THE NO BREAKFAST FALLACY

Why the Club of Rome was wrong about us running out of resources

Tim Worstall

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1. Introduction

The scene is an early morning current affairs radio show. Very important people talk to the nation here.

Evan Humphries (for it is he): "Mr. Worstall, why is it that your new report shows that soon all will be dead?"

Worstall: "Evan, it's 7 am. Currently there is food in the fridges of the nation for breakfast. But in two hours time that will be eaten, gone, there will be no more. Therefore everyone will die because NO BREAKFAST."

Sorry, might I just rerecord that?

Worstall: "Evan, mineral reserves are disappearing at an alarming rate. Official figures show that within 30 years most of them will be used up and there are no more reserves. Industrial civilisation will crash, billions die, because NO MINERALS."

In that first instance we would agree with Worstall: eating breakfast does mean no breakfast in the fridge. We'd also agree that Worstall is mad because we understand that there is a vast industry dedicated solely to replenishing that breakfast before 7 am tomorrow. Pigs will get on with makin' bacon, those that were baconed into existence

6 months ago will be slaughtered, their older bretheren sliced after they've been nitrated and the warehousing and retailing system will click on another day and provide the necessary bacon for that next day. And so on ad infinitum.

The second explanation of why we're all going to die will get you a book contract, vast wealth and if you're lucky, a Fellowship of the Royal Society. For no one really seems to understand what a mineral reserve is nor what it is that a lot of the mining industry does. A mineral reserve is a lot closer to that fridge than it is to any other part of the preparation chain. Yet when people talk about mineral availability they tend to talk about those mineral reserves. Which are, in this rather tortured analogy, the fridges of the nation, those minerals that we have ready and prepared for consumption. Very large parts of the mining industry are like that food production system, preparing the hugely larger amount of mineral resources into those reserves where they are near ready for consumption. And of course food availability is not limited to those crops or animals that are currently extant: nor are those mineral resources. The whole planet is made of minerals so there's rather a large amount to go around even after we consider those resources.

This book is not trying to solve nor even discuss all environmental problems that exist. It's not even trying to discuss all that might occur over the use or not of all minerals and or metals. It doesn't address the possible pollution of areas by mineral processing, it doesn't address nor even attempt to the possible problems of actual use: say, algal blooms from the over use of pesticides.

It attempts to discuss one thing and one thing only. Are we likely to run out of any of the minerals or metals that we like to use in anything of a timescale that should be of concern to us today? To avoid excessive narrative tension we shall reveal the answer now: no.

It's true that there are many people who insist that we are just about to run out of everything that makes industrial civilisation possible. But as this book walks through their arguments we find that they've simply misunderstood the numbers that they use to discuss matters. Those misunderstandings coming in different grades of silliness, of course. In one chapter we look at some claims made in New Scientist and find that they have entirely and completely misunderstood what a mineral reserve is or means. They note that there are no mineral reserves of several metals and conclude that we're about to run out of them. Everyone in the metals industry points out that there are no reserves of these metals because of the definition of what a reserve is. That there are no reserves does not mean the end of availability: of the specific three that New Scientist worries about there never have been reserves, cannot be reserves, and yet we've been using the metals for decades and will be able to for millennia to come.

We also look at the Club of Rome's predictions in "Limits to Growth" and find that they too sink on the reef of their own misunderstandings of definitions in this field. They assume that the total amount of some mineral available to us is a set multiple of the mineral reserves we have of it. Far from that being true, that there is a set ratio for all minerals, there is no perceptible ratio at all. Simply no connection between what we currently define as reserves and the amount ultimately available to us.

Jeremy Grantham claims that we're about to run out of the minerals vital for fertilisers: his argument fails over the time value of money. Something you would expect a financier as successful as he is to understand but apparently not.

The one thing that everyone does get right is that this generation is likely to run out of, consume all of, the minerals we currently have classified as mineral reserves. This is entirely correct. It is also supremely unimportant. For every generation runs out of the mineral reserves they have at the start of it. For the best colloquial explanation of what a mineral reserve is is those minerals we have prepared for our use in the current generation. We use other words to describe the total amount of minerals available to us in the future and this book takes you through those. It also presents some entirely standard estimations of how long the conventional resources available to us are likely to last. And then offers some rather more controversial estimates of what the true availability of minerals is. At which point it becomes apparent that there's nothing to worry about for tens of thousands of years at a minimum, more likely millions to billions. And if anyone thinks that humanity is going to have problems in that time scale then might I just point to evolution? That thing which tells us that there's most unlikely to be a humanity to worry about at that distance?

The structure of the book is as follows. First we look at the standard economics of resource availability. Many reject this so we only explain it, not use it centrally to our argument. We move on to discuss recycling and why and when we should do it and when we shouldn't. After that, a discussion of one recent availability scare, that for rare earths. Given that I called it right as the scare was starting I rather revel in proving that I did so. We then walk through what is actually a mineral reserve and why it's important that we understand the distinction. At which point we are armed to understand the monumental ignorance on display in the New Scientist, after which we examine what Grantham is ignoring. After that we look at energy requirements and deposit degradation, ending the main part of the book with a look at what the Club of Rome got wrong.

Finally, the standard and controversial estimates of how long we've got left of usage of all of the minerals and metals that anyone actually keeps decent records about. And the book finishes with a boring bit, an extract from the official definitions of what is a mineral reserve, a resource and so on. Just to prove that the definitions I'm using are not some phantastical that I've just made up for the purpose of argument.

The end result of all of this is that you should, by the end, understand that we're just not about to run out of any of the mineral or metal building blocks of industrial society. There are environmental problems out there, ones it would be a good idea to solve. It's also entirely possible that a less consumerist, less material perhaps, society would be a good idea: entirely up to you on that. The point here is only that there's no obvious resource availability problem with our continuing as we are: something that I for one hope we do. For as the various predictions of the IPCC point out, if we do so continue then it's probable that near the end of this century that we'll finally beat absolute poverty globally. Something I won't be around to see but I still think that a damn good idea.

2. The standard economics of resource depletion

There is a standard economic explanation of why we're not going to run out of everything and thus society won't be spiralling around the u-bend any time real soon. That explanation being "substitution". This is simply the idea that not only are there different ways of doing the same thing there are also different things that we can do which will achieve the same goal. So, if we run short of the resources to do either one thing in one manner or to achieve our goal in one manner then we can "substitute" to one of the resources and or methods. Further, the best way (according to economists at least) of working out what and when to substitute is to use the price system. Of course, one needs the engineers and technologists to work out exactly how such things work, but it is that price system that tells us when and where to do so.

To take a simplistic example: glass is, or at least can be, a substitute for copper. It also can't be in some other uses. Imagine that, as we do, we use copper to wire up the internet to some hypothetical grandmother's apartment. We also use copper to make the motherboards of the computer onto which she downloads her cat pictures. Glass is used for her windowpanes say. Now the relative prices of glass and copper change: copper becomes very much more expensive than it had been but glass stays the same price. We might, at that point, substitute fibre optic glass for the connection to the internet, which we know we can do, for that copper cabling and use that newly freed up copper to provide a motherboard or two to provide others with computers upon which they can get their LOLcats.

This is indeed extremely simplistic. But it is also obviously true: we know of different ways of achieving much the same thing. As another example, those cute little earbuds that come with your iPhone depend upon our using a rare earth metal called neodymium. If we were to run out of that Nd we know of many other ways of making magnets that would perform the same function. They wouldn't be as small, this is true, but we can make them. And indeed we have made them in the past out of SmCo (samarium cobalt) and AlNiCo (aluminium, nickel, cobalt). Those last would be considerably larger than those cute little earbuds, this is true, but it would be possible to substitute. You'd need to have headphones about the size of those made by Beats, recently bought by Apple to contain them in fact. Given that Beats have become increasingly popular this doesn't actually sound like all that bad a substitute at all.

The point that economists like to make is that everything, absolutely everything, is substitutable. They are saying this in a somewhat technical manner, this is true. For said economist starving is a substitute for food. The absence of one does lead to the other: sure, we would normally call that a consequence but in this jargon that's a substitute. So not all substitutions are desirable, but they are always, by definition possible.

We can go much further with substitution as well. Think what we're really saying when we talk about renewable energy. We're arguing that instead of using fossil fuels we can, for example, use some silicon and a bit of gallium and copper to power our society. Sure, some argue that we cannot, that it's intermittent power and so on, others argue that we can and that's that. But everyone is arguing about the suitability of that substitution, not the fact that it can be done at all. And given that it's the ecological types who keep telling us that we can power civilisation with solar power (probably correctly, even if it won't look exactly as it does now) they should rather grasp the idea that we can substitute everything else.

To give another example that's been in the news just recently we can substitute pulped seaweed for mined fertilisers. It's not a very effective substitute, this is true, it's almost certainly one that doesn't scale up either but it can be done. The pulped seaweed is something like 1%:1%:1% nitrogen: phosphorous: potassium while the stuff that we make in factories from what we've dug up is more like 10:10:10, but it can be done.

As to why the price system to decide which substitutes to use (recall, everything is substitutable. Therefore anything that we are using is in itself a substitute for something else that we're not using) this really brings us to Hayek's point about the limits of knowledge. There's simply no way that any one of us can calculate all the effects of our use of anything at all. We are reliant upon all of the interweaving influences of what the thing is, how it was produced, the 10 or 30 levels of processes that went into its manufacture and so on. It really simply isn't possible for us to track back all the way through the system to see what is the total effect of whatever it is that we are considering using.

Hayek went further than this obvious point and said that there's no way that anyone can do this. No system, no statistical bureau, no method of economic organisation can possibly do this. The only method we have that can possibly do it is the interaction of market prices in the market place. That is, the only calculating machine that we have for the economy is the economy itself. This is of course rather a blow to those who would see themselves as the planners of the society to their satisfaction (this is Kip's Law: those who would have a planned society always, but always, see themselves as the planners) but it is also true. For an exhaustive and excellent proof of this look up Cosma Shalizi's essay, "In Soviet Union Optimisation Problem Solves You". The proof starts with the observation that if we want to plan something then we need some function to optimise and who does actually know the utility function for an entire society? The proof closes with the point that even if we could solve this knotty problem (we can't) then in a society with some 1 billion items on offer at any one time then we're still perhaps one hundred iterations of Moore's Law away from actually being able to build computers that could do the calculation for us.

We're left with that price system as being our guide simply because we've not got anything else that works.

This is not to say that markets and their prices are perfect: we're talking about human beings here so nothing is ever going to be perfect. The most obvious point being that there are some things that aren't included in market prices. Thus markets don't and cannot process the information about them either efficiently or effectively. An example would be the effect of CO2 emissions upon the climate (no, please don't answer "none"). People don't pay the cost of such emissions while other people have to bear the effects of them. Given that these costs are external to market prices, while the benefits of the fossil fuel use accrue to the user, we expect that there will be rather more such use than there should be. Thus economists call this an externality: something external to market pricing. The solution to this was pointed out by Arthur Pigou (the man who brought Keynes into economics) near a century ago when he was studying the effects of rabbits from one farm on the fields of the farmer one over. If we introduce a tax to cover that external cost (a "Pigou Tax") then it will be in market prices, markets will process the information efficiently and our problem is solved. This is why every economist concerning themselves with the problems of climate change comes up with the same answer. Indeed, they're rather like the 7 year old trying to answer the classroom question. Hands in the air, near dancing in excitement as they say "Oooh, I know, I know, Teach, pick me!": the answer is a carbon tax. Near wetting themselves in pleasure at finally being asked something they know the answer to.

Markets and prices aren't perfect: no one has ever said that they are. But they are the best we've got even if they do sometimes need that nudge and that adjustment to cover those externalities.

However, scarcity, even future scarcity, isn't something that is an externality so we can't say that a future scarcity of minerals is external to market prices. For the simple reason that scarcity, relative and absolute, is something that markets deal very well with. Indeed, we might even say that they're exactly the things that markets deal almost perfectly with.

