price isn't the only problem. The rare earth group of elements, to which many of the most technologically critical belong, are generally found together in ores that also contain small amounts of radioactive elements such as thorium and uranium. In 1998, chemical processing of these ores was suspended at the only US mine for rare earth elements in Mountain Pass, California, due to environmental concerns associated with these radioactive contaminants. The mine is expected to reopen with improved safeguards later this year, but until then the world is dependent on China for nearly all its rare-earth supplies. Since 2005, China has been placing increasingly stringent limits on exports, citing demand from its own burgeoning manufacturing industries.

That means politicians hoping to wean the west off its ruinous oil dependence are in for a nasty surprise: new and greener technologies are hardly a recipe for self-sufficiency. "There is no country that has sufficient resources of all these minerals to close off trade with the rest of the world," says Jaffe.

So what can we do? Finding more readily available materials that perform the same technological tricks is unlikely, says Karl Gschneidner, a metallurgist at the DoE's Ames Laboratory in Iowa. Europium has been used to generate red light in televisions for almost 50 years, he says, while neodymium magnets have been around for 25. "People have been looking ever since day one to replace these things, and nobody's done it yet."

Others take heart from the success story › of rhenium. This is probably the rarest naturally occurring element, with a concentration of just 0.7 parts per billion in Earth's crust. Ten years ago, it was the critical ingredient in heat-resistant superalloys for gas-turbine engines in aircraft and industrial power generation. In 2006, the principal manufacturer General Electric spotted a crunch was looming and instigated both a recycling scheme to reclaim the element from old turbines, and a research programme that developed rhenium-reduced and rhenium-free superalloys.

No longer throwing these materials away is one obvious way of propping up supplies. "Tellurium ought to be regarded as more precious than gold – it is; it is rarer," says Jaffe. Yet in many cases less than 1 per cent of these technologically critical materials ends up being recycled, according to the United Nations Environment Programme's latest report on metal recycling, published in May.

Even if we were to dramatically improve this record, some basic geological research to find new sources of these elements is crucial – and needed fast. Technological concerns and necessary environmental and social safeguards mean it can take 15 years from the initial discovery of an ore deposit in the developed world to its commercial exploitation, says Hitzman.

Rhenium again shows how quickly the outlook can change. In 2009, miners at a copper mine in Cloncurry, Queensland, Australia, discovered a huge, high-grade rhenium seam geologically unlike anything seen before. "It could saturate the world rhenium market for a number of years – and it was found by accident," says Hitzman.

In the end, we should thank China for its decision to restrict exports of rare earths, says Jaffe, as it has brought the issue of technologically critical elements to our attention a decade earlier than would otherwise have happened. Even so, weaning ourselves off these exotic substances will be an immense challenge – as our brief survey of some of these unsung yet indispensable elements shows. ■

James Mitchell Crow is a freelance writer based in Melbourne, Australia

Further reading: US Department of Energy, *Critical Materials Strategy*, bit.ly/eLFwuo. American Physical Society and Materials Research Society, *Energy Critical Elements*, bit.ly/eO9QOT. US Geological Survey, *Mineral Commodity Summaries*, on.doi.gov/hzZqDO

NEODYMIUM

Rare earth element

ATOMIC NUMBER: 60
USED IN: high-performance magnets
DOE CRITICALITY RATING: critical

Neodymium is the epitome of green, having been first harnessed to generate the light in green laser pointers. Fittingly, it has found a place at the heart of more than one green energy technology: in the magnets that keep the motors of both wind turbines and electric cars turning.

When mixed with iron and boron, neodymium makes magnets that are, weight for weight, 12 times stronger than conventional iron magnets. That's one reason your latest laptop is so compact and lightweight: the magnets allow finer control in the motors that spin the hard disc and the arm that writes and reads data to and from it, allowing much more information to be stored in the same area.

These numerous uses make for a perfect storm threatening future supplies. In its Critical Materials Strategy, which assesses elements crucial for future green-energy technologies, the US Department of Energy estimates that wind turbines and electric cars could make up 40 per cent of neodymium demand in an already overstretched market. Together with increasing demand for the element in personal electronic devices, that makes for a clear "critical" rating.

