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Minerals scarcity: A call for managed austerity and the elements of hope

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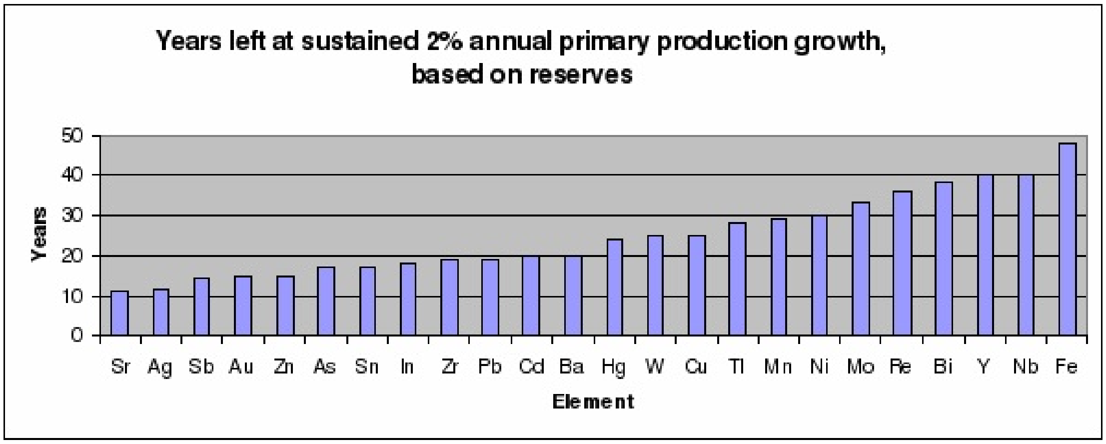
Tags: minerals, resource depletion [list all tags]

This is a guest post by André Diederen. Diederen is a senior research scientist at TNO, Holland, where he has been working since 1997 on defence related matters. His background is mechanical engineering (1987). Because a ruling paradigm in defence related matters is the precautionary principle and since this sector applies various non-abundant metals, he took a closer look at the availability of metals. The implications of metals scarcity reach far beyond the "niche" of defence related materials and might affect our entire industrial civilization.



Metal minerals scarcity:
A call for managed austerity and the elements of hope

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Abstract

If we keep following the ruling paradigm of sustained global economic growth, we will soon run out of cheap and plentiful metal minerals of most types. Their extraction rates will no longer follow demand. The looming metal minerals crisis is being caused primarily by the unfolding energy crisis. Conventional mitigation strategies including recycling and substitution are necessary but insufficient without a different way of managing our world's resources. The stakes are too high to gamble on timely and adequate future technological breakthroughs to solve our problems. The precautionary principle urges us to take immediate action to prevent or at least postpone future shortages. As soon as possible we should impose a co-ordinated policy of managed austerity, not only to address metal minerals shortages but other interrelated resource constraints (energy, water, food) as well. The framework of managed austerity enables a transition towards application (wherever possible) of the 'elements of hope': the most abundant metal (and non-metal) elements. In this way we can save the many critical metal elements for essential applications where complete substitution with the elements of hope is not viable. We call for a transition from growth in tangible possessions and instant, short-lived luxuries towards growth in consciousness, meaning and sense of purpose, connection with nature and reality and good stewardship for the sake of next generations.

Introducing metal minerals scarcity and managed austerity

Undoubtedly, the global economic growth of the last century, fuelled by and accompanied by exponential growth in population and consumption of resources like fossil fuels, water, food and metal minerals, is unsustainable. Now that we are nearing the second decade of the 21st century, we are beginning to notice the consequences of supply gaps of various resources. This paper focuses on the issue of metal minerals scarcity within the constellation of interconnected problems of scarcity of water and food, pollution and climate change and most notably scarcity of energy. In case of unlimited energy supply, metal minerals extraction would only be limited by the total amount of mineral resources. However, due to the scarcity of energy, the extraction rates of most types of metal minerals will cease to follow demand. Probably the only acceptable long-term solution to avoid a global systemic collapse of industrial society, caused by these resource constraints, is a path towards managed austerity. Managed austerity will have to be a combination of changes in technology and changes in both individual and collective human behaviour. Managed austerity could prevent non-desirable 'solutions' by doing much too little much too late (also known as 'business as usual') which could ultimately result in large scale conflicts, global chaos and mass starvation of the world's population.

Energy scarcity

Humanity has depleted a significant part of its inheritance of highly concentrated energy resources in the form of fossil fuels. Although huge quantities of these resources remain untapped, the worldwide extraction rate (production flow) has reached a plateau and will soon begin to decline [1,2,3,4,5,6]. The result is an ever widening supply gap because sustained global economic growth requires sustained growth in available energy. Figure 1 gives the general depletion picture for oil and gas [1] in giga barrels of oil equivalent (Gboe) and the left part of the bell-shaped curve strongly resembles a logistic curve. The initial stage of growth is approximately exponential, growth slows as saturation begins ('the low-hanging fruit has been picked') and at maturity growth stops and a maximum is reached. The maximum production rate is referred to as the 'peak' and is not a sharp deflection point in the curve but rather a plateau region.