Take that question that the Queen of England asked about the financial markets crash: why didn't anyone see it coming? The correct answer (no, it's not that economists know nothing) is that you cannot have anything more than a small minority of people predicting a crash at any one time. Because if any significant number of people see one coming they act now to get out of the way of the coming crash. Those actions precipitating the crash (think about it: the stock market is going to halve in value in two weeks' time and lots of people believe this; they will sell all their stock and the market will halve today, not in two weeks' time) and thus the prediction of when it will happen is wrong.

This same process works the other way around of course. If there's likely to be a shortage of something in the future then prices rise now not later. As I write this has been happening in fact: the general consensus is that oil will be higher in price in 6 to 12 months than it is now. For those American companies fracking for tight oil won't drill new wells given the current price. But they will keep running the ones they've already drilled because almost all of the cost is in the original drilling. Further, those wells have a highly productive life of some 6 to 12 months. We thus expect supply to be rather lower in 12 months time than it is now: and thus prices to be higher.

So, what's actually happening out there in the real world? Everyone and their grandmother is buying today's oil and hiring storage tanks, old oil tankers and anything else they can get their hands on to keep it in stock for those 6 to 12 months. They can make money by doing so, buy cheap sell high is a pretty obvious way of making a profit after all. And that action means that there's more buyers in today's market than there would be if we were looking purely at today's demand for oil. Another way of saying the same thing is that we've moved prices through time: the expectation of a shortage (or, in this case, more accurately the ending of a glut) means that we expect prices to be higher in the future than they are now. People buy now to profit from that pushing up prices then.

Future changes in supply and or demand are dealt with very well by prices and markets. This isn't to say that such predictions are always correct but those market prices do include the considered opinions of everyone interested enough to put their money on the table (and even those who have studied it and decided not to). Which, as with Galton's Ox, is about as good a prediction as we can ever come up with. There's no one out there who has more information than all of us put together and there's no one out there with different information than all of us put together after all.

So, future scarcity cannot be regarded as an externality, something that is not included in market prices and this is also something that markets cannot calculate the effects of. Thus we cannot say that the idea that we're going to run out of minerals is an externality. For it's already included in those very market prices that the economy is chewing through and calculating.

We're left with having to conclude that current market prices include all of the possibilities of future scarcity and given that they're not showing such we should conclude that there's not going to be any future scarcity. If we really were going to run out of terbium in 2013 (as one prediction that we'll look at later had it and no we didn't, we're still making compact fluorescent light bulbs out of terbium here in 2015) then the price would have become near infinite soon after that finding was publicised in 2008. It didn't. There also wasn't even the danger of running out in 2013 (80 million years' time is a possibility though, stock up now!).

But, of course, this is all economics. And as Brenda and everyone else has been pointing out, economists don't even know enough to predict a crash in the financial markets. So, no one is going to accept this explanation. We shall therefore agree that economists are just panty-waists who cannot theorise their way out of a wet paper bag and drop this explanation. We'll then go on to point out that it's still true that we're not facing any general or specific shortages of any useful or interesting metal or mineral in anything like a timescale that's of any interest at all to those of us alive today. By those of us alive today I do mean those of us interested in the lives of our descendants down to the nth generation as well. We're not even going to have tight supply of anything for thousands of years and that's probably quite enough time for us to be getting on with.

3. But shouldn't we be recycling everything anyway?

There's absolutely no doubt that at times recycling is a terribly sensible thing to be doing. It's also possible that at least sometimes recycling isn't a sensible thing to be doing. The trick is in devising a structure to work out which is which. That structure comes in three parts.

The first is that if you can make a profit by recycling something then you should be recycling it. For the profit is the very proof that you are adding value: that profit is the value by which your output is higher than the value of your inputs. Given that value added is, by definition, what everyone collectively can consume then recycling something to make a profit makes the human race richer. We like that. So, for example, when I take some offcuts of Russian nuclear alloys (the bits off the ends of the tubes they stick the uranium into for a reactor) and ship them off to be made into MAG alloy wheels for boy racers, and make a profit by doing so as I have done, this adds to the general wealth of the human race. Because value has been added: the activity was profitable.

We find, as we were urged to do in Blueprint for Survival, that the metals industry is pretty good at this and getting better too. The gold industry probably has the highest recycling rate of any industry on the planet, up at 99 to 99.9%. For just about the only amount of gold that's mined that isn't then continually reprocessed is the amount that weathers off plated onion domes. Or turns into grave goods: but do note that those gold crowns do come out before the body is burnt or buried. Much too valuable to just be thrown away. Other specific metals have different and lower recycling rates. Aluminium cans have a high one, not because aluminium is in short supply or anything but because the energy requirement of turning the alumina (aluminium oxide) into aluminium the metal is so high—about $900 a tonne by reasonable estimates. So, what we're recycling when we collect cans is not the precious resource of aluminium but that energy; it's much, much, less energy intensive to remelt those cans than it is to make the metal anew.

As an aside: it amuses those within the industry to note that you don't in fact recycle cans into cans. The two parts—the top and the side/bottom—are made from slightly different alloys. So you can't just chop up the old cans and make new. You can use old cans to make new aeroplanes and you can at times use old aeroplanes to make new cans, but you can't use old cans to make new cans.

As mentioned elsewhere in this book the iron and steel industry in the advanced countries feeds itself to a great extent on taking the last generation of our society and remelts it into the next generation of it. People do all of these things because they are profitable and profit means that value is being added.

There's also recycling that doesn't add value. This almost certainly should not be done. Because those losses are, as the inverse of profits, the sign that value is being destroyed by doing the recycling. For example, it's entirely possible to take old concrete and re-bake it so that it can be used again as new cement. It would also be mad to do so: far better simply to mince it up and use it as filler for the new concrete and bake a bit more of Portland to provide the cement itself. We really tend not to do things that lose value in that manner: what would be the incentive for anyone to do so?

Then there's the third class which is where all the problems come in. Because we might have something that is directly unprofitable to recycle but which we would like to still deal with because of some externality, something not accounted for in the price system.

One example of this is that we're told that we have a shortage of landfill space and so therefore we must recycle more of our general rubbish. Actually we don't have a shortage of holes in the ground (the size of the holes we dig for sand and gravel is slightly larger per year than the rubbish we're trying to get rid of) but we do have a shortage of holes with licences to throw things into. Our shortage is therefore an entirely self inflicted one of not allowing ourselves to throw things into landfills, not actually a shortage of them.

The underlying argument here is that we've a shortage of raw materials. Therefore we should be recycling the raw materials instead of putting them into holes in the ground. This argument works if we've a shortage of raw materials: but as this book is attempting to show, at least concerning metals and minerals we don't. So this justification for this sort of recycling doesn't in fact work. And yes, recycling these materials does cost more than using virgin material. We are making ourselves poorer by doing this.

It isn't true that this is always the case. It depends upon the validity of the justification for undertaking an unprofitable operation, not that it is in itself unprofitable. I am involved in a plan to clean up a

Superfund site in the US for example. An old minerals processing facility has some waste material lying around. That waste material contains interesting amounts of interesting metals, metals that we'd very much like to have. However, cleaning up that waste would cost more than the value of the metals to be recovered. So, leave it be?

Well, not quite, because that waste also has measurable amounts of thorium in it and thorium is radioactive. Not very radioactive and it's arguable about whether it really imposes a cost to human health by being left where it is. But it's also probably something that you don't want blowing around in the wind perhaps, and society has decided that it is something that should be cleaned up. But if that waste is to be treated (take the thorium out for secure storage, then the remainder can be dumped in a hole somewhere) then why not take out the valuable metals at the same time? As is being done in fact.

So, the fact that a particular piece of recycling is unprofitable doesn't necessarily mean it shouldn't be done. Only that whether it should or not depends on the validity of the reason we're giving as to why, despite the unprofitability, it should be done. Stopping radioactive dust blowing about the place? OK, possibly, yes. Because we're about to run out of minerals and metals? We're not; that justification doesn't work.

Much of the current craze for recycling everything at any cost is misguided, because it is driven by that false idea that we're short, or soon will be, of raw materials. The argument fails. And the reason it fails is because current prices are, as mentioned elsewhere here, already containing the information about whether there's going to be future shortages or not. That's something the price system does very well indeed: it balances supply, even future supply, against demand (even future demand).

4. But doesn't the Chinese rare earth story mean that we are in danger of running out?

There was, back in 2010, something of a scare that the world was about to run out of rare earths. China produced some 95% of the world's supply, they're essential for a lot of the modern gizmos and bling that we call consumer electronics and then China started to throw its weight around. By limiting exports so as to make the most of its near monopoly. Quite what they thought they were doing no one is quite sure. Maybe they thought they could simply gain higher prices by restricting supply. Perhaps it was a bit more inscrutable in that there were no limits on how much anyone could use to make something inside China. It was only exports of the raw materials, not manufactured goods, that were restricted. This would obviously be an incentive for people to take rare earth consuming manufacturing processes into China.

As a result there were all sorts of panics, bills floating around Congress to insist upon spending hundreds of millions to rebuild the American industry. Almost a war footing in fact (that the magnets inside certain American rockets were indeed made from Chinese rare earths did cause some concern).

However, what China failed to appreciate is that a contestable monopoly isn't an exploitable one. It's entirely possible for you to be the major, possibly even the only, supplier of something and thus be a monopolist. But as soon as you try to exercise that monopoly in order to boost your profits (or move high end manufacturing into China) then people will, if they can, start to compete with you. Only a natural monopoly, or one backed up by legislative fiat, can be taken advantage of in this manner.

Brave words from me of course but I did actually point this out at the time. In Foreign Policy magazine in fact, and as they've still not paid me I'll assume that the copyright is mine:

> Last week, the New York Times published a stunning story: China, amid a nasty territorial spat with Japan, had quietly halted shipments of rare-earth minerals to its East Asian neighbor, threatening to escalate a skirmish into a full-blown trade war. China swiftly denied the story, while other journalists rushed to confirm it. The Times reported on Sept. 28 that China, while still not admitting the existence of the ban, may be tacitly lifting it — but the damage to the country's image as a reliable supplier has been done.

In case you haven't been following this arcane dispute, here's a quick primer: Rare-earth minerals are the 15 elements in that funny box at the bottom of the periodic table — known as lanthanides — plus two others. About 95 percent of global production takes place in China, largely at one huge mining complex in Inner Mongolia. The lanthanides are essential to much of modern electronics and high-tech equipment of various kinds. The magnets in windmills and iPod headphones rely on neodymium. Lutetium crystals make MRI machines work; terbium goes into compact fluorescent bulbs; scandium is essential for halogen lights; lanthanum powers the batteries for the Toyota Prius. For some of these products, alternative materials are available (moving to a non-rare-earth technology would make those cute little white earbuds about the size of a Coke can, though). For others, there simply isn't a viable substitute.

For years, analysts have been issuing dire warnings about this situation, casting China's near-total monopoly and its steadily shrinking export quotas as a mortal threat to U.S. national security and global commerce. In 2005 testimony before the U.S. Congress, Frank Gaffney of the Center for Security Policy argued that China's interest in rare-earth elements "falls into a pattern of … activity around the globe that is clearly deliberate, well thought out, and ominous in its implications." A more recent report written by a military researcher at Fort Leavenworth, Kansas, urges the United States to stockpile the most important rare-earth elements and make studying the minerals a national strategic priority.

But the truth is that though most of the rare earths, both metals and oxides, do come from China, this isn't the same at all as having a monopoly that is sustainable — as Beijing is about to find out in a fairly painful manner. Now that the specter of a monopoly being exercised for political ends has been raised, there will be sufficient political will to break that monopoly.

Two important facts about rare earths help explain why: They're not earths, and they're not rare. China has reached its dominant supplier position through good old-fashioned industrial aggression, not innate geographical superiority. Cheap labor, little environmental scrutiny, and a willingness to sell at low cost have made other producers give up. For competitors, like the owners of Mountain Pass, a California mine that shut down in 2002 partly due to the China factor, that has been a daunting combination. For the rest of us, it has been fantastic: Affordable rare earths have helped power the information-technology revolution, driving down the cost of everything from hybrid cars to smart bombs.

