Critical elements

This page contains material taken from A. J. Hunt, The Importance of Elemental Sustainability and Critical Element Recovery for the Pharmaceutical Industry, in *Green and Sustainable Medicinal Chemistry: Methods, Tools and Strategies for the 21st Century Pharmaceutical Industry*, The Royal Society of Chemistry, 2016, ch. 5, pp. 54-62. .

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Elements are considered to be “critical” if they have significant supply risk issues and if restricted could harm a company’s business or nations economy. The chemical industry, including the pharmaceutical industry, is dependent upon petroleum feedstocks to supply a significant proportion of its starting materials. However in addition to this, metals and many other elements that are declining in stocks are also widely employed, in particular the use of platinum group metals catalysts, which will have a significant effect on the industry in future. The concept of elemental sustainability, a concept whereby each element within the periodic table is guaranteed for use by both current and future generations, is therefore becoming increasingly important. [1]

Learning Objectives

By the end of this module you should:

- Understand the factors contributing to elemental sustainability;
- Be aware of the alternatives to mining to source critical elements;

and be able to:

- Describe the current practices of obtaining elements;
- Describe linear and circular economies.

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What is elemental sustainability?

In this video, Dr Andrew Hunt at the Green Chemistry Centre of Excellence, University of York introduces the context of elemental sustainability and which ‘critical’ elements are more at risk due to unsustainable practices.

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Transcript

Elemental sustainability is a really important issue.

Really, we think about being sustainable in terms of carbon, so we think about trying to be carbon neutral but we don't think about being neutral in the use of all elements of the periodic table.

So this is some concepts that we've started to develop at the University of York, as well as other places around around the world, and what we want to try and do is actually guarantee all elements in the periodic table not just for the current generation but future generations as well.

So we don't want to do things today that will stop our children using these elements as well.

So it's a really really important concept and why is it in an important issue? Well, many of the elements that we have in the periodic table are actually being used a very quick rate.

So elements such as such as indium, in actual fact, if you look at the known reserves of indium there's only about 13 years of known reserves of indium left in the ground.

We're not actually destroying the indium.

We're not, you know, getting rid of it, what we are actually doing is dispersing it through the Technosphere.

So we're taking it out of the ground where it's in nice, concentrated seams often, these elements, and we're dispersing it through our modern society.

So, how many of you actually have a mobile phone at home, that's in a drawer, not being used? Put your hand up if you have a mobile phone that you've got, an old one, that

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you're not being used.

Okay, so pretty much everybody here put their hands up saying that they had a mobile phone in the drawer at home.

Well, in actual fact, these mobile phones probably contain more precious elements then you would find in concentrates.

So you spend a huge amount of resource digging this concentrate out of the ground, making a huge hole in the ground, when in actual fact if you were able to just recycle the elements in your mobile phone it would be much more efficient.

So we need to think about where we get our elements from in the future.

So for this talk I'm really gonna going to focus a little bit about the platinum group metals and what this periodic table doesn't show is actually how much of these elements are recycled.

OK, so this just talked about how many, what the current rate of use is and how much we have left in the ground.

So if we look at recycling rates, or current recycling rates, of these elements, in actual fact, the platinum group metals are pretty good, we're actually pretty good at recycling these elements so that's a plus.

Other elements, such as indium, we actually recycle less than 1% of this.

So there's many.

many elements out there that we need to think about doing more in terms of recovering and recycling these elements.

Also we need to think about where our elements come from.

You may have heard of conflict minerals, so we need to really be careful in terms of where the elements come from and how we source them.

And many elements, including the platinum group metals, come from specific parts around the world and there may be political issues that stop us gaining access to these elements.

That's a really important thing to note for the future.

In actual fact, where we're sat here in Europe, we don't have very many reserves in the ground so we need to think about using other sources of elements that we may have at

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our disposal..

The economic case

In this video, Dr Andrew Hunt at the Green Chemistry Centre of Excellence, University of York outlines the broader issue of elemental unsustainability in terms of economic impact.

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Transcript

Also the cost of elements has been increasing massively.

So here we can see the rare earth elements at the top, in the middle is the platinum group metals and at the bottom I've just got an example of tantalum.

So what you can see is over the last maybe five or so years, the increase, especially in the rare earths, in terms of firstly the price, but also the production has been steadily increasing as well.

Interestingly, you can see here there's a massive spike in the cost of tantalum and I'll get onto that in a second.