ERBIUM

Rare earth element

ATOMIC NUMBER: 68
USED IN: optical fibres
CRITICALITY RATING: not rated

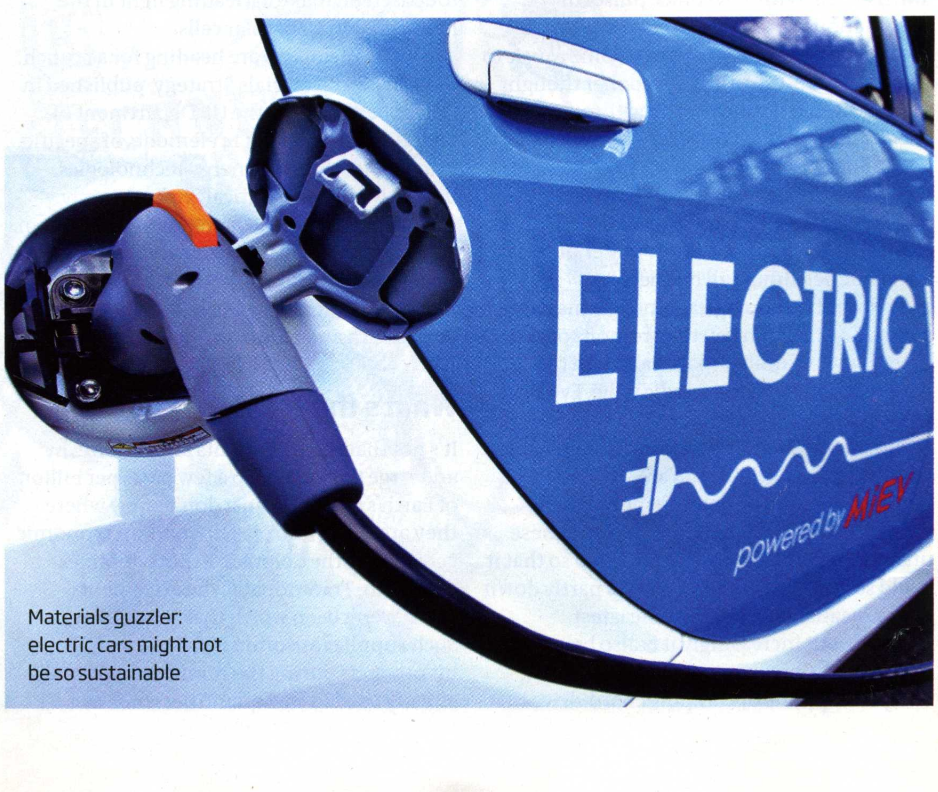
Reading this article online? Or keeping half an eye on your email while you read? If so you are probably doing it with erbium.

Erbium is a crucial ingredient in the optical fibres used to transport light-encoded information around the world. These cables are remarkably good at keeping light bouncing along, easily outperforming a copper cable transporting an electrical signal. Even so, the light signal slowly fades as it racks up the kilometres, making amplification necessary.

Excitable ions of erbium are just the ticket. Embedded every so often within short sections of the optical fibre wall, they are pushed into a high-energy state by irradiating them with a laser. Light signals coming in along the fibre then stimulate the excited erbium ions to release their stored energy as more light of precisely the right wavelength, giving the signals a boost.

The good news is that while supplies of erbium are relatively tight, demand for optical fibres is not skyrocketing as it is for other technologies. On current trends, this is one element we will continue to be able to live with.

"It's not that these materials are not there – it's just that we don't know where they are"



Materials guzzler: electric cars might not be so sustainable

CRAIG RUTTLE/BLOOMBERG VIA GETTY IMAGES

TELLURIUM
Metalloid

ATOMIC NUMBER: 52
USED IN: solar cells
CRITICALITY RATING: near-critical

In 2009, solar cells made from thin films of cadmium telluride became the first to undercut bulky silicon panels in cost per watt of electricity generating capacity. That points to a cheaper future for solar power – perhaps.

Both cadmium and tellurium are mining by-products – cadmium from zinc, and tellurium from copper. Cadmium's toxicity means it is in plentiful supply: zinc producers are obliged to remove it during refining, and it has precious few other uses. "The people who manufacture cadmium telluride photocells often say one of the best things you can do with cadmium is to put it between two sheets of glass and leave it there," says Robert Jaffe, a physicist at the Massachusetts Institute of Technology.

