

Elements of Scarcity

by David J. Cole-Hamilton

We used to chant a rhyme when we were young (I had three dominant sisters and no brothers!): “What are little girls made of? Sugar and spice and all things nice. What are little boys made of? Slugs and snails and puppy dog’s tails.” The truth is, of course, that they are all made from the same things, as is everything around them that makes up our diverse and beautiful world as well as much of the universe—the 90 natural elements that are the building blocks of life. It is an amazing thought that these are *only* building blocks so it is essential that we should nurture and cherish all of them if we are to continue to enjoy life in its abundance.

That is why the European Chemical Society, EuChemS, has decided to celebrate the *International Year of the Periodic Table* by designing and releasing a new version of the Periodic Table which highlights these 90 elements (Figure 1) [1]. It has been designed with the aim of placing it in every age-appropriate school in Europe and already many countries are delivering poster sized versions to schools. Following its launch in the European Parliament by Catherine Stihler and Clare Moody MEPs, it has achieved publicity in at least six continents.

The Periodic Table

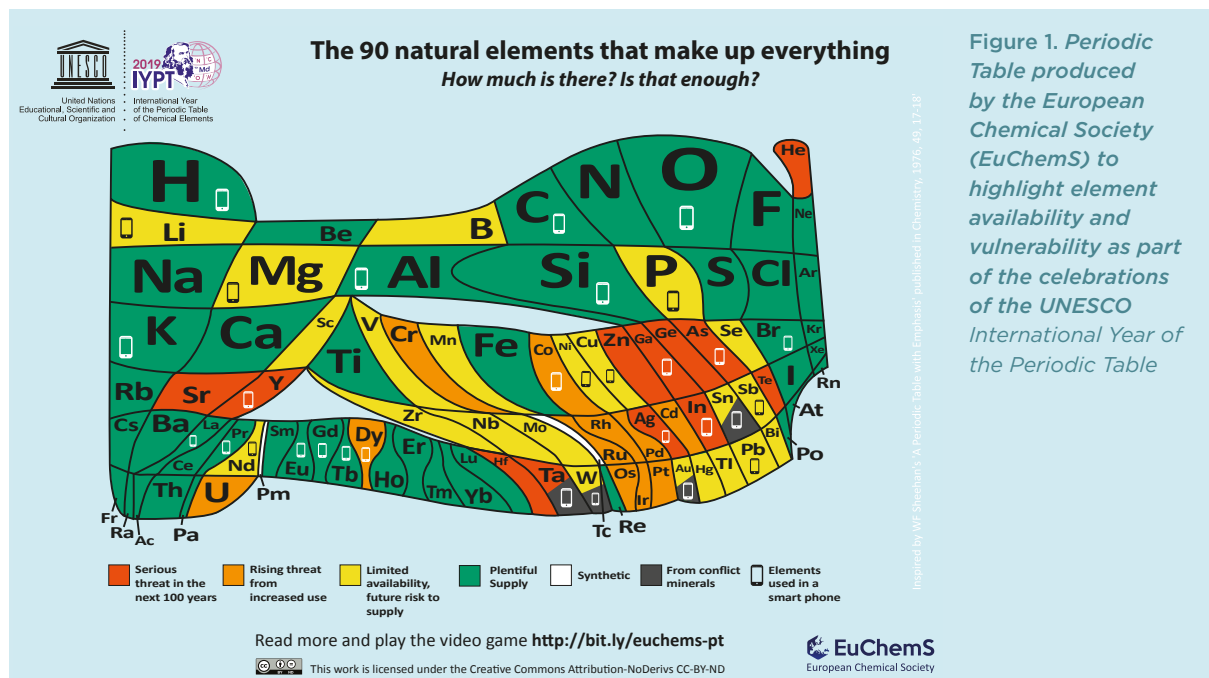
The Periodic Table is something almost everyone has seen during their school education. To chemists it

is beautiful summary of the whole of chemistry, which can be used to predict the properties of elements and to direct new research aimed at developing important new compounds and materials with amazing properties, as summarised in many of the other chapters of this issue of *Chemistry International*.