But the non-rarity of the rare earths themselves means that China's position isn't sustainable. That California mine, for instance, could potentially supply 20 percent of world demand, currently around 130,000 tons a year. Another facility, Lynas Corp.'s Mount Weld in Australia, has the capacity to produce a similar amount. In fact, there are enough rare earths in the millions of tons of sands we already process for titanium dioxide (used to make white paint) to fill the gap, while we throw away 30,000 tons a year or so in the wastes of the aluminum industry. There's that much or more in what we don't bother to collect from the mining of phosphates for fertilizers, and no one has even bothered to measure how much there is in the waste from burning coal.

If rare earths are so precious, why isn't the United States working harder to collect them? The main reason is that, for these last 25 years, China has been supplying all we could eat at prices we were more than happy to pay. If Beijing wants to raise its prices and start using supplies as geopolitical bargaining chips, so what? The rest of the world will simply roll up its sleeves and ramp up production, and the monopoly will be broken.

But, of course, it's not that easy. Rare earths aren't found in nature as separate elements; they need to be extracted from each other, a process that involves thousands (really, thousands) of iterations of boiling the ores in strong acids. There is also almost always thorium, a lightly radioactive metal, in the same ores, and it has to be disposed of. (Thorium leaking into the California desert was a more serious problem at Mountain Pass than low prices.) So ramping up production would mean that Western countries would need to tolerate a level of pollution they've been all too happy to outsource to China.

Another possibility is that we find a new and different way to separate rare earths, as we find new and different sources for the ores. The main difficulty is that chemistry is all about the electrons in the outer ring around an atom, and the lanthanides all have the same number of electrons in that outer ring. Thus we can't use chemistry to separate them. It's very like the uranium business: Separating the stuff that explodes from the stuff that doesn't is the difficult and expensive part of building an atomic bomb precisely because we cannot use chemistry to do it — we have to use physics.

The very fact that China has been supplying us all these years means that while Western academics in their ivory towers have been continuing to research all sorts of lovely things, very few of these findings have been tested in the real world. One possible solution, lightly investigated in academia but not elsewhere, is adopting the technology used to separate titanium. It might work with the lanthanides, or it might not. But we should try it, along with other high-tech methods, to make the best of our own strengths rather than trying to compete with China — the land of cheap labor and environmental unconcern — on its own terms.

In the end, the question of whether China has been using its rare earths access to threaten Japan doesn't matter as much as the possibility that it might — and the certainty we'd better do something about it.

September 29th 2010[1]

What then went on to happen is that the rise in rare earth prices meant that Lynas Corporation and Molycorp (Australian and American companies respectively) were able to raise the finance to get their mines up and running again. Between the two of them they supply or soon will do some 50,000 tonnes a year of rare earths. Which is around and about the total non-China consumption of them actually. Rare earth prices have collapsed back down below where they were when China started to flex those economic muscles.

This brought, in 2014, this comment from Marginal Revolution:

Bonus points to Tim Worstall, economist blogger and rare earth dealer, who in 2010 at the height of the crisis pointed out that rare earths were neither rare nor earths and China's monopoly had been won only by low prices that accrued to our benefit. "If Beijing wants to raise its prices and start using supplies as geopolitical bargaining chips," he wrote, "so what? The rest of the world will simply roll

1 This article originally appeared at http://foreignpolicy.com/2010/09/29/you-dont-bring-a-praseodymium-knife-to-a-gunfight/

> *up its sleeves and ramp up production, and the monopoly will be broken." Nailed it.*[2]

The reason I bring this up is not just the ego gratification of having been right: although that's always pleasurable. It's to hammer home the point that even though China did have that 95% of the market, and 30% of the world's mineral reserves of rare earths, it was a relatively trivial (because in the sense of the global economy, a four year turnaround time really is breathtaking speed) task to replace that supply. This won't be true of all minerals and metals, of course not. Not that fast at least. But as this book is trying to point out, there's enough of everything out there that we can do it if we wish to. And we'll only wish to when we have to.

There really isn't any mineral that anyone has a sufficient lock on to be able to create an exploitable monopoly. Simply because there's too much of all of them out there.

2 http://marginalrevolution.com/marginalrevolution/2014/11/what-happened-to-the-rare-earth-crisis.html

5. What actually is a mineral reserve?

The mining industry is full of highly competent people: but they do tend to be engineers who as a profession have a fairly simple world view. Something works or it doesn't, something is either this or that with little ground for delicate shadings and blendings of one thing into another. In mining, the split is between dirt and ore.

All dirt is made up of exactly the same elements and minerals that ore is made up of. Fairly obviously, it has to be, as we've only those 92 elements out of which the entire universe is constructed. The different between dirt and ore is in the proportions of the mixture. We could, without any doubt whatsoever, dig up the average suburban garden and at some vast great expense we could produce at least a modicum of all the elements up to uranium. The amount of helium would be at the "a few atoms" level, that of tellurium not much more but there would be notable amounts of that uranium and actually useful amounts of iron, silicon, aluminium and so on.

Ore is simply dirt that has a preponderance of something that we'd like to have and a preponderance of it in a form that we know how to extract it easily. The actual dividing line between the two really being "can we make a profit by extracting it?". If we can it's ore, if we can't it's dirt.

For example, one estimate has it that the North Sea contains $5 trillion worth of gold. It's also estimated that it would cost $20 trillion to extract it. Thus the North Sea is, despite being seawater, dirt in our mining nomenclature. This isn't true of all seawater and all minerals of course. Maldon has a factory (its product available on every supermarket shelf) which extracts, profitably, sodium and chlorine from seawater and sells it. Sodium chloride boiled out of seawater being the other name for "sea salt". Similarly the Dead Sea is so salty, and with such a preponderance of magnesium salts instead of just sodium ones (just to confuse matters, "salt" is sodium chloride, but "a salt" is any compound, copper oxide, magnesium sulphide, scandium iodide, they're all salts) that a factory there boils the water (using the sun normally) to produce magnesium itself. And there's other parts of the world where saline reservoirs (sometimes drying out seas, at others lakes similarly drying out) are used to produce bromine and iodine and even lithium.

The point being that it's *concentration* that matters. That mountain over there could be—almost certainly will be—some 10 to 20% iron. But we know of mountains in Australia that are 90% iron oxide. So, the richer concentration is ore (so much so that Mount Whaleback is now Mount Hole In The Ground) and those other mountains you see around are, as far as iron is concerned, dirt.

Do note that this differentiation is a purely economic one. It's not that we cannot extract that 10% of iron from that mountain: it's why the heck would we bother when we can get the same stuff cheaper elsewhere? The economics of course depending upon the price of the element we're looking at, the concentration of it in the dirt and the technology we have available at hand. All three combining to tell us whether at current technological levels, at current market prices, can we process that dirt and make a profit? If we can then it's ore, if we can't it's dirt.

And it if is ore then we make further distinctions. These are explained in boring and formal detail in the appendix. But the easiest way to think of this is to use Donald Rumsfeld's known unknowns terminology.

We have what we can call our known known. This is the ore where we know what it is, where it is, how much of it there is, we know the technology we would use to extract everything and we're certain we can do it at current prices and make a profit. We've done pretty much everything we can to prove this as well, short perhaps of baking a fluffy cake out of it. The more formal name for this sort of ore is *mineral reserve*. Another useful name for this sort of ore is the current working stock of mines in actual production.

Note what this means. A mineral reserve, all mineral reserves added together, are nothing like all the amount of that mineral or element that is actually available to us. They are, as above, what we have proven to be such, and only what we've proven. And we tend only to prove such deposits when we decide that we want to go and ask someone for some money to dig them up. That's why we can also describe mineral reserves as being the working stock of mines already in production (they had to prove the minerals were there to get the money to open the mine) or those just about to go into production (because you don't get the money to open a mine until you've proved your mineral reserves).

At heart this is the most important lesson of this book. The usual numbers that people bandy about for mineral availability are the mineral reserve numbers. The working stock of extant and soon to be in operation mines. This is nothing at all to do with how much of any element we can eventually recover—it simply has no link to it at all.

This is also why reserves tend to run at some 20-40 years of production. Because it costs money to do the proving. So, if you're not going to start on a mine for 20-30 years, why spend the money to prove it now? In other words, if we take 30 years to be a generation then mineral reserves run out every generation. Because we start now with perhaps 30 years' worth of reserves, gradually consume them, but at the same time we prove more projects and thus convert them from dirt into ore and add them to our mineral reserves.

That dirt we prove into reserves comes from our known unknowns, our mineral resources. We know a great deal about where there's likely to be more minerals that we'd like to dig up at some point. We just haven't done the detailed work to actually prove it to our technical and economic standards. However, you can only describe something as a mineral resource if you're pretty sure that it will convert into a reserve once that measurement and testing work is done. You can't just point to a hill and say it's got copper in it. You've got to show that there is, in quantity, that it's pretty obvious that it will be economic, that you'll get the necessary licences and so on but that you haven't actually proven all of this. Only then can you call it a resource. And fairly obviously resources tend to be associated with the reserves that we've already identified. We're mining this side of the hill, we're pretty sure the other side is much the same, but it's going to take us 30 years to mine this side so we'll wait to do the detailed work on the other side for a bit.

Note here that there's no relationship at all between the amount of whatever we have in reserves and the amount we have in resources. There's no ratio, no rule of thumb, that we can use to say, well, if we've got x in reserves then we've got 10x in resources. This is the mistake the Club of Rome made in their estimations about Limits to Growth as described in that chapter. And sorry, but it's simply wrong, there is no such ratio or relationship. Reserves tend to be for those few decades that will last the current generation. As the table at the back of this book shows resources stretch from absolutely nothing out to thousands of years.

We also have unknown knowns. The world hasn't been fully surveyed yet, not even close (I have been doing some work in the Krusny Hory, known as the Ore Mountains in English, and this area has been mined for 800 years. Even now it's not entirely surveyed, let alone more remote places). However, we do know quite a lot about geology in general and we can predict where there are likely to be sufficient concentrations of this or that for it to be ore, not dirt.

As an example, (and this description will horrify geologists but it's accurate enough to a given level of simplicity) one way that some of the more interesting minerals turn up is as a result of magma moving up towards the surface. Could be in a volcano that blows or just a pipe of that magma that cools before it does. As it moves and cools different elements crystallise out at different points along the tube of magma (yes, geologists, we know you're cringing, but this is for simplicity's sake). So, for example, in that Krusny Hory we find that one such magma pipe was there millions of years ago and over time it got folded over so that it's now more horizontal than vertical. And at the western end we find tin ores (the area was Central Europe's equivalent of the Cornish tin mines for centuries) which contain pretty much no tantalum nor scandium. At the eastern end to the same tube the tin ores are high in Ta and Sc, and we also see considerable concentrations of tungsten around the place. One wrong but useful way to think about it is that the tube of magma distilled out the various elements at different points along its route.

The point about our unknown knowns is that we know very well that there are similar geological formations out there. Those stories of slave mining of tantalum (coltan as the campaigners have it) in the Congo are from a particularly rich version of exactly this sort of geological feature. Madagascar is known to contain much the same sort of thing as well. But no one has ever conducted a proper survey of these areas for these minerals (wolframite, columbo tantalite and so on). A bit of work has been done, mostly surface occurrences, but no one has done proper drilling surveys over these vast areas. Yet from what we know about basic geology—how and why various metals end up concentrating in the same place to make ore—we know very well that there are more of these sorts of places out there. So our mineral resources are not, by any means at all, the limit to what we can actually make available. We absolutely know that there's more out there, we're just not quite sure exactly where or in quite what quantity. They're known unknowns.