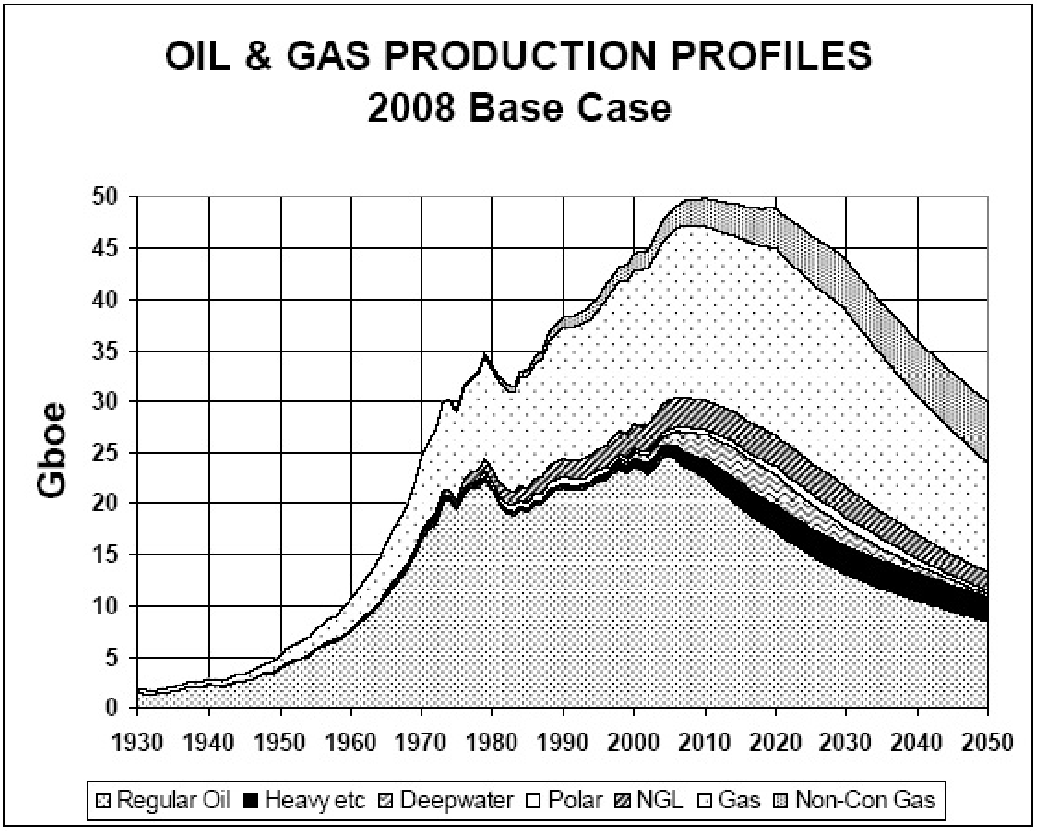


Figure 1: Depletion curve for oil and gas [1]

It is important to realise that the peak date in the depletion graph (figure 1) is not the same as the half date because production can continue for a long period after the peak. The actual depletion curve will presumably be asymmetric, having a peak date before the half date. Although the exact peak date for oil and gas is being contested (ranging from 2005 to somewhere during the next few decades), experts and authorities seem to converge on a peak date within the next few years. Oil and gas are currently the world's most important energy sources. Transportation for instance is currently almost entirely dependent on oil. Coal will not be able to fill the energy gap after the peak in oil and gas. According to [7] coal may peak around 2025. Again, this does not imply exhaustion of coal reserves, it is quite possible that more coal will be left for extraction after the peak date than has been extracted in total in the years before. The crucial point is that a maximum production rate will be reached after which supply can no longer follow demand. It is estimated that oil, gas and coal combined will reach their 'peak all fossil fuels' close to 2020 [8]. All other energy resources combined (nuclear, hydro, wind, solar, biofuels, tidal, geothermal and so on) cannot fill the supply gap in time [9,10,11,12]. Timely and massive utilisation of these other energy resources is limited by various constraints like lack of concentration, intermittency, issues related to conversion and storage and last but not least the required massive input of fossil fuels and metal minerals. Therefore we will probably be confronted with a peak in global energy production within the next 10 to 15 years, despite progress in technology.

Metal minerals scarcity

The depletion graphs of most metal minerals will resemble the curve for oil and gas (figure 1). Figure 2 gives an example for zirconium mineral concentrates [13].

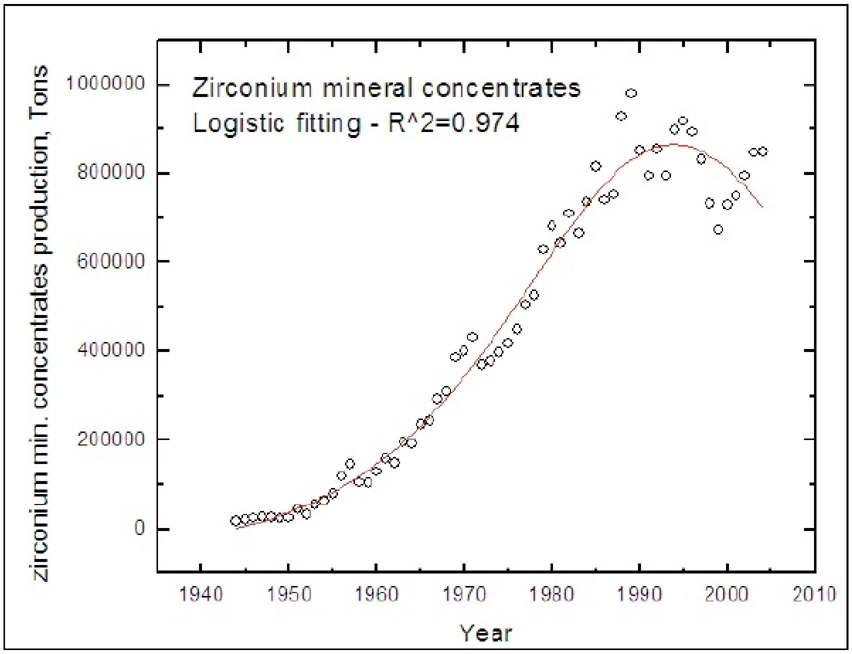


Figure 2: Depletion curve for zirconium mineral concentrates [13]

