Rare earth elements are vital to the electronics industry, but one country supplies 97% of the world’s needs.

By David Boothroyd.

What do Ics, lasers, optical fibres, capacitors, displays and headphones have in common? Answer: they are all electronic products that depend on one or more of the rare earth elements. And that list is far from complete.

There are 17 rare earth elements, all vital to the electronics industry in some form. Yet, despite their name, some rare earth elements are relatively plentiful: cerium is, apparently, as abundant as copper. They are regarded as ‘rare’ because deposits of these elements are generally not exploitable commercially.

Though typically used in relatively small quantities per product, a major worry has emerged recently about the guaranteed continuation of their supply – some 97% of rare earths are currently supplied by China.

Over the last few years, China has been reducing its exports of rare earths and recently cut back more drastically, by around 70%. And an ominous note was sounded when China completely halted supplies to Japan after a row about Japan’s arrest of a Chinese boat captain. He was released and supplies resumed. Squabbles aside, the prediction is that, within a few years, China will need its entire output of rare earths to satisfy its own domestic demand.

So action is being taken to avoid the drastic scenario of the supply of rare earths simply coming to a halt (see below). If it did, it is astonishing how many electronic products we use every day would become either much more difficult – even impossible – to make or much more expensive.

Take one of the most widely used rare earths – neodymium. It was first used to generate the light in green laser pointers, but then it was found that, when mixed with iron and boron, neodymium makes magnets that are 1 2 times stronger than conventional iron magnets. Result: neodymium magnets are used in in-ear headphones, microphones, loudspeakers and hard disk drives, as well in hybrid cars and generators.

Where low mass is important, they are vital: for example, in laptops, they provide finer control in the motors that spin the hard disk and the arm that
writes and reads data to and from it, allowing much more information to be stored in the same area.

In its Critical Materials Strategy, the US Department of Energy (DoE) estimates new uses of neodymium, in products like wind turbines and electric cars, could make up 40% of demand in an already overstretched market, which is why any shortages would be critical.

Most of the rare earths vital to electronics are less well known: erbium is one example, a crucial ingredient in optical fibres. For long distance optical fibre transmission, amplification is vital and is achieved with the help of erbium. Embedded within short sections of the optical fibre, excitable ions of erbium are pushed into a high energy state by irradiating them with a laser. Light signals travelling down the fibre stimulate the erbium ions to release their stored energy as more light of precisely the correct wavelength, amplifying the signals.

Tellurium is an element that could see a huge increase in demand because in 2009, solar cells made from thin films of cadmium telluride became the first to outdo silicon panels in terms of the cost of generating a Watt of electricity. Until now, there has been little interest in tellurium, but if it leads to significantly cheaper solar power, demand will rocket and that is why the DoE anticipates potential shortages by 2025.

Hafnium is another rare earth proving itself vital to the semiconductor industry; hafnium oxide is a highly effective electrical insulator. It outperforms the standard transistor material, silicon dioxide, in reducing leakage current, while switching 20% faster. It has been a major factor in enabling the industry to move to ever smaller process nodes.

Also central to semiconductors is tantalum, key to billions of capacitors used worldwide in products like smartphones and tablet computers. In its pure form, this metal forms one of two conducting plates on which charge is stored. As an oxide, it is an excellent insulator, preventing current leakage between the plates, and is also self healing, reforming to plug any current leakage.

One of the most widely used rare earths is indium, which we all spend a lot of time looking at. The alloy indium tin oxide (ITO) provides the rare combination of both electrical conductivity and optical transparency, which makes it perfect for flat screen displays and TVs, where it forms the see-through front electrode controlling each pixel. A layer of ITO on a smartphone's screen gives it the touch sensitive conductivity to which we have been accustomed in the last few years. Mixed with other metals, indium becomes a light collector and can be used to create new kinds of solar cells, together with copper and selenium.

Jaffe: “The magnetic properties of pure metals and relatively simple alloys have been thoroughly explored and there is nothing as good as rare earth magnets.”
Another rare earth valuable for its magnetic properties is dysprosium. When mixed with terbium and iron, it creates the alloy Terfenol D, which changes shape in response to a magnetic field, a property known as magnetostriction. Dysprosium can also handle heat; while magnets made from a pure neodymium-iron-boron alloy lose magnetisation at more than 300°C, adding a small amount of dysprosium solves the problem. This make the element invaluable in magnets used in devices such as turbines and hard disk drives.