Rumsfeld ends with unknown unknowns and that's not quite right for our fourth group. We're pretty sure that we've a reasonable handle on the general composition of the lithosphere, the hard part of the Earth above that boiling magma. It's a% iron, b% silicon and so on and on down to 0.001 parts per million tellurium or whatever that tiny fraction is. We also know that it's not equally distributed but that we can get at least a little bit of just about anything by processing enough of almost anything. We do have a pretty good handle on what's out there: we just don't know how we would extract it profitably, that's our unknown here. And of course it is that which determines the total availability of metals and minerals to us. Yes, the technology of extraction is a boundary but the true binding constraint over the life of civilisation is going to be the number of actual atoms there are of any particular kind. There's some number of copper atoms on Earth, meteorite strikes are an infinitesimal change to that, so absent sailing off into space there is some limited, even if very large, number of copper atoms that we can use. Our unknown is not their existence, it's how the heck do we get them out to use them?

It might be worth having a look at the back of this book right about now, peruse the table there. I've listed out the mineral reserves, mineral resources, total resources (ie, the percentage content of the lithosphere) of each of the minerals and metals that anyone keeps tabs upon. This does not include any of the fossil fuels. But you will see that reserves tend to be there for that generation, that few decades, out. Resources can be anything at all from nothing (for a reason we will discuss later) to thousands of years. Total availability is measured in millennia at the very least and there's some that people complain we're about to run out of that will actually last until the heat death of the universe.

Finally, I've added an entirely made up idea of "real resources". If we mined 1% of the surface area of the planet, to 10% of the depth of the lithosphere (we do already mine to that depth in a few places), how much of each element of mineral would be available to us? Go have a look but to ease the uncertainty there's not anything that we're going to run out of anytime soon.

Yes, of course this idea of real resources is somewhat ridiculous. It's there just to show that there's really not any likely shortage looming. Unlike the results you get from only looking at mineral reserves which is what all of the alarmists are doing.

6. The New Scientist's mistake

There is no excuse or explanation possible for the concatenation of piffle that the New Scientist served up some years ago, in their 27 May, 2007 issue.[3] They told us, in hugely exciting terms, that a number of metals were right on the verge of running out. Terbium, hafnium, gallium, these would be, by today, either already exhausted or about to run out. This hasn't happened, obviously, and the reason they got their prediction so wrong is that they didn't understand the very first thing about how the calculation of reserves and what is available to us works. Something that is rather the subject matter of this book of course.

Just to show quite how far out they are, here's one possibility that they discuss:

> *Similar tensions over supplies of other rare metals are not hard to imagine. The Chinese government is supplementing its natural deposits of rare metals by investing in mineral mines in Africa and buying up high-tech scrap to extract metals that are key to its de-*

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3 http://www.sciencearchive.org.au/nova/newscientist/027ns_005.htm

> *veloping industries. The US now imports over 90 per cent of its so-called "rare earth" metals from China, according to the US Geological Survey. If China decided to cut off the supply, that would create a big risk of conflict, says Reller.*

Er, yes, that big risk of conflict turned out to be that they did do so and we all went off and opened up two new mines. New Scientist is obviously doing something here but it's not obvious that it's science, however new it is, nor is it entirely clear that it refers to the same universe the rest of us are using.

Geologists are a hardy breed and the German sense of humour is notably robust. Getting a chuckle out of a group of German geologists usually requires a fart joke, or dropping your pants. And the men are worse of course. But I told some working for me that there was this prediction that hafnium was going to run out in 2017 and it brought roars of laughter:

> *In a more sophisticated analysis, Reller has included the effects of new technologies, and projects how many years we have left for some key metals. He estimates that zinc could be used up by 2037, both indium and hafnium - which is increasingly important in computer chips - could be gone by 2017, and terbium - used to make the green phosphors in fluorescent light bulbs - could run out before 2012.*

Only someone possessed of the most absurd ignorance could possibly make such an howlingly incorrect prediction.

What they've done is look around the world and see that there are in fact no mineral reserves of hafnium. This is entirely correct, there aren't. There's a couple of stocks of it (ie, piles of metal above ground) and it appears to be this that they are saying will provide the world with material between 2007 and 2017. Most likely, the stock the

US Department of Defence used to hold just in case a shooting war broke out.

However, think back to what our definition of a mineral reserve is. It's an ore (or some dirt concentrated enough) that we can mine it and make a profit. And there's nothing at all on the planet that we can mine for hafnium and make a profit by doing so. Hafnium just doesn't produce ores that can be exploited. Thus, given that there's nothing to mine that we can make a profit from there's no mineral reserves.

However, this doesn't mean that we can't go and get hafnium: obviously not for we have had hafnium, at least in the past, and there never has been an ore that we can profitably mine hafnium from directly. The answer is that hafnium is always produced as a by-product. That is, we go off and process something else, making a profit by doing so, and then there's something left over which contains the hafnium we want and desire. This is quite common among the minor metals: there's nothing, no mineral, that offers our target metal in a form that we can gain directly. Gallium, germanium, terbium, indium, hafnium... You can see where this is going, can't you?

So where does our hafnium come from then?

Quite how much we use as a species each year is unknown, or at least officially unrecorded. According to a friend who trades the stuff regularly (as opposed to me, who has only handled it a couple of times) 500 tonnes a year would be a useful guesstimate. And if we've no reserves and no stocks, it must becoming from somewhere. And the answer is zirconium.

Zirconium and hafnium are, chemically, extremely similar. And all zirconium ore (usually zircon, a sand, from which we extract zirconia, the oxide, from which we make zirconium, the metal) contains

2-4% hafnium. That's just the way this universe is organised, was made by the bloke that God got in to do the engineering. Normally we don't care: the two are so chemically similar that we simply don't differentiate and almost all of the zirconia and zirconium that we do use in various things is that 2-4% hafnium. However, in physical properties they're rather different: the most important one being that zirconium is transparent to neutrons and hafnium is opaque.

This is pretty handy when we want to build a nuclear reactor. Both can deal with the heats, pressures and so on of the inside of a reactor. But if we put the uranium fuel into tubes of zirconium (and that's what you are seeing when you look at those videos of fuel rods being loaded into a reactor) then the neutrons from the reaction can flood through the reactor and set off that chain reaction that we desire. Of course, we don't want too much of a chain: so we often have hafnium rods that we can slot down into the reactor itself to absorb some of those neutrons.

This of course means that at some point we've got to get that 2-4% hafnium out of our zirconium. Because we want pure zirconium for our fuel rods. And that's where our hafnium comes from. It's not even a by product of the processing of zirconium: it's a by product of the very specific form of it that we want for the nuclear industry and pretty much only for the nuclear industry.

There's no ore we can get it from: no deposits, no mineral reserves. But there's lots of it about. Perhaps some 20,000 tonnes a year of hafnium in the zirconia/zirconium that we use outside the nuclear industry. If we wanted more than the nuclear industry provides us with we'd just go through that very boring and very expensive process on a bit more of the Zr. And, as above, we use about 500 tonnes a year at present. Do also note that there's absolutely no shortage at all of the zircon that we extract all of these things from, there's plenty of mineral reserves and resources of that.

So, we've our intrepid scientists telling us that we're going to run out of hafnium in two years' time now. And they're wrong. They're wrong because they appear not to have the slightest clue how hafnium is produced nor why simply looking at numbers for mineral reserves isn't the right way to work these things out.

This isn't, by the way, some obscure article in an out of the way magazine. This piece is now extracted and used in education would you believe it?

And the problems with gallium and terbium are exactly the same. Terbium is a rare earth, a rare rare earth. But the point about the rare earths is that you always find them together. The 15 lanthanides are chemically very similar and an ore has all of them in varying quantities. It's not possible to go mining for terbium and make a profit: you've got to extract all of them, sell all of them, and maybe you'll be able to make a profit on the basket. But if that's true then there are no mineral reserves of terbium. Which is what our intrepid and informed scientists have done. They've noted that there's no reserves and concluded that we ran out three years ago. The major use for terbium these days is compact fluorescent light bulbs and you'll have noted that they still infest the lighting sections of the supermarkets these days. We've not run out: they were wrong simply because they didn't know what they were talking about.

And so too with gallium. There's no ore we can get it from. There's a number of by-products that we can, the most usual being in the process of turning bauxite into alumina (the oxide precursor to making aluminium). This process is essentially boiling everything in a big vat of caustic soda (or lye as it is known) and the gallium comes out into solution. Stick the right gizmo on the side of the tank and it will concentrate out into the gizmo. Most such Bayer Process plants don't have that gizmo so most of the many thousands of tonnes of gallium we could have each year simply pass into the waste stream (where it sits in great lakes for decades). As we only use a few hundred tonnes a year of gallium this is fine, no sweat off our nose. There is no shortage of bauxite containing gallium: we're just not going to run out of it presuming that we continue to process for aluminium.

Now we could just say, well these blokes have been silly billies, haven't they? And chuckle and move on. But public policy is being determined by people who believe this nonsense. We've had Al Gore telling us, in those very serious tones of his, that these sorts of metals are about to run out and therefore we must recycle. Then again, Al has been telling us all about sea level rises for some time now and he's still bought beachfront property so it's not obvious that he takes all these warnings all that seriously. But the European Union Parliament has released reports stating that we're in imminent danger of running out of these sorts of materials. Informed by just this sort of error. People just not understanding where the things they want to talk about come from.

Please do understand this. The idea that we're going to run out of hafnium, gallium, terbium or another oft mentioned, germanium, could only be advanced by people wallowing in their own purblind ignorance. There's not the slightest possibility of us even running a bit short of any of them for thousands of years. To claim that we're about to, or even that by now we will have, run out of them is the scientific equivalent of taking the short bus to school.

Yet this is the sort of information that is being passed on as "science" and informing public policy. It's simply wrong, provably and obviously so to anyone with the slightest bit of industry knowledge. So, please, can we stop believing these idiots.

7. Jeremy Grantham's interesting mistake

Jeremy Grantham is an interesting one. Very wealthy—having made himself so as a financier and fund manager—he's off on one of those tears that tend to happen to men rich in maturity and achievement: *apres moi la deluge*. That is, now that I'm old, wise and successful I can spend my time telling everyone that society is going to the dogs. He, for example, funds a centre concerning climate change at my *alma mater*, the LSE, where Nick Stern is employed to think deep thoughts and Bob Ward is more amusingly employed as an attack bulldog on Twitter. Grantham is, of course, entirely at liberty to spend his money in any manner he chooses but I can't help thinking that he might do a little better if he were to dig deep into his own knowledge bank to examine his enthusiasms.

One of which is that we're going to run short of potassium and phosphorous real soon now and thus, as is the way with the would be Cassandras—Aiee! We All Die!—because potassium (from potash) and phosphorous (from phosphate rock) are the two essential ingredients, when added to the nitrogen fixed from the air, in making the modern fertilisers that all industrial agriculture uses to feed us all. And it is entirely true that we'd be in somewhere between 'something of a pickle' and 'in the process of Aiee! We All Die!' without them. Seven billion people just aren't going to get fed on the yields available without these inputs to farming. It is a fairly important question then: are we going to run out of these two?

A brief perusal of the numbers at the back of this book will show that we've got slightly more than we usually do of these two in our mineral reserves. Grantham agrees with these numbers: given that we're both getting them from the same source, the US Geological Survey, this isn't all that surprising. However, Grantham does make the mistake of saying that once those mineral reserves are gone then, well, whadda we gonna do? Starve?

He took to the pages of Nature to write this all out as a Commentary for them. Something which prompted me to write to the magazine, a letter that they printed. I should note here that there's a very great difference between a letter in Nature ("Dear Sirs, I think your previous correspondent might be grievously mistaken") and a Letter to Nature (Dear Sirs, I have discovered the secret of life, it is a double helix...."). I have managed a letter in Nature and I'm quite obviously never going to manage a Letter to Nature. Ho hum and so be it etc.