Many warnings in the past of impending metal minerals shortages have been proven wrong because of the availability of cheap and abundant fossil fuels. Every time the ratio of reserves to production of a certain metal mineral became uncomfortably small, the reserves of that mineral were being revised upwards because it became economically feasible to extract metals from the so-called reserve base or resource base. Reserves are defined as those ores that can be economically extracted at the time of determination and the term reserves need not signify that extraction facilities are in place and operative. The decades-old paradigm which states that reserves will be revised upwards (to include lower ore grades) as soon as supply gaps are looming, is no longer valid without cheap and abundant energy. Mining and extraction (concentration) consume huge amounts of energy. The energy required for extraction grows exponentially with lower ore grades. This is illustrated in figure 3 for iron ore and aluminium ore [14]. The highest ore grades have already been depleted or are already being mined. Because of energy constraints, the largest parts of mineral deposits are out of reach for economically viable exploitation, see figure 4 [15].

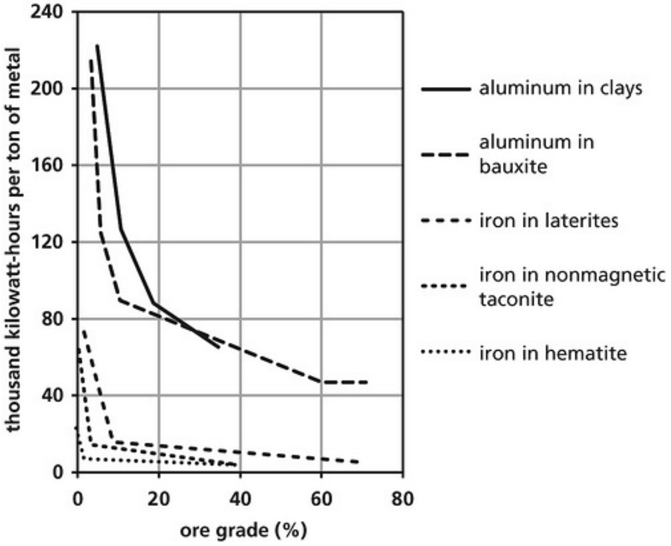


Figure 3: Relation between required energy for extraction and ore grade [14]

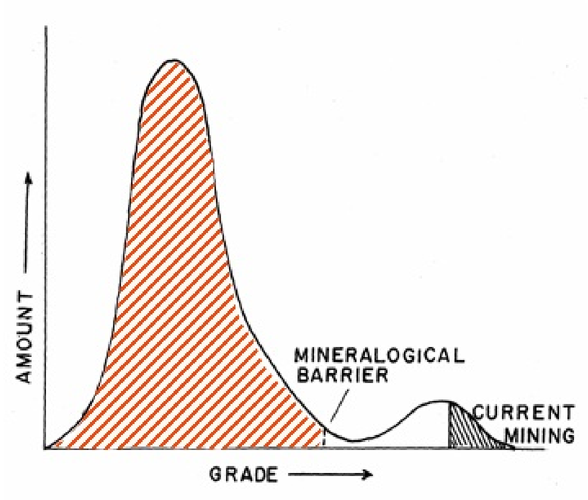


Figure 4: Mineralogical barrier for most elements [15]

Below the so-called mineralogical barrier (the red shaded area in figure 4), one would essentially have to pull the rock chemically apart to extract all individual elements. This is of course prohibitively energy intensive. For this reason it is very doubtful that meaningful parts of the reserve base or resource base of many metal minerals will ever be upgraded to reserves [16]. It is even questionable whether all currently stated reserves are fully exploitable given the ever growing constraints with regard to energy required [13].

The trend of geologically and physically based minerals scarcity will be further enhanced by other factors. Global ('average') shortages will most likely be preceded by spot shortages because of geopolitics and export restrictions, as many important metal minerals are concentrated in just a few countries, often outside the western industrialized world (e.g. China).

Extraction rates and reserves of metal minerals

Known data of extraction and consumption rates of metal minerals and their reserves indicate that the so-called ‘peak production’ for most metal elements will lie in the near future. The data from table 1 and figures 5 through 9 support this statement.

Table 1 represents an overview presented by the US Geological Survey [17] of global annual primary production and global reserves of a large number of metal minerals. Their production goes into various products and compounds, part of them being steels, alloys and metal products. The remaining ‘lifetimes’ are calculated based on a modest consumption growth of 2% per year. The elements predicted to have a ‘lifetime’ of less than 50 years are summarized in figure 5. Of course, these minerals are not completely depleted in this period, but their peak production lies well before the estimated moment. Compare the result for zirconium with figure 2: the remaining ‘lifetime’ of zirconium is 19 years and the peak date is already behind us (1994). Although exact data fail, the elements strontium through niobium (of figure 5) will soon reach their peak production or have already passed their maximum extraction rates.