To the general public, however, the Periodic Table (Figure 2) is at best a curiosity and a worst a reminder of boring days in classrooms where it hung forlornly as an obscure grid on the wall. This is why the EuChemS Periodic Table appears so different from a normal periodic table. It has been designed to catch the eye so everyone will ask “What is that?” As soon as that question is asked, interest is aroused and people will dig more deeply to understand more.

Element availability

In the EuChemS Periodic Table, the area occupied by each element is proportional to the amount of that element in the earth’s crust and in the atmosphere (this only affects nitrogen) [2]. The scale is logarithmic (log megatonne atoms) since the less abundant elements would be invisible on a linear scale. Even so, we have had to enlarge some of the smaller ones so they can be seen. The very different amounts of the elements leads to a Periodic Table with humps and sweeping curves rather than a grid of straight lines. It also allows the lanthanoids (lanthanum to lutetium) to be placed in their rightful position. The overall shape is based on an original idea of J. F. Sheehan, [3] as modified by K.



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A. Carrado, [4] but the areas all had to be redrawn to obtain the right relative sizes.

The transuranic elements have all been omitted because none of them occurs naturally to a significant extent, although plutonium, which is present in trace amounts in natural uranium, is now available in quite high quantities as a byproduct of nuclear power generation. Technetium does occur in small amounts in the earth's crust, and is extensively used in medical imaging but all of that is prepared in the laboratory from a radioactive isotope of molybdenum.

Element vulnerability

Of course, the amount of an element that is available does not tell us anything about whether we should be worried about its supply. This also depends on the extent to which it is used and whether or not it is recycled.

The EuChemS Periodic Table colour codes [5] each element to indicate how long it will last if we continue to use it at the rate we do at the moment. With one exception, elements are not lost to us, they are dispersed more widely and become more and more difficult to collect and supply. In the Table, elements coloured red are expected to be dispersed within 100 years whilst those in green are plentifully available, in some cases being recycled by natural processes. Orange and yellow colour elements that may become vulnerable as we use them more.

Four elements—tin, tantalum, tungsten, and gold—are partially coloured black. These are elements that come from mines where wars are fought over the mineral rights or where profits from the mines fund wars. Most of these are in the Democratic Republic of the Congo. These elements also come from other places so care must be taken to ensure that samples used in manufacturing do not come from these mines. Traceability is the process by which ores are tagged and traced throughout

their life from the mine through all the processing steps to the final manufacture of a device. It is also being extended to the fate of that element after the end of the useful life of the device. This is crucially important to ensure that we do not have elements in our pockets from places where people have died to extract them.

Elements in a smart phone

31 of the elements in the EuChemS Periodic Table bear a smart phone symbol because they are used in manufacturing most smart phones [6]. Overall, there may be as many as 70 that are used in one smart phone or another. A smart phone has been chosen because almost everyone has one or more but it is representative of many other common electrical goods like laptops, tablets, etc.

Amongst the 31 elements in the smart phone, six are expected to be dispersed within 100 years and all four elements from conflict minerals are included. This is why traceability is so important in the smart phone industry and most manufacturers do try to make sure they know the origin of these elements.

At present, an astonishing 10 million smart phones are exchanged in Europe **every month**; 12 million in the USA. Think about the amounts of these scarce elements that represents and then think about what happens to them. A very significant percentage of used phones are kept in drawers by their owners (> 50% of UK homes have at least one) [7] these elements are lost to society. The rest are sometimes re-used but eventually end up in the developing world. There, artisanal miners, often children, try to extract the gold from them using strong acid, sometimes in open pools in the street. The remains of the phones are piled up by the roadside or sent to landfill.

Let's take a look at a couple of examples of elements in your phone:

1	H																	2	He																																																																																																																																																																		
3	Li	4	Be																	5	B	6	C	7	N	8	O	9	F	10	Ne																																																																																																																																																						
11	Na	12	Mg																	13	Al	14	Si	15	P	16	S	17	Cl	18	Ar																																																																																																																																																						
19	K	20	Ca	21	Sc	22	Ti	23	V	24	Cr	25	Mn	26	Fe	27	Co	28	Ni	29	Cu	30	Zn	31	Ga	32	Ge	33	As	34	Se	35	Br	36	Kr																																																																																																																																																		
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Figure 2. A standard Periodic Table, although this one is made by the technique of macramé by Jane Stewart for the International Year of the Periodic Table. It consists of 200,000 knots. Photograph courtesy of Helen Stewart.