But the point I made in said letter was that mineral reserves running out in a generation or two? So what? What's important is the total amount of a resource that is available to us, not what we've currently got pegged out and ready for excavation. I can never recall which way around this goes, phosphorous and potassium, I've just looked it up and I still cannot recall but one is 0.2% by weight of the entire lithosphere (ie, all the rock down to about 50 km) of the planet Earth and the other is some 2% of it. These simply are not things we are going to run short of. I also pointed out further that we've mineral resources, that is minerals that we know where they are, what they're made of, know roughly how we would process them and think we can process them using current technology and at current prices, to last for thousands of years.

While fertiliser is an important point, something we really don't want to run out of, no, there's no imminent shortage of any component of it (and just to clear up one other misconception, it's not made from oil based products but from natural gas, of which we have an abundance) and so no, we do not for this reason need to conserve their use or figure out some other way to feed ourselves.

There might well be other reasons: organic farming doesn't allow their use and if that's the sort of thing that floats your boat then fine. Overuse can most definitely lead to algal blooms which kill off fish in certain waters (The Gulf of Mexico is prone to this) which could be another reason not to use them. But an actual physical shortage, no, it's just not going to happen.

So, after my triumphant letter in Nature ("Dear Sirs, Your correspondent is all wet") I was referred to some of Grantham's deeper writing. Where he acknowledges that mineral reserves are not all that matter. Mineral resources can indeed be converted into reserves simply by spending money on them to prove them. But he worries that the mineral reserves will run out in 60 years (it is amusing, to me at least, that he's worrying about two minerals where the reserves are rather larger than usual) and we don't seem to have anyone doing the work to convert those resources into reserves. How can we solve this problem?

At which point there's a minor amusement: there's a company called Sirius looking to do exactly that up in Yorkshire. A large deposit of just the right sort of stuff to be making these fertilisers from. It's in a National Park, or similar kind of conservation area, so they've all sorts of people they have to appease to get the right sort of stamp on their permissions and documents. And at one point one of those bureaucracies denied the application on the grounds that there was no one out there who wanted to buy what would be produced. Which rather puts Grantham's worries about a shortage of fertilisers into some perspective. Or of course he could be correct and the bureaucrats wrong.

But the error he makes is one that he as a financier should understand intuitively. It costs money to convert a resource into a reserve and why would you do that 60 years before you need to?

To illustrate, there's an interesting company out there called Sherritt International. They're a nickel and cobalt miner and processor. They also handle the processing of the Cuban nickel ore that is one of the island's major hard currency lifelines. And, of course, those nickel mines were confiscated at the time of the revolution without compensation. So, under the Helms Burton act, the one that allows for the confiscation of anything produced in Cuba from assets confiscated without compensation at the revolution, that ore isn't processed in the US. Obviously: it would be confiscated. In *theory*, so should any nickel made from that ore, even after it is processed at Sherritt's Canadian plant. In theory anything made from scrap of that nickel that's been around the recycling circuit once or twice should be confiscated but no one does go quite that far. But one of Sherritt's contracts over the years has been supplying nickel to the Canadian Mint to make the country's coins from. Which does mean that, under Helms Burton, anyone wandering over the border with a pocket full of Canadian quarters should have them confiscated. This doesn't actually happen, Canadian coins circulate on the US side of the border on a 1:1 basis with American coins, as the American ones do on the Canadian side of the same border. But we might still take this as evidence that there's someone in the Canadian Mint with a more than puckish sense of humour.

Not that that's anything to do with the point we want to make about Grantham. Which is that Sherritt has been building a new plant to process some nickel laterite ores in Madagascar. It's a huge plant with a vast cost: $4 billion was the last number I heard. The plant is producing: nickel is coming out of it. However, the deposit they are mining, while it is actually producing nickel, is still not, technically speaking, defined as a mineral reserve as yet, it's still a mineral resource. Because that mineral requires a new type of processing plant, to a new (at least, newish, Sherritt was a contractor building something similar in Australia a decade or more back, a mine that went bust) design. So, it only becomes....well, recall what our definition of a mineral reserve is? It's a deposit that we know we can, we have proved we can, mine using current technology and at current prices *and make a profit*.

This new plant does not yet make a profit (it's possible I am a little out of date on that). Therefore we haven't proven that the new technology actually works by the definitions we use and thus the deposit of the mineral, one that is already producing nickel as an output, is not a mineral reserve. Despite our having spent $4 billion trying to prove that it is.

Now, of course, this is an extreme example, this is why I use it. But imagine what would happen in the following conversation:

"Mr. Grantham, we'd like $4 billion to prove a new potassium deposit, to turn it from a resource into a reserve."

"Hmm, good idea. When do you think you'll start producing?"

"About 60 years, when the current mines are projected to be exhausted"

"And you want to spend $4 billion now then wait 60 years? Get out of my office now!"

"But, but, Mr. Grantham, you said it was important that more resources be converted to reserves!"

"But there's 60 years left! Pablo, where's my shotgun?"

The point being that money has a time value. There is absolutely no point at all in spending money now to prove a reserve that won't be mined for 60 years. That's the sort of thing you might do in 50 years' time. And Grantham should know this if he just thought for a moment about what he's saying.

And this is also why mineral reserves tend to only ever last a grandfather out at any one point in time. Simply because there's no point in paying now to prove reserves we're not going to use for a grandfather or two.

We don't have a shortage of mineral resources, not even of those vital to our feeding ourselves. And the reason we don't convert those resources into reserves is that doing so before we're just about ready to open the mine itself is a mind-bogglingly stupid idea. As Grantham himself would know if he thought for a moment but as Grantham seems not to want to acknowledge. Or, perhaps, think about.

8. But what about the energy, eh, eh?

There is one possible critique of this rosy picture I've painted of mineral availability that might, possibly even could, be true. Which is that while there's lots out there obviously those deposits are going to become ever more difficult to mine. We've already had the low hanging fruit and new ores that we find or attempt to exploit will inevitably have higher energy requirements as they're deeper, of lower grade and so on.

It is indeed possible that this might be true, it could even be true. As it happens, it's not in fact true. And we can show this with three examples from the current world of mining. The original mistake being made is to think that we've surveyed the whole world: we haven't. And not only that, we didn't survey and then decide logically to extract from that low hanging fruit. As we didn't we did not in fact process the easiest deposits first, something that's really rather easy to show.

At the moment the Chinese economy is slowing down a bit, just as the iron ore companies have been ramping up their output. There's therefore an oversupply of iron ore floating around the world on those giant ore carriers and the price has, quite naturally, collapsed. A couple of years back that price was well north of $150 a tonne, now it's floating around $50. As these things go that's a huge price difference. And also as these things go we can expect some number of these mines to close as they're now unprofitable.

So, if our original contention that we start by mining the easy stuff were correct then it should be the new mines that are closing. They must, logically from our premise, be the mines with greater energy requirements and lower quality ore. However, given that this isn't what is happening our original premise might have an error somewhere in it.

For what is actually happening is that the newest and largest mines, those in the Pilbarra region of Australia, have the lowest production cost. It is the older mines in China that are closing, and the even lower grade mines in North America have largely been closed for some time now.

The point being that that contention is therefore wrong. It is not true that we started mining the easy stuff and therefore, obviously, all future mining will be more expensive.

We can also see this in the tantalum market. Most will only know this through the campaigns about the appalling conditions at mines in the DR Congo, formerly Zaire. There are places there where warlords have been enslaving the locals to mine columbo tantalite (more commonly called, by the NGO activists, coltan). No, I do not approve of this. Rather, I want to use it as proof of the error in that original assumption.

It's a general rule in mining that the big mine, with lots of machines, is going to be cheaper per unit to run than an artisanal mining operation (artisanal here means blokes with shovels). Like so many human operations there are large economies of scale in the business. Yet there's a tantalum mine in Australia called Sons of Gwalia (where they mine the quite beautifully named mineral "wodginite") which is now closed, having gone bankrupt. Yet we've those artisanal mines in the DRC still making good profits even while using nothing but sweat, bad backs, shovels and household colanders. And only a minority of them are those slave mines: many more are simply the locals running local operations to collect that valuable mineral.

So how can a modern, fully equipped and mechanised mine be beaten by a hugely more inefficient form of mining? The secret is that the Congo deposits are vastly richer than those in Australia. And note the point there: the richer deposit was found later than the one that was opened earlier. It simply is not true that newer deposits that we exploit inevitably require more energy or that the ore grade is lower.

And finally on this point we can look at the tin market. Most Brits know that Cornwall was the centre of the world's tin industry for centuries. Most Central Europeans would point out that the Krusny Hory (or Erzgebirge in German, Ore Mountains in English) competed for many centuries as well: but we Brits tend not to know those sorts of things. We might also even be aware of the way in which tin mining is now largely in SE Asia. We might know this by another of the NGO campaigns where they berate Apple for the conditions in which tin is mined on two Indonesian islands, Bangka and Belitung.

Such berating is slightly unfair, as the pictures of people digging the stuff up with their hands are acknowledged to be of illegal miners: illegal even under Indonesian law. Not that that stops NGOs when they can bandy the Apple name around of course. But our point here is that again we seem to have had higher cost mines replaced by lower cost ones: how can that be if inevitably we're going to move from low cost deposits to higher cost ones?

The answer again is that we just never did survey the world and then decide where to mine first. And with tin we can explain why as well.

The Krusny Hory and Cornish deposits are what are known as "hard rock" deposits. That is, you have to dig down into the Earth, hack out the rock, then crush and mill it down to a particular size (that size depending upon the exact material and known as the "liberation point". The size at which you can liberate the cassiterite, the tin ore, from the surrounding rock). Once you've done that you can then separate out that cassiterite fairly easily. While modern day operations use big machines to do it, the basic principle is just like panning for gold. The tin ore is a different weight from the surrounding rock and so you can float one off the other.

As we've already mentioned these sorts of minerals seem to crystallise out at different stages of the cooling of a magma plume. So, to go tin mining you find a plume, find which bit has the tin and start digging, crushing and milling. Which is exactly how the Cornish and Krusny Hory industries worked. But they've been beaten out of the market (from my office window I can see a hill in the Krusny Hory that has Europe's largest tin deposit beneath it: there's no shortage of tin left) by the lower cost material from Indonesia. Why?

Because an alternative way of doing this is to go and find a plume that has already been ground down for you by erosion. We've been, after all, through a number of cycles of vulcanism, mountains forming and then eroding back into the silt at the bottom of the sea. And if that weathering broke down a mountain that had one of those tin deposits in it then you might find that that tin is now at the bottom of the river.

Or, as happened in SE Asia, the mountains of Vietnam, Cambodia, Thailand and so on have been gradually weathered down over time. And the sea level used to be rather lower, as when there was a land bridge to Australia. Meaning that the Mekong and other rivers ran very much further to the sea than they do now. Look back up to how we separate out the tin ore: through water action. So, our mountains have weathered down to the liberation point of the ore, that ore has gone down into the silt of the rivers and the movement of the water has helped to separate it out. Those Indonesian islands now have stripes of tin ore through the sand (or, perhaps did until recent extraction efforts) which is easy enough to collect. In the shallow waters offshore one can actually vacuum up tin ore using something like a Mr. Henry domestic cleaner. Although being at sea with the electrical cable running to shore is not recommended.

This is known as an alluvial deposit. And the point is that as we were digging up Cornwall and the Czech German border we had no idea at all, for centuries, that all that easily available tin was there just for the picking up on the other side of the world (that other side of the world might have had something to do with it).

It simply isn't true that we have already exploited the easy deposits and that therefore we will face ever rising energy costs and ever poorer grades of ore in those reserves and resources that are out there. It could have been true, it might have been true, but it just isn't.

9. Where the Club of Rome went wrong

That the Club of Rome did go wrong at some point is obvious. For their predictions back in 1972 were that we should all be dead in the gutter by now. More specifically, that we should be facing serious, widespread and insoluble shortages of minerals and metals by now. As the rest of this book shows this simply isn't true. So, what is it that they did wrong?

To be excruciatingly fair I should point out that they used a slightly different forecasting technique. Instead of, as I have, using a simple straight line forecast (ie, usage this year is what we'll use next year) they used a dynamic model. If x number of people require y amount of, say, iron, then if population grows to x+ then iron consumption will climb to y+. That's fair enough, obviously, and they also look at previous growth rates in the usage of various minerals and metals and extrapolate those out. That's not so fair for a slightly complex reason.