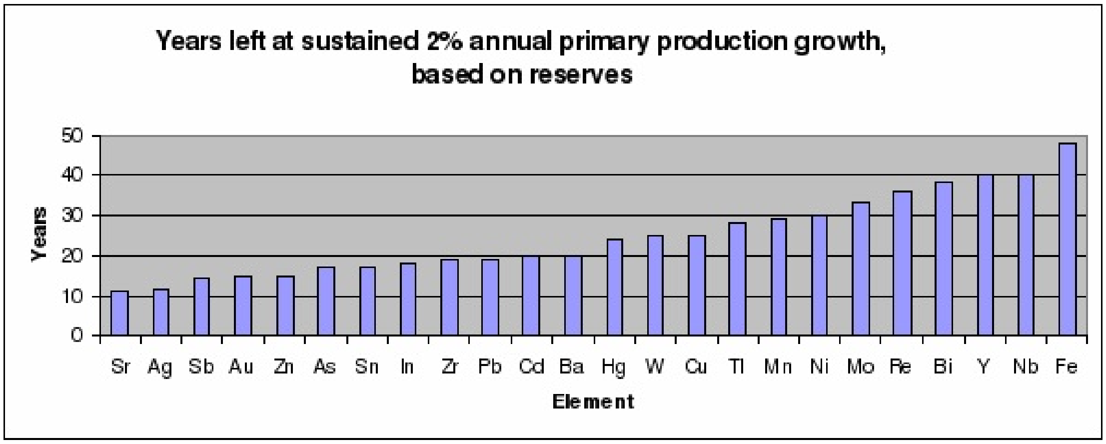


Figure 5: Years left of reserves at a sustained annual global primary

production growth of 2% (based on table 1)

Figure 6 through 9 depict in more detail global annual production rates and the known reserves. The annual primary production of iron dwarfs all other metal elements combined. Despite its huge reserves, iron will last less than 3 generations (less than 50 years) as far as cheap and abundant primary production is concerned, due to the enormous scale of its annual global consumption. The only viable long-term alternative to iron and in fact all metals at this scale of consumption would be magnesium. Magnesium reserves are virtually unlimited because of its abundance and associated accessibility in seawater [20].

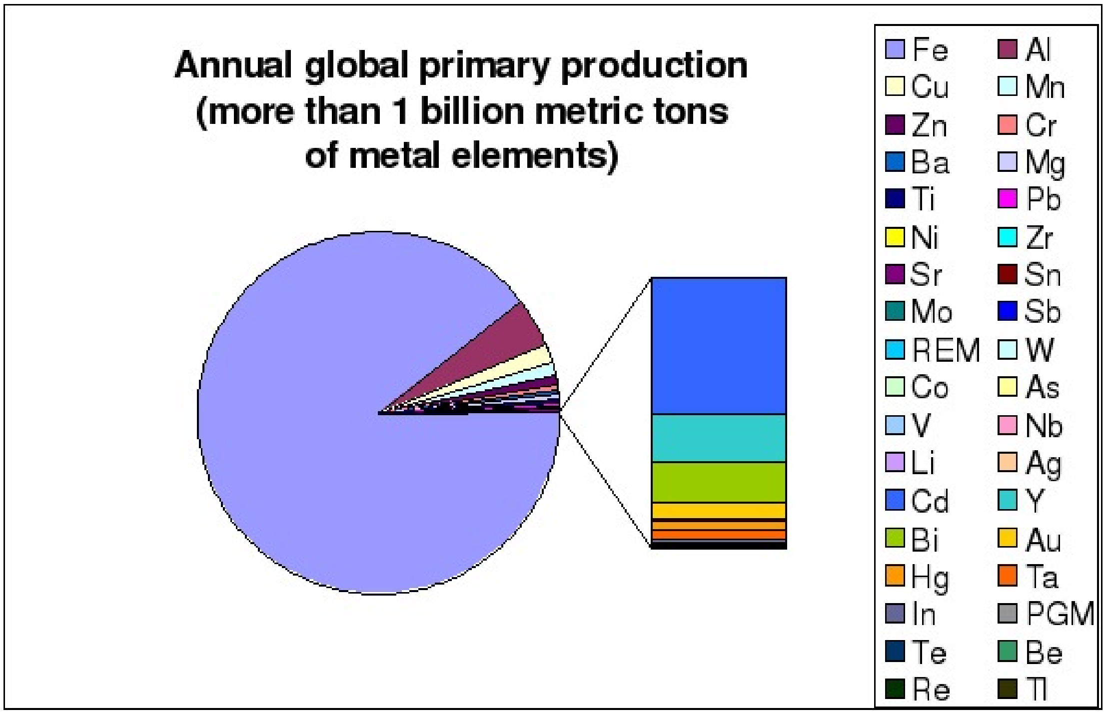


Figure 6: Distribution of annual global primary production (based on table 1)