Tantalum (Ta)

Tantalum can come from conflict minerals and the amount available is enough for less than 50 years at current usage rates without recycling. It is used in microcapacitors because the highly dielectric constant of tantalum oxide means that very thin films are efficient insulators. Each iPhone has one tantalum based capacitor on the mother board containing 2 cents worth of tantalum. That does not sound like much, but remember the huge number of iPhones in circulation (> 40 % market share). In the period 2001-2006 only about 1 % of the tantalum used was from conflict zones. As tantalum is dispersed and the price from non-conflict sources increases, the temptation to break the taboo and use material mined in conflict zones will increase.



Images Credits, see page 3.



in the sea off Japan in 2018. These deposits appear to be sufficient to supply our needs for many years to come.

Indium (In)

Indium is a component of indium tin oxide which makes up the conducting layer in every touch screen. It is used in cold welding of electrical circuits, in lasers and detectors for telecommunications, and in blue lights. Indium is a by-product of zinc manufacturing and there is only enough from this source for 20 years if we continue to use it at the current rate. After the zinc-related source is used up we shall still be able to acquire indium from other ores, but its concentration is lower and so the extraction price will be higher.

Cobalt (Co)

Cobalt is used in the lithium batteries that power so many of our devices and an increasing number of cars. Increased use could become a major cause for concern in years to come. More seriously, cobalt has not yet been classified as a conflict mineral. However, some of it comes from the Democratic Republic of the Congo, where it is mined under appalling conditions, often by children. As demand increases, it will be essential to use traceability to ensure that cobalt is not obtained by exploiting child labour.

Rare earth elements (lanthanoids)

Many of the lanthanoids are used to provide the bright coloured light emitters of a smart phone display, yet most of them are coloured green in the EuChemS Periodic Table suggesting that they are in plentiful supply. This is because large deposits of these elements were discovered

The one exception is dysprosium which does provide coloured emitters for phones but is coloured orange on the Table because it has another very important use— in the magnets which allow windmills to convert wind energy into electricity. The climate crisis caused by global warming means that we must urgently reduce CO₂ emissions from burning fossil fuels. To do this the use of windmills must increase and with it the consumption of dysprosium.

Helium (He)

The one element that can be lost rather than just dispersed is helium. It is the second lightest element and is very stable, being an inert gas. This means that if it is released it floats slowly up to the outer edges of the atmosphere then escapes the earth's gravitational pull and is lost into outer space forever. Helium is the second most abundant element in the universe, being the first and main product of nuclear fusion in stars, as discussed elsewhere in this issue. On earth, it is a different story. Helium is formed by the decay of radioactive nuclei in rocks and much goes straight to outer space, as described above. The rest collects in underground caves mixed with other gases.

Helium boils at 4° above absolute zero and provides the only liquid cold enough to cool the superconducting magnets in MRI scanners. This is its main use but other uses include weather balloons, inert atmospheres for semiconductor processing, lifting, and as a partial replacement for nitrogen in the air breathed by deep sea divers to avoid nitrogen narcosis. In most of these

applications, the helium is recycled, but the main one where it is not is when helium is used in party balloons, which take up about 10 % of helium. They either go down or burst and the helium is lost forever. Does this matter?

There are three main suppliers of helium, Qatar, whose fields are closed; the USA which will cease supplying in 2021; and a new field that has been discovered in Tanzania which will begin supplying in 2020. The Tanzanian field contains enough helium for 8 to 12 years at current usage rates if none of it were recycled. Recycling extends that horizon dramatically. However, if 10% of the helium from the Tanzanian field, the only significant one we currently know about, is lost every year, **ALL** of it will be gone in 80 to 120 years and there will be none left for MRI scanners. It is argued that the helium used in balloons is relatively impure at 95 % so uneconomical to purify. However, the Tanzanian field has less than 10% helium and that will be purified.

Phosphorus (P) and magnesium (Mg)

Phosphorus and magnesium are relatively abundant elements which are coloured yellow on the EuChemS Periodic Table, meaning that there could be problems of supply as a result of increasing usage in the longer term.