We don't need to take account of population so much these days. All indications are (and the UN population projections have always turned out to be overstated, not under) from the usual UN predictions that we're a couple of decades away from peak humanity. After peaking at some 9 billion people population is then going to start declining, reaching our current 7 billion again by the end of the century. So, population growth isn't all that important an adjustment to make to a straight line projection.

Growth in previous consumption leading to increase in future consumption, that's as I say more subtle. For it seems a reasonable enough assumption: if tungsten usage has been growing at 5% a year, per capita (to take care of that population issue) then why won't it grow at 5% a year into the future? Not that they do specifically say tungsten and 5%, this is just a theoretical example. The answer being that which metals and minerals we're using more of depends rather on the level of technology we've got at any one time. And we do find that once we reach a certain level then the use of any specific mineral or metal does tend to level off. That level being different for different technologies and also for the metals that they use. Obviously.

For example, the world iron ore trade is currently being driven by demand in China. As it happens, it turns out that building a society at a level above mud bricks for the first time sucks in vast amounts of iron and steel. China, according to some reports, currently consumes more than the rest of the world put together. Yet over the past decades the US consumption of virgin ("virgin" in metals parlance means produced from ore, not from recycled metal) iron and steel has been falling while total consumption of iron and steel has been rising gradually. The explanation is that when building a society the third or fourth time there's a lot of iron and steel that is recoverable from those earlier attempts that can be smelted into making the next generation of the buildings and consumer goods.

To make this more obvious: no one really expects the US level of car ownership to rise any further than it has done already. There's no unconquered markets of the poor or the un-transported who are about to flock out, if they could only afford it, to increase the total number of cars on the road. The market is essentially (pace population growth which isn't all that great an influence) a replacement market. For each new car sold there's another one, somewhere, coming off the road at the end of its operational life. That means there's a tonne and a half of steel (yes, they still like their cars heavy, the Americans) coming off the road at the same time as there's another tonne and a half coming onto them. Given that Nucor, a couple of decades back, worked out how to turn old cars into the auto rolling steel from which we make new cars we're consuming energy to do this but not very much iron ore.

Sure, this process isn't perfect—no such recycling process is. Contaminants build up (with steel, copper is a particular worry) and so you can't just recycle 10 million cars into 10 million cars. But the amount of virgin steel being used to top up this process is obviously of a different order of magnitude than the amount of steel that's going to go into creating the first generation of cars that leads to every Chinese citizen having one or more, as the Americans darn near do.

Again, this isn't perfect, but we do find that once a society gets to a certain level, that level dependent upon the metal and the technology it is used for, that the assumption of ever greater consumption growth fails. It's roughly happening for iron and steel in the advanced countries. It is also roughly happening for copper in the advanced countries (again, the global price is really driven currently by China sucking it in to build a developed country for the first time). Mercury consumption is falling per capita in all advanced countries. Thorium consumption per capita has fallen off a cliff (the major use was, for a time, in gas mantles, we don't use gas lighting any more).

So while it seems a reasonable assumption to take current growth rates in consumption of whatever it is and project it forward however many decades, that exponential growth thing, it's not actually true of minerals and metals. As it's not true it's not a good assumption to make however reasonable it is.

But this isn't where the Club of Rome really went wrong. There's two interesting errors they do make, one which is just an opportunity for a bit of snark, the other holes their argument below the waterline.

That snark is that they assume, certainly in their various updates, that metals and minerals will not substitute for fossil fuel usage. Which is a bit of a blow to the renewables industry really as that's what the renewables industry does. Solar cells are the substitution of silicon (with a bit of gallium and copper perhaps) for fossil fuels. Wind turbines are the substitution of aluminium, steel, copper and some rare earths for fossil fuels. Hydroelectric dams are the substitution of concrete for fossil fuels. And so on through the list of the renewables. The entire point and purpose of them is to produce energy without the use of fossil fuels: to substitute for them. And the technologies that are likely to actually meet our needs (and if we can even bring ourselves to mention nuclear power, obviously this is substituting uranium for them, thorium if we ever get around to those newer and better reactors) are in fact substituting metals and minerals for those fossil fuels.

But the real mistake they make is that they assume that mineral resources are some ten times minerals reserves. I hope the rest of the book shows you that there is in fact no relationship at all between the mineral resources available to us and the mineral reserves that we've got identified, counted and prepped up for use. Not just that there's no discernible ratio between them but that there's actually no relationship at all. So that is an error.

But there's more to it than that. It's an error that drives their entire finding. Which is, recall, leaving aside the more hysterical readings of their models that we should all be dead already, that there's no way that industrial society as it is constituted can carry on for more than a couple of hundred years. But that finding is entirely driven by their assumption of that relationship, that ratio that doesn't exist, between reserves and resources.

You can either take my assertion at the front of the book that mineral reserves always run out in a generation, because that's what mineral reserves are, the minerals we've got ready to use in the coming decades. Or you can look at the table at the back of the book where I go through the reserves and resources (under different definitions) available to us. You'll see that, with a few exceptions, reserves are in the 20 to 50 years of current consumption range. We might, as Terry Pratchett put it, call a 30 year period a generation, or a grandfather. About the time from that first flush of conjugal joy with one's life partner through to that solace of middle age, the holding of one's first grandchild. And mineral reserves tend to last about one grandfather.

So, if we assume, at the beginning and with no empirical or theoretical support, that minerals are only going to last ten grandfathers then our conclusion, that minerals are only going to last ten grandfathers (and, then, Aieee! We all die) isn't in fact a finding of our vast report and our calculations. It's an assumption that we've baked in. There's no way to play the numbers to get to a different conclusion having made that assumption.

The Club of Rome hasn't, didn't, prove that minerals and metals are going to run out soon enough. They assumed it and then announced that they'd proven it. And that really is a mistake. And it's a mistake that we really should not be basing our predictions, nor our plans, for the future of civilisation upon.

The reality is that there's no shortage of any metal or mineral that's likely to impact upon us or our descendants over any reasonable period of time. This does of course depend upon what we count as "reasonable" here but one thousand years seems reasonable enough to me. A thousand years ago in my native England the Danish King Cnut was ascending the throne to do that trick with the courtiers and the tide. Mining technology was limited to a few blokes with picks and shovels, they'd not even discovered coal as a general resource at the time. Iron was made with charcoal and there was just no one in Europe at all mining at greater than 50 or perhaps 100 feet deep. Anyone who wants to predict what mining technology is going to be like one thousand years from now is entirely welcome to do so. But please don't, having done so, start to think that the rest of us need to pay a blind bit of attention to your predictions as we decide how to live our lives now.

But that aside. The Club of Rome was wrong because they assumed at the start that there's a relationship between mineral reserves and mineral resources ultimately available to us. There isn't, it's a false assumption so they're wrong.

So perhaps we should stop paying attention to them.

10. Mineral estimates

The following is a list of the major and minor (but including no energy producing ones) minerals that are currently used and tracked. The source is the usual source for such things maintained by the US Government, the US Geological Survey available here: http://minerals.usgs.gov/minerals/pubs/commodity/

I have made no reference at all to the amount of any mineral or metal that is recycled. For some of them a large part of current production is indeed simply recycling of earlier mined material. It's also true that recycling rates for almost all of them have been rising over time. The reason for not including recycling rates is simply that this isn't the point of this exercise. It may well, indeed it often does, make sense to recycle for economic and financial reasons. But that is not the same thing as stating that we must recycle because without doing so we will run out of minerals. The aim here is to show that we're not going to run out of minerals whether we recycle them or not.

We'll certainly be richer by recycling some of them: but we won't be bereft of them if we don't.

Mineral reserves are, as discussed earlier, the minerals that we know where they are, we have mapped and tested them, we know that we can extract them at current prices, with current technologies and make a profit by doing so. A rough and ready, if not quite exactly accurate, description is that these are the stock in trade, or deposits, at mines that are already being worked.

Mineral resources are the minerals that we know roughly where they are, have good reason to think we can mine at current prices, with current technology, and make a profit by doing so. But we've not gone through the expensive process of actually proving this. At either end of the spectrum of resources they do bleed off into either something very akin to a reserve, we're just waiting for that final confirmation of our testing work say, and at the other end off into supposition based on little more than a shrewd guess. At that supposition end don't look for too much accuracy: we'll be right about the general range but not much better than that.

Total resource is not an industry phrase. It's entirely made up here, by me. We think we have a reasonably good idea of the composition of the lithosphere (that's the solid bit of the Earth floating on the magma). This is a "reasonable idea" to a certain not very accurate meaning of the word "reasonable". We may or may not have the correct digit in front of the number and we're likely, but not certain, to have the right number of zeros after it, to within an accuracy of one more or one less zero. What is called being accurate to within an order of magnitude. Thus 2 billion tonnes means almost certainly more than 100 million tonnes and almost certainly less than 30 billion tonnes.

Real resource is an even more fantastical figure again, entirely made up by myself. Clearly, we're not actually going to strip mine the entire lithosphere, whatever our hunger for shiny metals with which to make our gewgaws. Leaving the entire planet looking like Nauru (which was indeed strip mined in its entirety for phosphates) would not be a good idea.

So real resources is limiting those total resources in what seems like a rational manner. Firstly, we would not mine the lithosphere, only the crust itself. That crust is perhaps 10% of the lithosphere and we can, just about, with current mining techniques, mine that deep....there are gold mines going nearly this far down at present for example. I've also assumed that we would only ever strip mine 1% of the world's surface down to that depth of perhaps 10km. This would mean mining most of Australia (which we aren't going to do, Randy Newman was right, "Don't wanna hurt no kangaroo"), or a little more than Greenland and Saudi Arabia added together. Or a deep hole under 10 percent of the Pacific Ocean. And who would really notice if we did this to East Siberia?

Yes, I agree, of course this is absurd. We're not going to do that: but the reason we're not going to do that is because the minerals we would get from doing so are so vastly larger than any amount that we'd ever conceivably use as a species that we'd simply never do it. And that is the point of the calculation. If we mine one thousandth (that is, only to 10% of the depth of the lithosphere on 1% of the world's surface) then we have more metals and minerals than our species is ever going to use. That's even if you're extremely optimistic about how long our species is going to last as well.

I've then calculated how long it will take to exhaust mineral reserves, mineral resources and real resources at current rates of consumption. I have not tried to adjust for increasing rates of consumption (unlike the various Club of Rome analyses). I have also not, as above, adjusted for any recycling that might occur. Given the length of time of our available resources it just doesn't seem worth worrying about either of those two factors.