For tellurium, the situation is reversed. Because the global market for the element has been minute compared with that for copper – some $100 million against over $100 billion – there has been little incentive to extract it. That will change as demand grows, but better extraction methods are expected to only double the supply, which will be nowhere near enough to cover the predicted demand if the new-style solar cells take off. The US DoE anticipates a supply shortfall by 2025.

HAFNIUM
Transition metal

ATOMIC NUMBER: 72
USED IN: computer chips
CRITICALITY RATING: not rated

Hafnium's peerless heat resistance has taken it to the moon and back as part of the alloy used in the nozzle of rocket thrusters fitted to the Apollo lunar module. Since 2007, though, it has also been found much closer to home, in the minuscule transistors of powerful computer chips.

That's because hafnium oxide is a highly effective electrical insulator. Compared with silicon dioxide, which is conventionally used to switch transistors on and off, it is much less likely to let unwanted currents seep through. It also switches 20 per cent faster, allowing more information to pass. This has enabled transistor size to shrink from 65 nanometres with silicon dioxide first to 45 nm and now to 32 nm.

Such innovations keep our smartphones smart and small. And hafnium will probably not be the thing that slows that progress: despite its low profile, it is a relatively abundant element. Making up several parts per million of the Earth's crust, it is distributed widely around the globe.

TANTALUM
Transition metal

ATOMIC NUMBER: 73
USED IN: Almost all handheld electronics
CRITICALITY RATING: not rated


Touchscreen technologies face an uncertain future

TOOGA/THE IMAGEBANK/GETTY

Your smartphone or tablet computer is a veritable wonder of modern materials technology, with its touchscreen interface incorporating indium (page 40), compact lithium-ion battery and tiny processors packed with nanoscale transistors (see hafnium, left).

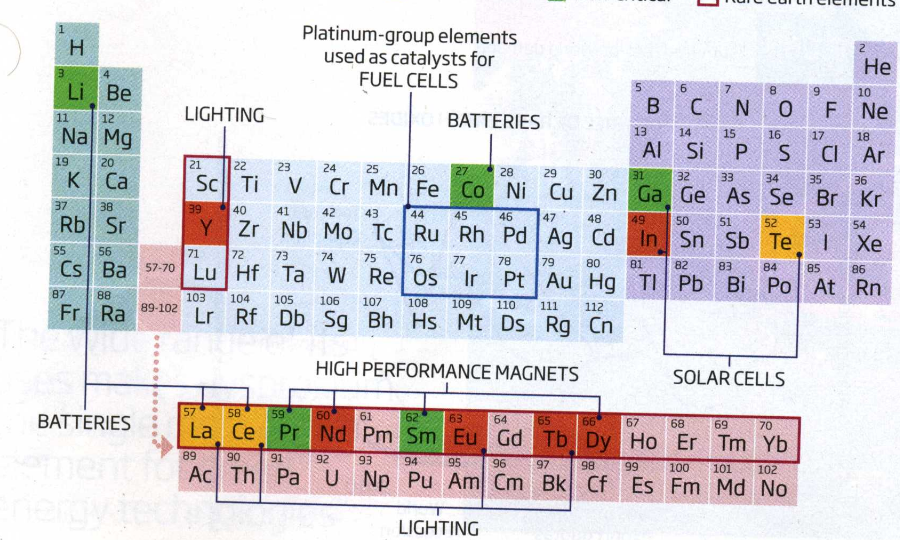
This also extends to its capacitors, the humble components that store energy and smooth power flow in electronic circuits. It is thanks to two-faced tantalum that they remain so slimline. In its pure form, this metal forms one of two conducting plates on which charge is stored. As an oxide, meanwhile, it makes a highly effective insulator, only a thin layer of which is needed to prevent leakage between the plates. As a bonus, the oxide is self-healing, rapidly reforming to plug any leak that lets current through.

It is fortunate, then, that the US Geological Survey believes that tantalum is in plentiful supply, with known deposits covering projected need. In fact, during the recent global economic slowdown, several mines were temporarily shut down as demand dropped. ›

Clean green future?