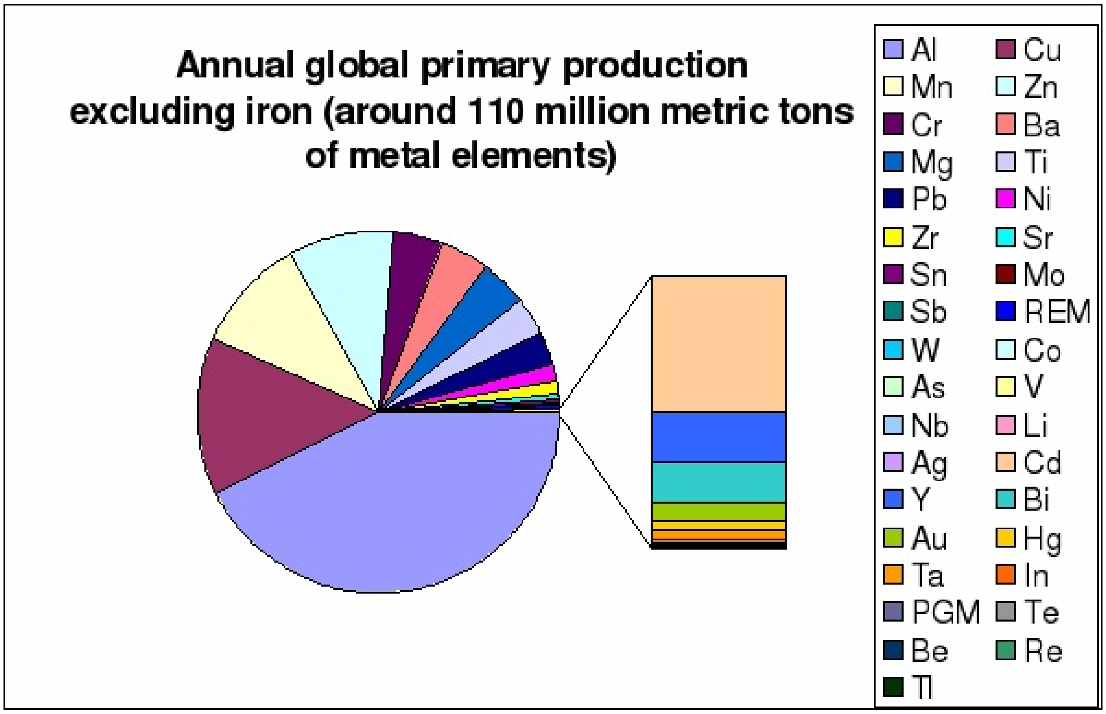


Figure 7: Distribution of annual global primary production without iron

(based on table 1)

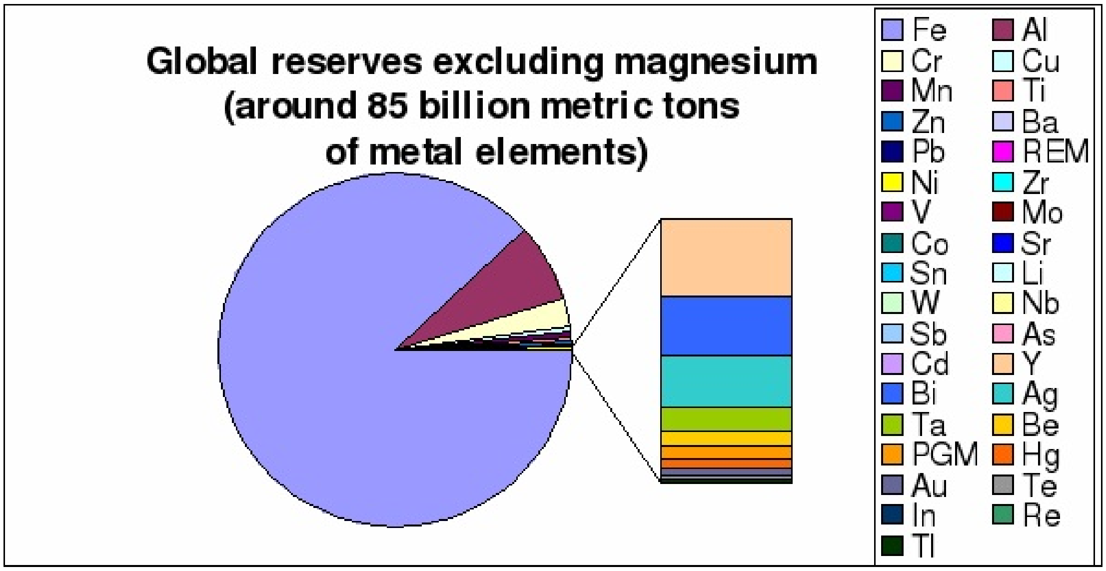


Figure 8: Distribution of global reserves excluding magnesium (based on table 1)

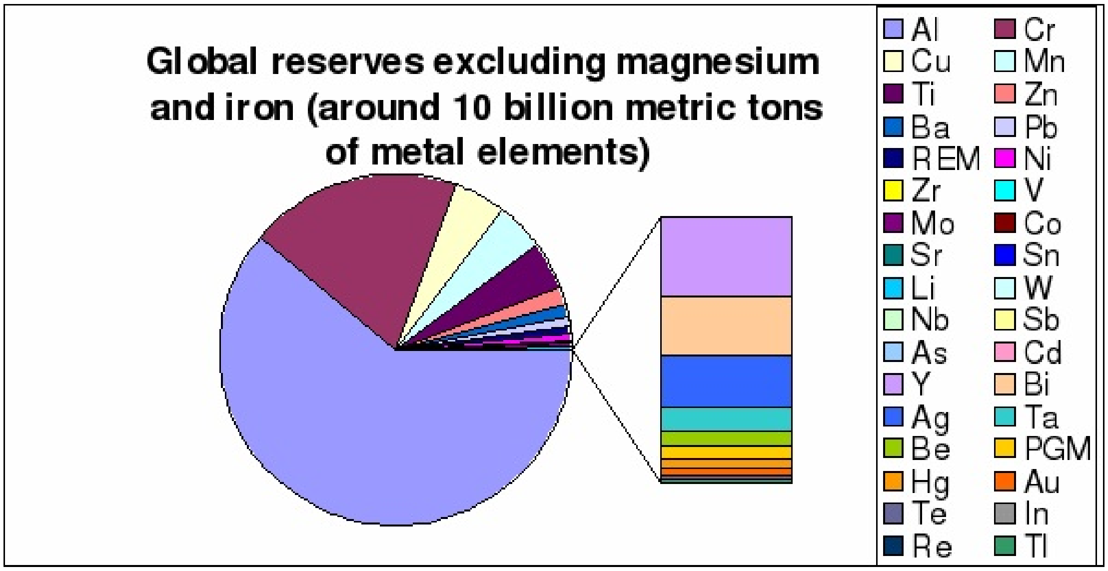


Figure 9: Distribution of global reserves excluding magnesium and iron (based on table 1)

On a trajectory of 'business as usual', we will have much less than 50 years left of cheap and abundant access to metal minerals. The production rate of metal minerals will start to decline well in advance of the depletion of reserves as it will take exponentially more energy input and metal minerals input to grow or even sustain the current extraction rate of metal minerals. To sustain and increase current production rates, resources have to be extracted at ever more distant locations (including deep mining and ocean floor mining) and at ever lower ore grades which require exponentially more energy to extract. In this sense it could even be stated that metal minerals scarcity aggravates energy scarcity.