The problem here is the way we use them. Magnesium is at the centre of chlorophyll, which gives the green colour to leaves and is responsible for converting CO₂ and water to sugar and the oxygen we breathe. Without it there would be no oxygen and no life. Phosphorus mainly comes from Morocco, where there are large deposits of phosphate rocks. It is used as phosphate in fertilisers.

In both cases they form part of the diet of humans and animals so they pass into the food chain. We either eat the plants directly or eat animals that have eaten plants. This means that the essential nutrients including magnesium and phosphorus are taken out of the soil and end up in human cadavers but mostly in human sewage. After processing they are flushed into the sea. As the population increases we flush more and more of the phosphorus and magnesium into the sea and less is available for growing plants.

What can be done—what can WE do?

The EuChemS Periodic Table has been designed to highlight a current and potentially growing problem, but it is not designed to force people to sit and wring their hands in despair. In the end, it provides a message of hope. **It is not too late if we act now.**

The Periodic Table provides a clarion call to start acting now and introduce a circular economy, which

reduces the amount of precious elements that we use, recycles these precious elements, repairs rather than replaces consumer goods and seeks to replace endangered elements with earth abundant ones.

Reduce

It seems abundantly clear that, until new helium fields are found or efficient MRI scanners are produced that do not need liquid helium we should never use helium in party balloons and we should insist that the 95% helium is purified and recycled. Just in case you are unconvinced, think about the plastic that makes up the balloon itself. It floats away and contaminates the environment. It can be eaten by birds and sea creatures causing premature death from plastic pollution. Even so-called biodegradable balloons take up to a year to degrade—the damage is done by then. This is partly why Gibraltar, where tens of thousands of helium balloons were released every year on their national day, has banned them. In addition, Network Rail in the UK reports that in 2018 there were 619 incidents, many of them dangerous, in which helium balloons interrupted the rail service. Often the fly-away clusters of balloons get caught in gantries and overhead cables. **Can we really justify throwing away this precious resource in frivolous party balloons?**

What about phones? Most people are persuaded to change their phone every 2 to 3 years as part of their contract. Is this really necessary? Most people never use the new features of new phones and most phones are in good condition when they are exchanged. Did you know that once you are eligible for an “upgrade” you are also eligible for a “SIM only contract”? This is much cheaper than the one you were on so why not save money and elements rather than having a new phone? **Can we really justify changing our phones every two years when precious resources in them are being used up? Think about this for all your electronic gadgetry, car, consumer goods etc. You could make a huge difference to life on earth.**

Repair

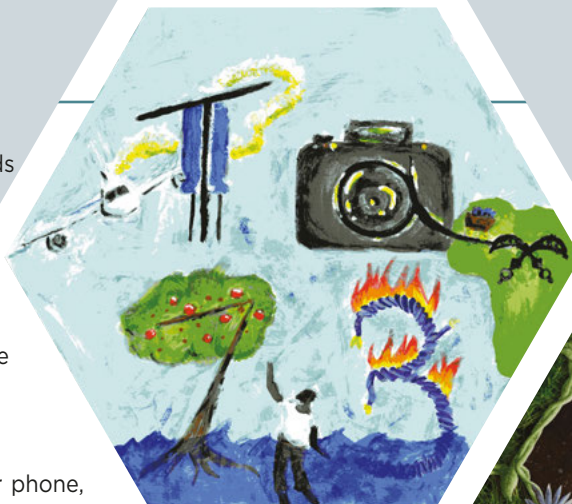
Sometimes the battery or screen on your phone may get weak or broken, the pump on your washing machine may break, you may need a new catch on your dishwasher and you will be advised that you need a whole new device. You almost certainly don't! A simple repair will be much less costly and more friendly to the environment. At present many mobile phone manufacturers make repairs very difficult by using special screws and extra strong glues. They should not be allowed to do this, at least until they tackle recycling,

and all consumer goods including phones should be made modular so that repairs are easy. It is sad that Google withdrew their modular phone before it even came to the market.