In 2010 the US Department of Energy assessed the risk of short-term supply disruption for 14 elements crucial to future green technology

Critical risk of supply disruption by 2015 | Near-critical | Non-critical | Rare earth elements



TECHNETIUM

Transition metal

ATOMIC NUMBER: 43
USED IN: medical imaging
CRITICALITY RATING: not rated

Technetium is exceedingly rare. Until 1937, it was just a hole in the periodic table. When element 43 was finally isolated, it was by the then-innovative expedient of synthesising it, rather than by digging it out of the ground.

That is because technetium, though present within uranium ores in Earth's crust, quickly falls apart through radioactive decay. What frustrated early element hunters is a boon for medical imaging. One of the element's forms, the isomer technetium-99m, has a half-life of just 6 hours – long enough for it to be injected into a patient and light up the body part of interest, but short enough to minimise radiation exposure.

Globally, around 30 million medical procedures involving technetium are performed each year. But two new Canadian reactors which were to secure supplies of technetium and other medical isotopes have been mothballed. So it questionable whether these procedures can continue at the same rate (*New Scientist*, 16 January 2010, p 30). For now, a handful of ageing reactors supplies the world's hospitals.

INDIUM

Post-transition metal

ATOMIC NUMBER: 49
USED IN: touchscreens, solar cells
CRITICALITY RATING: critical

We spend a lot of time looking at indium, yet rarely see it. The alloy indium tin oxide (ITO) possesses the rare combination of being both electrically conductive and optically transparent. That makes it essential for flat screen displays and televisions, where it forms the see-through front electrode controlling each pixel. A layer of ITO on a smartphone's screen gives it touch-sensitive conductivity, enabling the device to detect taps, swipes and pinches.

When mixed with other metals, indium loses its transparency and instead becomes a light-collector. Alongside cadmium telluride cells (see tellurium, page 39), solar cells made of copper, indium and selenium, sometimes with a sprinkle of gallium, are starting to challenge silicon's pre-eminence.

The US DoE puts a "critical" alarm on supplies of indium for the next five years, but will reduce this to "near-critical" for the period 2015 to 2025 as we get better at extracting the element or develop indium-free technologies such as conductive polymers or nanowires (*New Scientist*, 23 October 2010, p 40). Even so, without expanded production after 2015, the DoE says reductions in "non-clean energy demand" will be needed "to prevent shortages and price spikes". In other words, we might need to choose which is the more important – smartphones or solar cells.

DYSPROSIUM

Rare earth element

ATOMIC NUMBER: 66
USED IN: High-temperature magnets
CRITICALITYRATING: critical

LIKE neodymium, dysprosium is prized for its magnetic properties – not least, when mixed with terbium and iron to form the alloy Terfenol D. It has the peerless ability to change shape in response to a magnetic field.

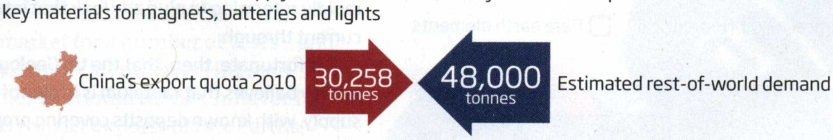
This "magnetostrictive" property has led to some far-out uses. The US navy has used Terfenol-D to develop an advanced active sonar transducer, producing and then picking up high-powered "pings" underwater.

Dysprosium's greatest selling point, however, is how it handles the heat. Magnets made from a pure neodymium-iron-boron alloy lose their magnetisation at temperatures above 300 °C. Adding in a small amount of dysprosium, at about 5 per cent by weight, solves that problem, making the element a vital component in high-performance magnets found in countless technologies from turbines to hard discs.

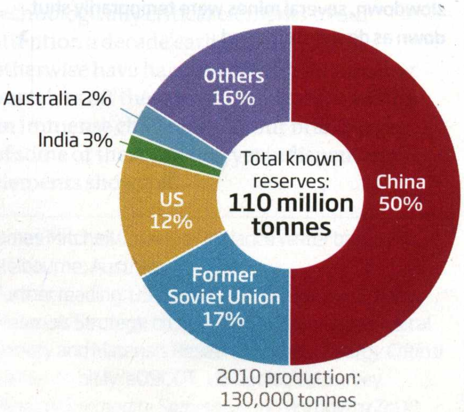
According to the US DoE, the wide range of its current and projected uses, together with the lack of any immediately suitable replacement, makes dysprosium the single most critical element for emerging clean energy technologies. China is the only country with significant known deposits, with the new mines opening in Australia and Canada only containing small quantities of the element in their rare earth ores. Even the US DoE's most conservative projections predict a shortfall of dysprosium before 2015.