Consequences of unmitigated metal minerals scarcity

During the next few decades we will encounter serious problems mining many important metal minerals at the desired extraction rates. Amongst them are all precious metals (gold, silver and platinum-group metals), zinc, tin, indium, zirconium, cadmium, tungsten, copper, manganese, nickel and molybdenum. A number of these metals are already in short supply (e.g. indium). Metals like gallium, germanium and scandium are not incorporated in table 1 by lack of data, but these metals suffer from a very low extraction rate as they are by-products (in very low concentrations) of other metal minerals; independent production growth is therefore not an option, thus making an increasing role for these elements impossible.

Besides the minerals with obvious constraints (low ratio of reserves relative to primary production), we can distinguish different 'categories' of metal minerals in table 1. First, several metal minerals which have a high ratio of reserves relative to primary production suffer from relatively low absolute amounts of reserves and associated low extraction rates, effectively making them non-viable large-scale substitutes for other metals which will be in short supply. It is up for debate for example whether lithium is a viable large-scale substitute for nickel in accumulators for electric energy as far as land mined lithium is concerned (it might be extracted from seawater in future [20], albeit at higher cost). Second, other metal minerals have no acceptable substitutes for their major applications, which is of special interest for those metals which will run out relatively fast at the present course, manganese being an important example. Third, even metals with a high ratio of reserves to primary annual production combined with large absolute amounts of reserves and associated extraction rates, can be susceptible to future supply constraints because they are located in just a few geographic locations. An example is chromium which is mainly located in Kazakhstan and southern Africa.

Without timely implementation of mitigation strategies, the world will soon run out of all kinds of affordable mass products and services. A few examples are given here. First, a striking example are cheap mass-produced consumer electronics like mobile phones, flat screen TVs and personal computers for lack of various scarce metals (amongst others indium and tantalum). Also, large-scale conversion towards more sustainable forms of energy production, energy conversion and energy storage would be slowed down by a lack of sufficient platinum-group metals, rare-earth metals and scarce metals like gallium. This includes large-scale application of high-efficiency solar cells and fuel cells and large-scale electrification of land-based transport. Further, a host of mass-produced products will suffer from much lower production speeds (or much increased tooling wear) during manufacturing owing to a lack of the desired metal elements (a.o. tungsten and molybdenum) for tool steels or ceramics (tungsten carbide). Among the affected mass-produced machined products are various household appliances and all types of motorized transport (cars, trains, ships and aero structures). The lack of various metal elements (a.o. nickel, cobalt, copper) for high-performance steels and electromagnetic applications will affect all sectors which apply high-performance rotating equipment. Besides transportation this includes essential sectors like electric energy generation (coal/oil/gas-based and nuclear power plants, hydropower, wind power). Also the vast areas of construction work in general (housing, infrastructure) and chemical process industries will be affected. The most striking (and perhaps ironic) consequence of a shortage of metal elements is its disastrous effect on global mining and primary production of fossil fuels and minerals: these activities require huge amounts of main and ancillary equipment and consumables (e.g. barium for barite based drilling mud).

These threats to the global economy require political, behavioural and governmental activities as well as technological breakthroughs. Of the breakthroughs, intensified recycling offers the opportunity to buy us time and innovative substitution may lead to sustainable options [18,19].

Efficiency: Jevon's paradox

A potent partial solution for metal minerals scarcity would be a better extraction efficiency, if it wasn't for Jevon's paradox. Jevon's paradox is the proposition that technological progress that increases the efficiency with which a resource is used, tends to increase (rather than decrease) the rate of consumption of that resource. So, technological progress on its own (without 'control') will only accelerate the depletion of reserves.

Recycling: delaying of effects

Recycling the current and constantly growing inventory of metal elements in use in various compounds and products is the obvious choice in order to buy time and avoid or diminish short- to medium-term supply gaps. Although recycling is nothing new, generally the intensity could be further enhanced. We should keep in mind though that recycling has inherent limits, because even 100% recycling (which is virtually impossible) does not account for annual demand growth. At the present course we need to continue to expand the amount of metal elements in use in order to satisfy demand from developing countries like China and India whose vast populations wish to acquire a material wealth comparable with the standard of living of the industrialized western world. Furthermore, recycling also costs lots of energy (progressively more with more intense recycling) and many compounds and products inherently dilute significant parts of their metal constituents back into the environment owing to their nature and use. So even with intense recycling, we will need a continued massive primary production to continue our present collective course.