Recycle

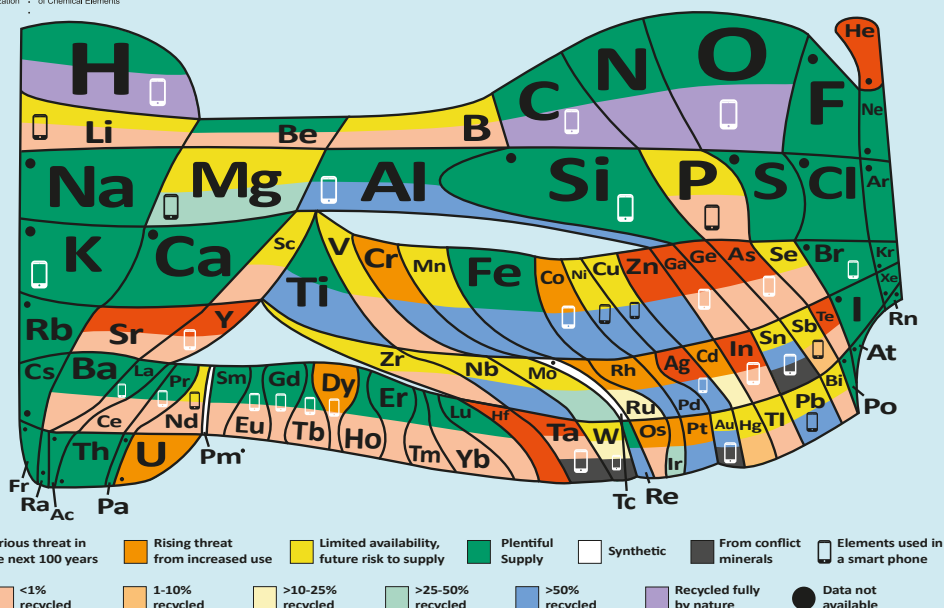
Even if you keep your phone, car, washing machine, etc for longer and repair it when it breaks down, eventually the time will come when it needs to be replaced. That is the time for recycling. Some items are already properly recycled. Look at the EuChemS Periodic Table again. Elements such as rhodium and platinum are in short supply but every car has some of each in its catalytic converter, which cleans up the exhaust emissions; yet these elements are not coloured red. This is because the elements in catalytic converters are recycled and indeed more than 50% of Rh and Pt in their myriad of uses are recycled (Figure 3) [8]. Why can't we do that with elements in electronic goods like phones and computers? We need to develop effective ways of recycling all the elements in mobile phones and

other electronic goods ethically. Some small companies do this already but we need to expand capacity dramatically. Then, **please do not keep your old phone in a drawer—recycle it ethically**, or give it to your granny, dad, or daughter until it is ready for recycling. This is **Reuse**, which is also part of the circular economy. A summary of the recycling of metals appears in Figure 3.



The 90 natural elements that make up everything

How much is there? Is that enough? What are we recycling?



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EuChemS
European Chemical Society

Figure 3. Modification of the EuChemS Periodic Table to include the extent to which element are recycled. Recycling data from https://www.resourcepanel.org/sites/default/files/documents/document/media/e-book_metals_report2_recycling_130920.pdf

Inspired by WF Sheehan's 'A Periodic Table with Emphasis' published in Chemistry, 1976, 49, 17-18'



Replace

Here, I do not mean replace your phone. What we need to do, in addition to all the things described above, is to find materials that do the same job as the ones we use currently but only contain earth abundant elements. Take the conducting film on touch screens: the film has to be transparent, colourless, conduct electricity and stick to glass. Indium tin oxide does all of these things exceptionally well, but it contains indium, whose supply is threatened, and tin, which can come from conflict zones. A huge amount of research is going on to find replacements. Graphene, made only from carbon, and calcium molybdate are amongst the front runners, but their performance does not match that of indium tin oxide yet. We need to ensure that this kind of research is fully supported.

Conclusion

The new EuChemS Periodic Table highlights the vulnerability of several elements to dispersion, but it also provides a clarion call for us to change our ways. If we adopt the circular economy consisting of reusing, reducing, repairing, recycling and attempting to replace vulnerable materials with less vulnerable ones, we shall be able to continue to enjoy our wonderful, diverse world for generations to come and reduce its pollution.

More information is available in support notes at <http://bit.ly/euchems-pt>, where the EuChemS Periodic Table can be downloaded in more than 30 languages. You can also download the video game *Elemental Escapades, A Periodic Table Adventure*. 



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