So the cost of these elements is going up..

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Factors affecting sustainability

In this video, Dr Andrew Hunt at the Green Chemistry Centre of Excellence, University of York gives some criteria to assess what makes an element 'critical'.

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Transcript

In the European Union and the US, there have been a number of studies that have highlighted elements that have been regarded as critical.

So critical elements really depend on what industry you're in, so the pharmaceutical industry will have a different set of critical elements to that of the aerospace industry.

But also each country will have a different set of elements and also continents as well.

So depending on where you're based in the world you might have a different set of critical elements.

So those elements vital to the European industry have been regarded as critical in the European Union and really these are high supply risk and large impact if they're restricted.

So factors that influence criticality are new technologies that come along, the population the increasing and the drive for more consumer goods, the restriction of supply and also many of the elements that we actually use today aren't mined for them themselves, they are actually mined as what's known as 'hitchhikers' or 'attractor' elements.

So we may mine for zinc and in mining for zinc we end up getting impurities of other metals and those metals are actually often more interesting for chemistry.

So in the European Union we did a study, actually this isn't the European Union, this is worldwide, we looked at all of the the list of critical elements and we took those elements that were actually common across all the list and these are those.

So on there you have the platinum group metals, the rare earths, but there are a whole range of different elements that are known..

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Alternate sources for elements

In this video Dr Andrew Hunt at the Green Chemistry Centre of Excellence, University of York highlights alternative sources to elements as opposed to traditional mining processes.

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Case study: phytoremediation

In this video Dr Andrew Hunt at the Green Chemistry Centre of Excellence, University of York presents the Phytocat project as a case study of an alternative means of obtaining some of these critical elements.

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Transcript

So we've done some work at the University of York where we've actually been growing pot plants in small tubes, we've been using Arabidopsis, we've been dosing it with platinum group metals, looking at the uptake, we've subjected the material to a stabilization process; what we've really been doing is carbonizing the material, so we essentially form a kind of palladium on carbon material, and then we can use these in applications.

So what we've done is we've shown that the plants take up the metals and actually form nanoparticles in situ.

We also see these nanoparticles are retained when we make a carbonized material and we can use them for a range of different reactions; in this case we've been doing some cross-coupling reactions, some suzuki reactions and they work very, very well.

This is actually a paper that we recently published, it's open access, so feel free to download it and read about this in more detail.

We have looked at re-use of the catalyst because we want to try and use the catalyst

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more than once to give it an added benefit and we've shown that we were able to use the catalyst around four times without a significant loss in activity.

However after the fourth use what we see is the distribution of nanoparticles, we end up getting much larger, bigger nanoparticles formed.

And why is this? Well in actual fact, what's happening is in the reaction some of the palladium is coming off the support, it's doing the reaction in a kind of quasi-homogeneous states and then what happens is it re-deposits back on the support.

So it re-deposits back on, but it forms larger nanoparticles which are less active.

But at the end of four uses we can we can burn off the plant material and recover our palladium as well.

So we've shown that we can use this with a large range of different substrates as well and it's a very effective method of actually developing catalysts by using this natural process that plants do on a daily basis.

We've gone one step further and we've gone from these little plants in these little pots to larger pot trials.

So this is a moving from Arabidopsis to Willow and we've shown the same thing, we get nanoparticles forming within the plants and we've also shown successful catalysis as well.

We now have field trials going on in Australia and New Zealand and pot trials going on in York, so it's quite a large project and it's working out very, very nicely.

But we think we're just kind of scraping the surface of this kind of technology and in actual fact, this is a review that we published recently where we actually showed that you can use this technology for a whole range of different elements and also a whole range of different applications, so from a green perspective there's a lot that we can do with this phytoremediation or phytoextraction technology..

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Summary and further reading

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Many elements that are utilised in chemical manufacturing and other industries are becoming more and more expensive and harder to source, and hence strategies should be adopted that promote the efficient use of those elements. At present primarily we have a linear system for obtaining elements i.e. extraction, manufacture, use and then at the end-of-life the product becomes waste. It is essential that we begin to use a more holistic approach including development of sustainable methods for extraction, manufacture, utilisation and recovery, in order to close the resource loop within the chemical manufacturing industry and promote a circular economy (**Figure 1**), whereby these critical elements are available to be used over and again.