Substitution: the elements of hope

It is self-evident that - at our current level of technology - substitution of scarce metals by less scarce metals for major applications will lead to less effective processes and products, lower product performance, a loss in product characteristics, or lead to less environmentally friendly or even toxic compounds. An important and very challenging task is therefore to realise the desired functionalities of such products with less scarce elements and to develop processes for production of these products at an economic scale. The best candidates for this sustainable substitution are a group of abundantly available elements, that we have baptised 'elements of hope' (see figure 10). These are the most abundant elements available to mankind and can be extracted from the earth's crust, from the oceans and from the atmosphere. They constitute both metal and non-metal elements. Hydrocarbons for production of materials (including plastics) could be extracted progressively more from biomass, albeit at a much lower extraction rate than from concentrated (fossilized) biomass (oil, natural gas and coal). Not coincidentally, all macronutrients of nature (all flora and fauna including the human body) are found among the elements of hope: nature either uses these elements (metabolism, building blocks) or has shown to be tolerant to these elements (in their abundant natural forms). Substitution based on the elements of hope therefore is potentially inherently environmentally friendly.

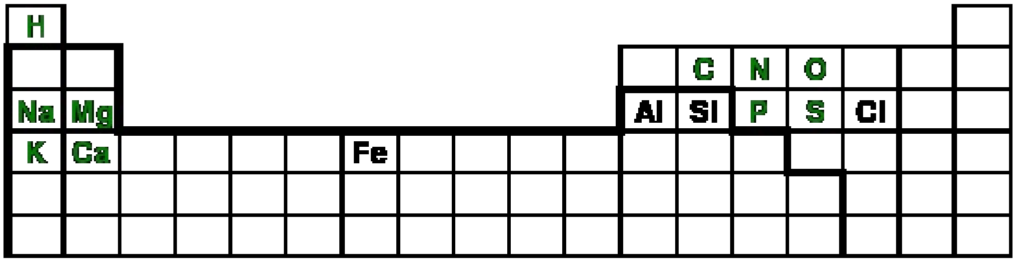


Figure 10: The elements of hope; the green elements are macronutrients, the elements within the thickened section are metals (Si being a metalloid)

Responsible application: frugal and critical elements

We can look at the remaining global reserves of metal minerals as a toolbox for future generations (see figure 11). An important part of the toolbox is reserved for the elements of hope. Another part of our toolbox is reserved for less abundant but still plentiful building blocks, the ‘frugal elements’. These elements should only be applied in mass for applications in which their unique properties are essential. In this way their remaining reserves will last longer (most notably copper and manganese). For the sake of completeness, also the non-metals belonging to this category are included in figure 11. Finally a small corner of the toolbox is reserved for all other metal elements, the ‘critical elements’, which should be saved for the most essential and critical applications. Not described in figure 11 but also belonging to the critical elements are other non-metals and the metal trace elements with high atomic mass (not previously mentioned in this paper by lack of data from [17]).

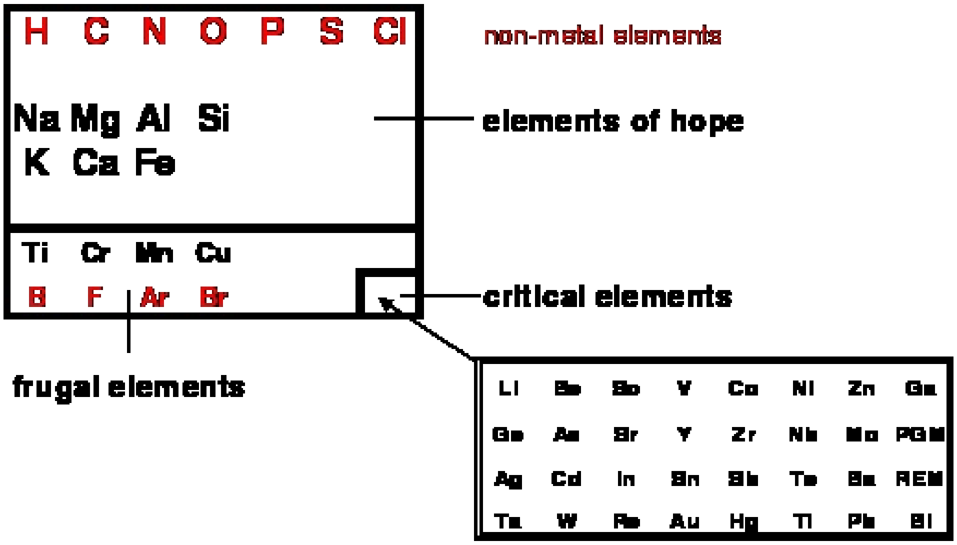


Figure 11: The toolbox containing the elements of hope, the frugal elements and the critical elements;
PGM = Platinum-Group Metals;
REM = Rare-Earth Metals;
the red elements are non-metals;
B,Si,Ge,As,Sb,Te are metalloids

(for a better resolution version of fig. 11, see this link)