Mineral	Annual production (tonnes unless stated otherwise)	Reserves (tonnes unless stated otherwise)	Exhaustion of reserves (years)	Resources (tonnes unless stated otherwise)	Exhaustion of resources (years)	Total resources (tonnes unless stated otherwise)	Real resources (tonnes unless stated otherwise)	Exhaustion of real resources (years)
Aluminium	45 million	See bauxite	See bauxite	See bauxite	See bauxite	12,250,000,000 billion	12,250,000 billion	270 million
Antimony	180,000	1.8 million	10	c.6,000,000 as at 2,000 CE	33	30,000 billion	3,000 billion	16 million
Arsenic	45,000	c.1 million	22	11 million in copper and lead deposits (more elsewhere)	270	270,000 billion	270 billion	6 million
Bauxite (for aluminium)[1]	263 million	28 billion	106	55–70 billion	>200 years	12,250,000,000 billion	12,250,000 billion	270 million
Beryllium	260	15,000	58	80,000	300	356,000 billion	356 billion	c.1.5 billion
Bismuth	7,400	320,000	50	Unknown (a byproduct)	n/a	4,075 billion	4 billion	550,000
Boron	4.6 million	210 million	45	"Adequate for the foreseeable future"	48,435,000 billion	48,435 billion	48,435 billion	10 million
Bromine	580,000	13,400,000	23	100 trillion (it can be and is co-extracted with salt)	Somewhere around the sun going nova	288,500,000 billion	288,500 billion	Around the heat death of the universe
Cadmium	23,000	500,000	21	Unknown but very large in zinc ores and certain coals	~	20,500 billion	20 billion	800 million
Cesium	Unknown ("a few thousand kilos a year are used in the US")	169,000	34,000	Large in association with lithium metals	~	395,000 billion	395 billion	c.59 billion
Chromium	24 million	>460 million	20	>12,000 000,000	500	23,760,000 billion	23,760 billion	c.1 million
Cobalt	110,000	7.5 million	68	15 million (maybe 1bn in manganese nodules in ocean)	140 conventional, 9,000 unconventional	3,750,000 billion	3,750 billion	34 million

Mineral	Annual production (tonnes unless stated otherwise)	Reserves (tonnes unless stated otherwise)	Exhaustion of reserves (years)	Resources (tonnes unless stated otherwise)	Exhaustion of resources (years)	Total resources (tonnes unless stated otherwise)	Real resources (tonnes unless stated otherwise)	Exhaustion of real resources (years)
Copper	17 million	680 million	40	3,000,000,000 not including undersea nodules and sulfide deposits	175	10,425,000 billion	10,425 billion	600,000
Gallium	273	Large in the bauxite we mine for aluminium	~	1 million	3,600	2,800,000 billion	2,800 billion	10 billion
Germanium	118	Unknown	~	Unknown but large in coal fly ash	~	235,000 billion	235 billion	c.2 billion
Gold	2,700	52,000	20	Including seawater, very large	~	410 billion	410 million	150,000
Hafnium	Unknown but perhaps 500	None	~	Large in zircon sands	~	580,000 billion	580 billion	1 billion
Helium[2]	173 million m^3	Unknown but >7,500m^3 (helium also constantly generated by radioactive breakdown)	43	31,000,000,000 m^3	180	Unknown but rising due to radioactive decay	Unknown but rising due to radioactive decay	Unknown, but if consumption is lower than generation, never.
Indium	670	Unknown	~	Unknown	~	22,950 billion	23 billion	34 million
Iodine	28,000	7.6 million	271	90 billion in seawater (extractable by harvesting seaweed)	27 million	54,000 billion	54 billion	c.20 million
Iron ore	3,000 million	170,000 million	57	800 billion (ie. 800,000 million)	270	Content, not ore: 7,824,000,000 billion	7,824,000,000 billion	2.6 million
Lead	5.2 million	89 million	17	2,000,000,000	380	1,900,000 billion	1,900 billion	360,000
Lithium	37,000	13 million	350	40 million	1,100	2,850,000 billion	2,850 billion	70 million
Magnesium	6.1 million including compounds	2,400,000,000 including compounds	400	12,000,000,000 in ore, near unlimited from seawater	2,000	3,510,000,000 billion	3,510,000 billion	c.300 million

Mineral	Annual production (tonnes unless stated otherwise)	Reserves (tonnes unless stated otherwise)	Exhaustion of reserves (years)	Resources (tonnes unless stated otherwise)	Exhaustion of resources (years)	Total resources (tonnes unless stated otherwise)	Real resources (tonnes unless stated otherwise)	Exhaustion of real resources (years)
Manganese	16 million	630 million	40	Very large	Unknown	147,000,000 billion	147,000 billion	9 million
Mercury	2,000	94,000	47 (perhaps too soon given falling demand for this poisonous metal)	600,000	300	10,100 billion	10 billion	5 million
Molybedenum	250,000	11 million	44	c.20 million	80	190,000 billion	190 billion	800,000
Nickel	2.1 million	75 million	36	130 million (not including seabed manganese nodules)	62	16,650,000 billion	166,650 billion	800,000
Niobium	69,000	>4,000,000	60	Unknown but "more than adequate to supply projected needs"	Unknown	2,850,000 billion	2,850 billion	40 million
Phosphate rock (for phosphorous for fertilizers)	210 million	67,000,000,000 billion	300	300,000,000,000	1,400	166,500,000 billion (of phosophorus, not phosphate rock)	166,500 billion	800 million
Platinum group metals[3]	380,000 kg	66 million kg	170	100 million kg	260	1,600 billion	1.6 billion	2.6 million
Potash (K2O for potassium for fertilizers)	34,000,000	9,500,000,000	280	250,000,000,000	7,300	3,258,000,000 billion (as potassium)	3,258,000 billion	90 million
Rare earths	110,000	110 million	1,000	"Very large"	Unknown	9,725,000 billion (for just cerium, one of 17 rare earths)	9,725 billion (cerium alone)	80 million
Rhenium	52,000 kg	2,500,000 kg	50	11,000,000 kg	210	185 billion	185 million	3.5 million
Rubidium	4,000 kg	113,000,000 kg (just one mine in Canada)	28,000	Unknown but very large	Unknown	20,250,000 billion	20,250 billion	Heck, sometime after three contractions of the universe to pinpoint and Big Bangs again?

Mineral	Annual production (tonnes unless stated otherwise)	Reserves (tonnes unless stated otherwise)	Exhaustion of reserves (years)	Resources (tonnes unless stated otherwise)	Exhaustion of resources (years)	Total resources (tonnes unless stated otherwise)	Real resources (tonnes unless stated otherwise)	Exhaustion of real resources (years)
Scandium	2,000	98,000	49	Unknown but vast in coal	Unknown	7,500 billion	7.5 billion	3.75 million
Silicon	7.6 million	Vast (it's basically boiled sand)	Unknown but a long long time	Similarly vast	Lotsa time	41,496,000,000 billion	41,496,000 billion	5.5 billion (about the time the Sun goes Red Giant)
Silver	24,000	540,000	23	Large	Unknown	11,250 billion	11 billion	450,000
Strontium	380,000	6.8 million	18	1,000,000,000	2,600	55,000,000 billion	55,000 billion	150 million
Sulfur	70 million	A byproduct of refining, as long as we use oil there's plenty	Unknown	600 billion or more	8,000	61,500,000 billion	61,500 billion	900,000
Tantalum	765	>150,000	200	Large	Unknown	285,000 billion	285 billion	370 million
Tellerium	80	24,000	300	Large	Unknown	350 billion	350 million	4.3 million
Thallium	10	380	38	17,000	1,700	99,000 billion	99 billion	10 billion
Thorium[4]	Near zero	1.4 million	Unless we get thorium based reactors: unlikely	2.5 million	Ditto with reactors	1,380,000 billion	1,380 billion	Oh, come on, puhleeze
Tin	230,000 (including a lot of recycling)	4.9 million	21	Large	Unknown	251,250 billion	250 billion	1 million
Titanium	7 million	700 million	100	2,000,000,000	290	852,000,000 billion	852,000 billion	120 million
Tungsten	73,000	3.2 million	44	Large	Unknown	8,147,500 billion	8,147 billion	110 million
Vanadium	63,000	14 million	225	63 million	1,000	21,375,000 billion	21,374 billion	340 million
Zinc	13 million	250 million	20	1,900,000,000	140	11,200,000 billion	11,200 billion	860,000
Zirconium	1.42 million	48 million	34	60 million	42	27,562,500 billion	27,562 billion	19 million

Notes:

1 The United States and most other major aluminum-producing countries have essentially inexhaustible subeconomic resources of aluminium in materials other than bauxite.

2 Worth noting that fracking, gas condensates and the rise of LNG mean that economic recovery of the small amount of helium present in all natural gas is becoming possible, hugely expanding supplies.

3 These are numbers for platinum and palladium. The more minor members of the group, iridium, osmium, rhodium, ruthenium, do not have detailed statistics. But the general relationships between use, reserves, resources etc. are roughly the same.

4 Production is pretty much nothing. Usage is also pretty much nothing. As an aside I once shipped 8 kg of thorium to a customer. From the trade statistics that was 50% of all trade in thorium in the US that year.

Please do note that there's two interesting patterns here. The first is that mineral reserves tend to last a generation or two out (using Terry Pratchett's estimation of 30 years, or a "grandfather" as a reasonable guess at the length of a generation). This is because, as noted elsewhere in this book, mineral reserves are best defined as the minerals that we have prepared for use in the next generation or two out. The second pattern of interest is that there is absolutely no relationship whatsoever between mineral reserves and the amount of that specific element or mineral that is available to us on either theoretical or practical grounds. None whatsoever: and there's only the vaguest link between reserves and the official resources available. This is where, as also noted elsewhere here, the Club of Rome goes so wildly wrong. There simply isn't the relationship which they assume there is as the basis of their calculations.

One other point of interest: the biggest shouting about things we're going to run out of concerns potassium and phosphorous (ie, Jeremy Grantham) and rare earths (all sorts of people worried about China).

What are the three elements where we seem to have not just the greatest resources available to us but the largest already defined mineral reserves? Quite, interesting, isn't it, that the greatest noise is being made about those things that even by the justifications of those doing the shouting are of the least concern.

11. Definitions of mineral reserve and mineral resource

Even I will admit that this is a pretty boring bit but this is here simply to show that the differences I am making between mineral reserves, mineral resources, ore and dirt really are true. These specific regulations are the Canadian Institute of Mining (and Metallurgy and Petroleum but they seem not to put those last two into their acronym, CIM) ones. While these are not absolutely and exactly the same as those that apply everywhere, all the various countries that have stock markets where a mining firm can list, or is likely to (UK, US, Australia, etc), have rules very similar to these.

It's important to note that it is listing rules that apply here too. The genesis of these rules was to impose some sort of order on people who would approach the public for the money to develop particular sites. It's easy enough to shout "There's gold in them thar' hills" and collect the money from the rubes as you do so. So, stock market authorities over the years have insisted upon rules about what you can and cannot say. You can claim that there's all sorts of valuable stuff in a property: I see mining companies doing so every day. But if you say that there's resources there then you'd better have proven them to these standards. And if you want to claim that there's reserves then again you must have proven that to these standards. Then, when someone wants to go around and count what are mineral reserves they go around and add up what the mining companies are claiming as proven reserves. Which, as above, obviously conform to these standards.

What doesn't happen is that there are mineral reserves which are not owned by someone. Because, by definition, mineral reserves are profitable to exploit with current technology and at current prices. That means that mineral reserves are valuable: things that are valuable are owned by people. On the simple basis that if something which is valuable is owned by nobody then it very soon will have someone claiming ownership. This is Friedman's $20 bill in the street in action.

Resources, those things that may or may not be valuable might not be owned by anyone. But reserves, those things which by definition are, will be. So, we can indeed gain a reasonable estimate of what reserves there are by adding up those people who claim to own such valuable reserves.

So, here is CIM's shorter version of the definitions of reserves and resources. The full version can be gained though Google (for a number of different country variations) or from cim.org:

CIM DEFINITION STANDARDS

The CIM Definition Standards presented herein provide definitions and guidance on those definitions for Mineral Resource and Mineral Reserve and their confidence categories. The category to which a mineral resource or mineral reserve estimate is assigned depends on the level of confidence in the geological information available on the mineral deposit; the quality and quantity of data available on the deposit; the level of detail of the technical and economic information which has been generated about the deposit, and the interpretation of the data and information.

Throughout the CIM Definition Standards, where appropriate, "quality" may be substituted for "grade" and "volume" may be substituted for "tonnage". Technical Reports dealing with estimates of Mineral Resources and Mineral Reserves, or summarizing the results of Mining Studies (Preliminary Feasibility or Feasibility Studies), must use only the terms and definitions contained herein.

DEFINITIONS

Qualified Person

Mineral Resource and Mineral Reserve estimates and any supporting Technical Reports must be prepared by or under the direction of a Qualified Person, as that term is defined in NI 43-101.

The Qualified Person(s) should be clearly satisfied that they could face their peers and demonstrate competence and relevant experience in the commodity, type of deposit and situation under consideration. If doubt exists, the person must either seek or obtain opinions from other colleagues or demonstrate that he or she has obtained assistance from experts in areas where he or she lacked the necessary expertise.