Other rare earths include: technetium, used in medical imaging; lanthanum and cerium, the main components of a ‘mischmetal’ (an alloy of rare earth elements) used to create the negative electrode in nickel metal hydride batteries – and cerium also helps to polish disk drives and monitor screens; yttrium, important in microwave communication, and yttrium iron garnets act as resonators in frequency meters; and europium and terbium.

The last have been used for decades to produce images in colour tvs, thanks to their phosphorescent properties – terbium for yellow-green and europium for blue and red. More recently, energy saving compact fluorescent light bulbs have used them to generate the same warm light as the incandescent tungsten bulbs they replaced.

Is there a single reason why the rare earths have proved so valuable for such a range of technologies? The answer is no – it is more a result of each element’s particular physical characteristics, notably the electron configuration of the atoms, according to one of the world’s leading experts, Karl Gschneidner, a senior metallurgist at the DoE’s Ames Laboratory.

"Some of the properties are quite similar; basically, their chemical properties. That is why they are difficult to separate from each other in their ores and that is why they are mixed together in the ores. But many of the physical properties vary quite a bit from one another, especially those which depend upon the 4f electron [a particular electron shell in the configuration of the atom], that is the magnetic, optical and electronic properties. Even some of the physical properties, which are not directly connected to the 4f electrons, vary considerably. For example the melting points vary from 798°C for cerium to 1663°C for lutetium."

What makes the rare earths so special is the way they can react with other elements to get results that neither could achieve alone, especially in the areas of magnets and phosphors, as Robert Jaffe, a Professor of Physics at MIT, explains.

"The result is high field strength, high coercivity, light weight magnets, clearly valuable in tiny devices where magnetically stored information has to be moved around, like hard disk read/write operations. The magnetic properties of pure metals and relatively simple alloys have been thoroughly explored and there is nothing as good as rare earth magnets. Two paradigms for magnetic material are NeBFe (neodymium-boron-iron) and SmCo [samarium-cobalt], with the former most popular now.

"In phosphors, europium, terbium and others absorb high frequency light and then re emit the light in regions of the spectrum that are very useful in manipulation of colour, hence their use in flat panel displays and compact fluorescent lights."

Another example is neodymium oxide, which can be added to cct glass to enhance picture brightness by absorbing yellow light waves. Neodymium has a strong absorption band centred at 580nm, which helps clarify the eye’s discrimination between reds and greens.

Given how vital they are for the electronics industry and other technologies – by one estimate, £3trillion worth of industries depend on them – it is remarkable that the world has been so complacent about sourcing rare earths, allowing a single country to virtually monopolise the supply. But that is now changing.

For example, the Mountain Pass mine in California is being reactivated by Molycorp Minerals in a £781million project, having been mothballed in 2002. Others include the Nolans and Mount Weld Projects in Australia, a site at Hadas Lake in Canada and projects in Russia and Malaysia. In Elk Creek, Nebraska, Quantum Rare Earth Development is drilling to look for supplies and has called on President Obama to move aggressively to create a stockpile of rare earths.

Another associated problem is the lack of people with rare earth expertise, as Gschneidner says. “There is a serious lack of technically trained personnel to bring the entire rare earth industry – from mining to OEMs – up to full speed in the next few years. Before the disruption of the US rare earth industry, about 25,000 people were employed in all aspects. Today, there are only about 1500.”

Despite these moves, it could be years before supplies are enhanced significantly. For the longer term, there are prospects of better sources emerging. Just a couple of months ago, scientists from the University of Tokyo announced they had found the minerals in the floor of the Pacific Ocean in such high density that a single square kilometre of ocean floor could provide 20% of current annual world consumption. Two regions near Hawaii and Tahiti might contain as much as 100billion tonnes.

The team was led to the sea floor because they reasoned that many rock samples on land containing metallic elements were originally laid down as ocean sediments. "It seems natural to find rare earth element rich mud on the sea floor," they said.

A final extraordinary fact about rare earths is that, despite their importance, we have hardly bothered to recycle them. In an age where metals like aluminium, copper, lead and tin have recycling rates of between 25% and 75%, it is estimated that only 1% of rare earths are recycled. If we do not correct that quickly, over the next few years at least, rare earths could live up to their name with a vengeance.

According to the US Geological Survey, the Elk Creek Carbonatite in Nebraska is potentially the ‘largest global resource of niobium and rare earth elements’. Courtesy: Quantum Rare Earth Development