Scarce rare earths

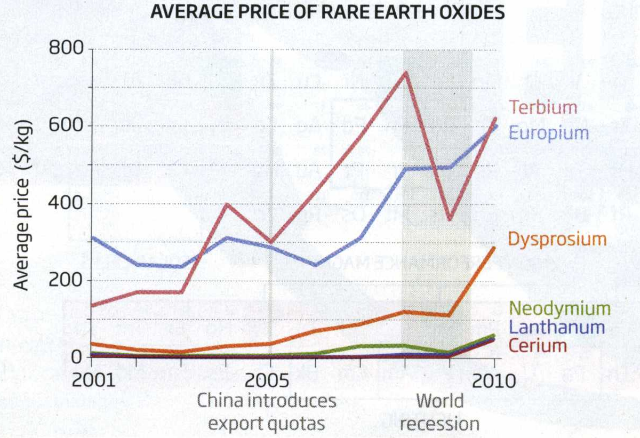
China currently mines over 90% of the supply of rare earth elements, yet limits its exports. It has 50% of the world's reserves. These are key materials for magnets, batteries and lights



RARE EARTH RESERVES



AVERAGE PRICE OF RARE EARTH OXIDES



LANTHANUM AND CERIUM

Rare earth elements

ATOMIC NUMBERS: 57; 58
USED IN: Batteries
CRITICALITY RATINGS: near-critical; near-critical

When it comes to batteries, lithium is the true Olympian. Lithium-ion batteries are unsurpassed in energy density, and dominate the market in laptops, cellphones and other devices where a slimline figure is all-important.

Yet they are also rather explosive characters: computer manufacturer Dell recalled four million lithium laptop batteries in 2006 amid fears they might burst into flames if overheated. That risk makes them unsuitable for use in electric and hybrid electric cars, leaving the market to the less explosion-prone nickel-metal-hydride batteries.

This is where lanthanum and cerium come in. They are the main components of a "mischmetal" mixture of rare earth elements that makes up the nickel-metal-hydride battery's negative electrode. The increased demand for electric cars, and the elements' subsidiary roles as phosphorescents in energy-saving light bulbs, place lanthanum and cerium on the US DoE's short-term "near-critical" list for green technologies – a position also assumed by lithium in the medium term.

Meanwhile, a mischmetal mixture is not totally inert: strike one and it produces a spark. This property has seen it being widely adopted as the ignition element in cigarette lighters – clearly no skill for would-be Olympians.

EUROPIUM, TERBIUM AND YTTRIUM

Rare earth elements

ATOMIC NUMBERS: 63; 65; 39
USED IN: energy-efficient lighting
CRITICALITY RATINGS: critical; critical; critical

Europium and terbium have long been an entertaining double act: their phosphorescent properties – terbium in yellow-green and europium in blue and red – help to produce the images on most television screens. Their rare earth cousin yttrium plays a quiet but crucial supporting role, hosting the red-releasing europium ions.

These colourful qualities have recently secured the europium-terbium duo another gig in energy-saving compact fluorescent light bulbs. These bulbs work by exciting mercury vapour to emit ultraviolet light, which is then absorbed by phosphorescent materials coating their insides to produce visible frequencies of light. One complaint made about early versions was that they did not produce the same warm light as the incandescent tungsten bulbs they replaced – a problem resolved by switching the coating to the right blend of terbium and europium.

The next generation of energy-efficient lighting, based on LEDs, might see europium strike out alone: adding europium ions to a blue LED turns some of its light yellow, giving a white output overall. That could free up terbium to pursue its own projects, such as perhaps replacing dysprosium in the manufacture of high temperature permanent magnets.

All that depends on securing additional supplies, however. According to the DoE, europium could be in short supply as early as 2015 – and terbium even sooner. For yttrium we have already reached crunch time: demand outstripped supply in 2010. ■

Smelting lanthanum in inner Mongolia for hybrid and electric cars

"The wide range of its uses makes dysprosium the single most critical element for green energy technologies"