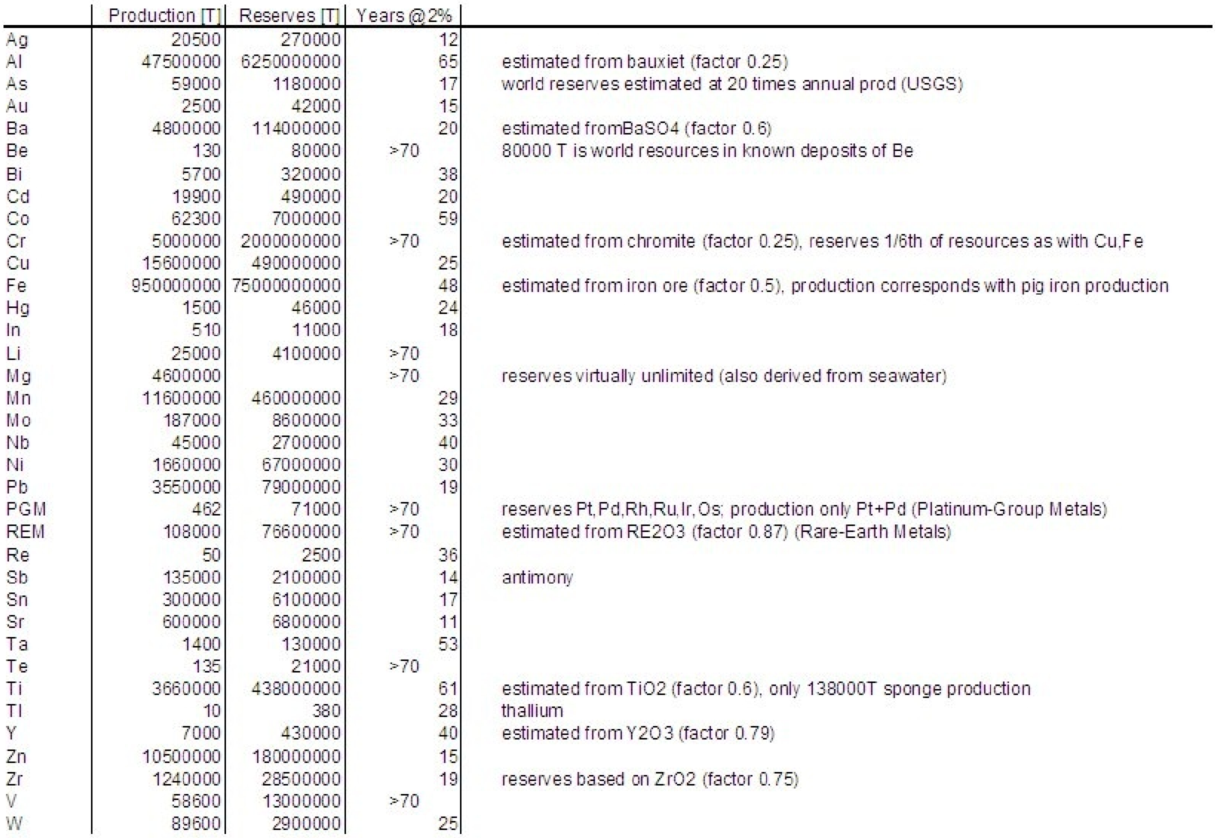
Conclusion: a call for action, ingenuity and responsible behaviour

Because of the surging scarcity of energy, even large-scale substitution and recycling cannot circumvent supply gaps in metal minerals. This is because production of metals consumes vast amounts of energy and so do substitution technologies and intensive recycling. The introduction of managed austerity is required to convince us all to live using less.

With this paper we call for action. We can increase the lifespan of the reserves of various materials by making a shift towards large-scale application of the elements of hope with a sensible use of the frugal and the critical elements. In order to do this mankind will have to mobilize its collective creativity and ingenuity. Technology alone is not enough to achieve this goal, nor can the challenge of metal minerals scarcity be treated as an isolated problem: it is part of a host of interrelated problems. A solution calls for nothing less than a globally co-ordinated societal response. The scarcity of energy, of food and water, of metal minerals and the effects of pollution and climate change all call for intervention by authorities to facilitate a transition towards collective responsible behaviour: managed austerity. They call for a transition from growth in tangible possessions and instant, short-lived luxuries towards growth in consciousness, meaning and sense of purpose, connection with nature and reality and good stewardship for the sake of next generations.

TABLE 1 (Table 1: Primary production and reserves in metric tons of element content, based on and derived from [17]])

(for a higher resolution version, see this link)



	Production [T]	Reserves [T]	Years @2%	
Ag	20500	270000	12	
Al	47500000	6250000000	65	estimated from bauxiet (factor 0.25)
As	59000	1180000	17	world reserves estimated at 20 times annual prod (USGS)
Au	2500	42000	15	
Ba	4800000	114000000	20	estimated fromBaSO4 (factor 0.6)
Be	130	80000	>70	80000 T is world resources in known deposits of Be
Bi	5700	320000	38	
Cd	19900	490000	20	
Co	62300	7000000	59	
Cr	5000000	2000000000	>70	estimated from chromite (factor 0.25), reserves 1/6th of resources as with Cu,Fe
Cu	15600000	490000000	25	
Fe	950000000	75000000000	48	estimated from iron ore (factor 0.5), production corresponds with pig iron production
Hg	1500	46000	24	
In	510	11000	18	
Li	25000	4100000	>70	
Mg	4600000		>70	reserves virtually unlimited (also derived from seawater)
Mn	11600000	460000000	29	
Mo	187000	8600000	33	
Nb	45000	2700000	40	
Ni	1660000	67000000	30	
Pb	3550000	79000000	19	
PGM	462	71000	>70	reserves Pt,Pd,Rh,Ru,Ir,Os; production only Pt+Pd (Platinum-Group Metals)
REM	108000	76600000	>70	estimated from RE2O3 (factor 0.87) (Rare-Earth Metals)
Re	50	2500	36	
Sb	135000	2100000	14	antimony
Sn	300000	6100000	17	
Sr	600000	6800000	11	
Ta	1400	130000	53	
Te	135	21000	>70	
Ti	3660000	438000000	61	estimated from TiO2 (factor 0.6), only 138000T sponge production
Tl	10	380	28	thallium
Y	7000	430000	40	estimated from Y2O3 (factor 0.79)
Zn	10500000	180000000	15	
Zr	1240000	28500000	19	reserves based on ZrO2 (factor 0.75)
V	58600	13000000	>70	
W	89600	2900000	25	

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