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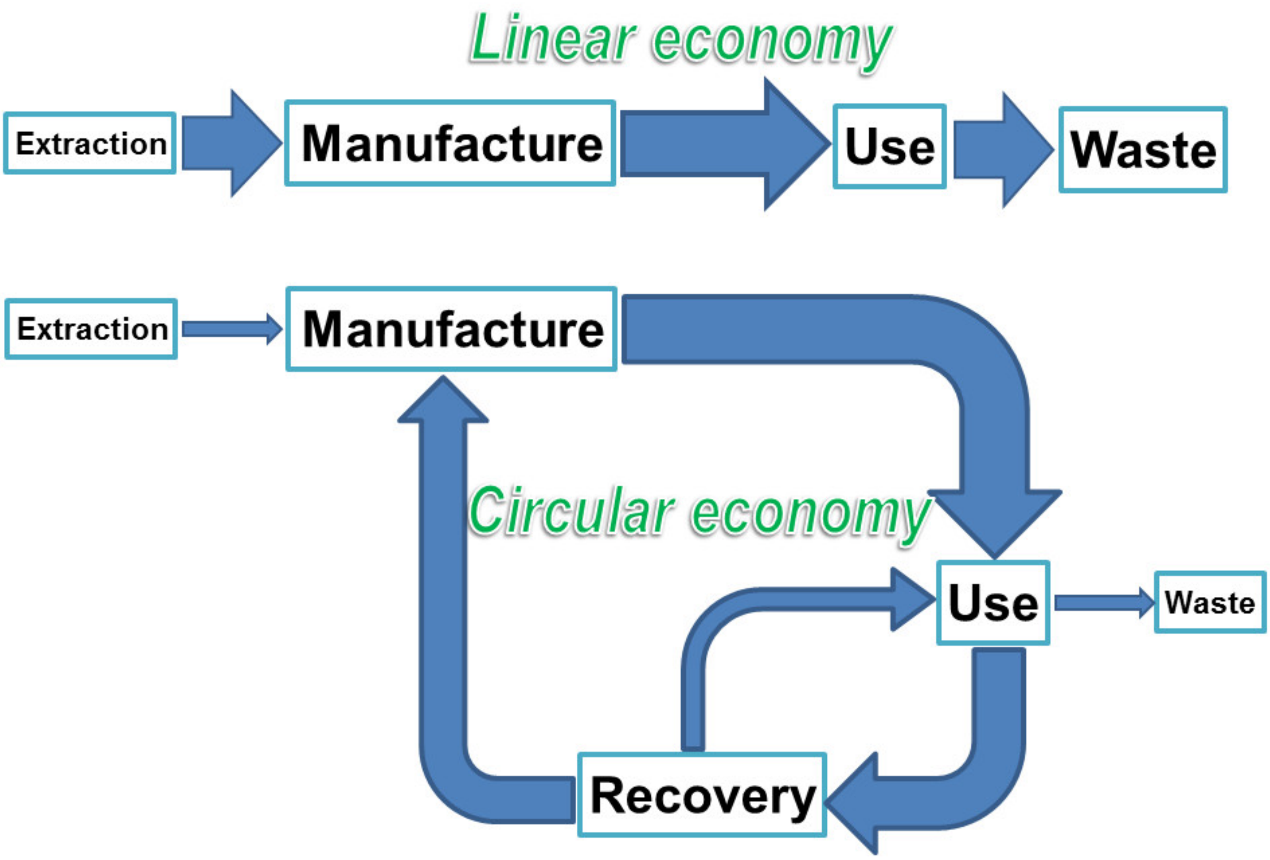

Figure 1: ***A simple material flow cycle demonstrating the areas that must be addressed to meet the challenges of elemental sustainability, which could lead to a circular economy. Reproduced from A. J. Hunt [1] with permission from the Royal Society of Chemistry***

Recommended reading:

A. J. Hunt, The Importance of Elemental Sustainability and Critical Element Recovery for the Pharmaceutical Industry, in *Green and Sustainable Medicinal Chemistry: Methods, Tools and Strategies for the 21st Century Pharmaceutical Industry*, The Royal Society of Chemistry, 2016, ch. 5, pp. 54-62.

A. Hunt, *Element Recovery and Sustainability*, Royal Society of Chemistry, Cambridge, UK, 2014.

1. A. J. Hunt, The Importance of Elemental Sustainability and Critical Element

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Recovery for the Pharmaceutical Industry, in *Green and Sustainable Medicinal Ch*

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