Determination of what constitutes relevant experience can be a difficult area and common sense has to be exercised. For example, in estimating Mineral Resources for vein gold mineralization, experience in a high-nugget, vein-type mineralization such as tin, uranium etc. should be relevant whereas experience in massive base metal deposits may not be. As a second example, for a person to qualify as a Qualified Person in the estimation of Mineral Reserves for alluvial gold deposits, he or she would need to have relevant experience in the evaluation and extraction of such deposits. Experience with placer deposits containing minerals other than gold, may not necessarily provide appropriate relevant experience for gold.

In addition to experience in the style of mineralization, a Qualified Person preparing or taking responsibility for Mineral Resource estimates must have sufficient experience in the sampling, assaying, or other property testing techniques that are relevant to the deposit under consideration in order to be aware of problems that could affect the reliability of the data. Some appreciation of extraction and processing techniques applicable to that deposit type might also be important.

Estimation of Mineral Resources is often a team effort, for example, involving one person or team collecting the data and another person or team preparing the Mineral Resource estimate. Within this team, geologists usually occupy the pivotal role. Estimation of Mineral Reserves is almost always a team effort involving a number of technical disciplines, and within this team mining engineers have an important role. Documentation for a Mineral Resource and Mineral Reserve estimate must be compiled by, or under the supervision of, a Qualified Person(s), whether a geologist, mining engineer or member of another discipline. It is recommended that, where there is a clear division of responsibilities within a team, each Qualified Person should accept responsibility for his or her particular contribution. For example, one Qualified Person could accept responsibility for the collection of Mineral Resource data, another for the Mineral Reserve estimation process, another for the mining study, and the project leader could accept responsibility for the overall document. It is important that the Qualified Person accepting overall responsibility for a Mineral Resource and/or Mineral Reserve estimate and supporting documentation, which has been prepared in whole or in part by others, is satisfied that the other contributors are Qualified Persons with respect to the work for which they are taking responsibility and that such persons are provided adequate documentation.

Pre-Feasibility Study (Preliminary Feasibility Study)

The CIM Definition Standards requires the completion of a Pre-Feasibility Study as the minimum prerequisite for the conversion of Mineral Resources to Mineral Reserves.

A Pre-Feasibility Study is a comprehensive study of a range of options for the technical and economic viability of a mineral project that has advanced to a stage where a preferred mining method, in the case of underground mining, or the pit configuration, in the case of an open pit, is established and an effective method of mineral processing is determined. It includes a financial analysis based on reasonable assumptions on the Modifying Factors and the evaluation of any other relevant factors which are sufficient for a Qualified Person, acting reasonably, to determine if all or part of the Mineral Resource may be converted to a Mineral Reserve at the time of reporting. A Pre-Feasibility Study is at a lower confidence level than a Feasibility Study.

Feasibility Study

A Feasibility Study is a comprehensive technical and economic study of the selected development option for a mineral project that includes appropriately detailed assessments of applicable Modifying Factors together with any other relevant operational factors and detailed financial analysis that are necessary to demonstrate, at the time of reporting, that extraction is reasonably justified (economically mineable). The results of the study may reasonably serve as the basis for a final decision by a proponent or financial institution to proceed with, or finance, the development of the project. The confidence level of the study will be higher than that of a Pre-Feasibility Study.

The term proponent captures issuers who may finance a project without using traditional financial institutions. In these cases, the technical and economic confidence of the Feasibility Study is equivalent to that required by a financial institution.

Mineral Resource

Mineral Resources are sub-divided, in order of increasing geological confidence, into Inferred, Indicated and Measured categories. An Inferred Mineral Resource has a lower level of confidence than that applied to an Indicated Mineral Resource. An Indicated Mineral Resource has a higher level of confidence than an Inferred Mineral Resource but has a lower level of confidence than a Measured Mineral Resource.

A Mineral Resource is a concentration or occurrence of solid material of economic interest in or on the Earth's crust in such form, grade or quality and quantity that there are reasonable prospects for eventual economic extraction.

The location, quantity, grade or quality, continuity and other geological characteristics of a Mineral Resource are known, estimated or interpreted from specific geological evidence and knowledge, including sampling.

Material of economic interest refers to diamonds, natural solid inorganic material, or natural solid fossilized organic material including base and precious metals, coal, and industrial minerals.

The term Mineral Resource covers mineralization and natural material of intrinsic economic interest which has been identified and estimated through exploration and sampling and within which Mineral Reserves may subsequently be defined by the consideration and application of Modifying Factors. The phrase 'reasonable prospects for eventual economic extraction' implies a judgment by the Qualified Person in respect of the technical and economic factors likely to influence the prospect of economic extraction. The Qualified Person should consider and clearly state the basis for determining that the material has reasonable prospects for eventual economic extraction. Assumptions should include estimates of cutoff grade and geological continuity at the selected cut-off, metallurgical recovery, smelter payments, commodity price or product value, mining and processing method and mining, processing and general and administrative costs. The Qualified Person should state if the assessment is based on any direct evidence and testing.

Interpretation of the word 'eventual' in this context may vary depending on the commodity or mineral involved. For example, for some coal, iron, potash deposits and other bulk minerals or commodities, it may be reasonable to envisage 'eventual economic extraction' as covering time periods in excess of 50 years. However, for many gold deposits, application of the concept would normally be restricted to perhaps 10 to 15 years, and frequently to much shorter periods of time.

Inferred Mineral Resource

An Inferred Mineral Resource is that part of a Mineral Resource for which quantity and grade or quality are estimated on the basis of limited geological evidence and sampling. Geological evidence is sufficient to imply but not verify geological and grade or quality continuity.

An Inferred Mineral Resource has a lower level of confidence than that applying to an Indicated Mineral Resource and must not be converted to a Mineral Reserve. It is reasonably expected that the majority of Inferred Mineral Resources could be upgraded to Indicated Mineral Resources with continued exploration.

An Inferred Mineral Resource is based on limited information and sampling gathered through appropriate sampling techniques from locations such as outcrops, trenches, pits, workings and drill holes. Inferred Mineral Resources must not be included in the economic analysis, production schedules, or estimated mine life in publicly disclosed PreFeasibility or Feasibility Studies, or in the Life of Mine plans and cash flow models of developed mines. Inferred Mineral Resources can only be used in economic studies as provided under NI 43-101.

There may be circumstances, where appropriate sampling, testing, and other measurements are sufficient to demonstrate data integrity, geological and grade/quality continuity of a Measured or Indicated Mineral Resource, however, quality assurance and quality control, or other information may not meet all industry norms for the disclosure of an Indicated or Measured Mineral Resource. Under these circumstances, it may be reasonable for the Qualified Person to report an Inferred Mineral Resource if the Qualified Person has taken steps to verify the information meets the requirements of an Inferred Mineral Resource.

Measured Mineral Resource

A Measured Mineral Resource is that part of a Mineral Resource for which quantity, grade or quality, densities, shape, and physical characteristics are estimated with confidence sufficient to allow the application of Modifying Factors to support detailed mine planning and final evaluation of the economic viability of the deposit.

Geological evidence is derived from detailed and reliable exploration, sampling and testing and is sufficient to confirm geological and grade or quality continuity between points of observation.

A Measured Mineral Resource has a higher level of confidence than that applying to either an Indicated Mineral Resource or an Inferred Mineral Resource. It may be converted to a Proven Mineral Reserve or to a Probable Mineral Reserve.

Mineralization or other natural material of economic interest may be classified as a Measured Mineral Resource by the Qualified Person when the nature, quality, quantity and distribution of data are such that the tonnage and grade or quality of the mineralization can be estimated to within close limits and that variation from the estimate would not significantly affect potential economic viability of the deposit. This category requires a high level of confidence in, and understanding of, the geology and controls of the mineral deposit.

Modifying Factors

Modifying Factors are considerations used to convert Mineral Resources to Mineral Reserves. These include, but are not restricted to, mining, processing, metallurgical, infrastructure, economic, marketing, legal, environmental, social and governmental factors.

Mineral Reserve

Mineral Reserves are sub-divided in order of increasing confidence into Probable Mineral Reserves and Proven Mineral Reserves. A Probable Mineral Reserve has a lower level of confidence than a Proven Mineral Reserve.

A Mineral Reserve is the economically mineable part of a Measured and/or Indicated Mineral Resource. It includes diluting materials and allowances for losses, which may occur when the material is mined or extracted and is defined by studies at Pre-Feasibility or Feasibility level as appropriate that include application of Modifying Factors. Such studies demonstrate that, at the time of reporting, extraction could reasonably be justified.

The reference point at which Mineral Reserves are defined, usually the point where the ore is delivered to the processing plant, must be stated. It is important that, in all situations where the reference point is different, such as for a saleable product, a clarifying statement is included to ensure that the reader is fully informed as to what is being reported.

The public disclosure of a Mineral Reserve must be demonstrated by a Pre-Feasibility Study or Feasibility Study.

Mineral Reserves are those parts of Mineral Resources which, after the application of all mining factors, result in an estimated tonnage and grade which, in the opinion of the Qualified Person(s) making the estimates, is the basis of an economically viable project after taking account of all relevant Modifying Factors. Mineral Reserves are inclusive of diluting material that will be mined in conjunction with the Mineral Reserves and delivered to the treatment plant or equivalent facility. The term 'Mineral Reserve' need not necessarily signify that extraction facilities are in place or operative or that all governmental approvals have been received. It does signify that there are reasonable expectations of such approvals.

'Reference point' refers to the mining or process point at which the Qualified Person prepares a Mineral Reserve. For example, most metal deposits disclose mineral reserves with a "mill feed" reference point. In these cases, reserves are reported as mined ore delivered to the plant and do not include reductions attributed to anticipated plant losses. In contrast, coal reserves have traditionally been reported as tonnes of "clean coal". In this coal example, reserves are reported as a "saleable product" reference point and include reductions for plant yield (recovery). The Qualified Person must clearly state the 'reference point' used in the Mineral Reserve estimate.

Probable Mineral Reserve

A Probable Mineral Reserve is the economically mineable part of an Indicated, and in some circumstances, a Measured Mineral Resource. The confidence in the Modifying Factors applying to a Probable Mineral Reserve is lower than that applying to a Proven Mineral Reserve.

The Qualified Person(s) may elect, to convert Measured Mineral Resources to Probable Mineral Reserves if the confidence in the

Modifying Factors is lower than that applied to a Proven Mineral Reserve. Probable Mineral Reserve estimates must be demonstrated to be economic, at the time of reporting, by at least a Pre-Feasibility Study.

Proven Mineral Reserve (Proved Mineral Reserve)

A Proven Mineral Reserve is the economically mineable part of a Measured Mineral Resource. A Proven Mineral Reserve implies a high degree of confidence in the Modifying Factors.

Application of the Proven Mineral Reserve category implies that the Qualified Person has the highest degree of confidence in the estimate with the consequent expectation in the minds of the readers of the report. The term should be restricted to that part of the deposit where production planning is taking place and for which any variation in the estimate would not significantly affect the potential economic viability of the deposit. Proven Mineral Reserve estimates must be demonstrated to be economic, at the time of reporting, by at least a Pre-Feasibility Study. Within the CIM Definition standards the term Proved Mineral Reserve is an equivalent term to a Proven Mineral Reserve.

As I've been saying, a mineral reserve is where we've identified the mineral, measured it, weighed it, worked out the processing method, think we'll get permission to mine it, and have proven that at current technological limitations and at current price levels we can make a profit by doing so. A mineral resource is where we think all of that will be true but we haven't proven it yet.

Or, as has also been said, mineral reserves are really the work in stock of currently extant mines, mineral resources are where it's likely we'll put a mine at some (possibly far future) date. Neither are, in any manner whatsoever, hard limits on the amount of any mineral or element that is or will be in the future available to us.

It's vitally important that this is understood. Reserve and Resource are measures of how much money we've spent to prove things, not at all to do with the amount of anything that is available.