MEDEAS TECHNICAL NOTE: An exergy assessment of minerals

Thermodynamics and the assessment of mineral resources

Thermodynamics unifies concepts. Whilst a deep understanding of this science is not easy and its application in many cases used only superficially, this branch is a founding one, whose messages are both well placed and poignant for those wishing to investigate and push for sustainability. The First Law provides the definition for the metrics of energy and the basis of material and energy balances. The Second Law is often used in a metaphorical way. However, the Second Law plays more than a metaphorical role in the analysis of the evolution and consumption of the planet's natural resources, particularly the abiotic ones, which up until recently had nowhere near enough been comprehensively examined.

Furthermore and with good reason, it is the physical not the economic which must serve as the reference point, as it is the latter which is subject to the former and not the other way round. Apart from that, no single currency has stood the test of time, which begs the question: how does one reliably measure the dispersion of societal mineral stock, or the exhaustion of mines? How can one fairly or adequately account for the use of energy, water or soil? All such questions find their answer in the use of one universal unit of measure, exergy. Exergy has the ability to undertake the global and intergenerational analysis that monetary units simply cannot. It can also quantitatively demonstrate the effect of waste, mine extraction, water consumption or soil erosion on resource stocks, which can then be extrapolated to indicate those risks posed on society, should they continue or even accelerate. This is because it is the variation of an intensive property with respect to a reference environment, which exergy quantifies in SI units (e.g. kJ). This then means that the same unit with which one measures energy, can also be used to measure materials. This then serves to avoid the possibility of trying to add apples to oranges. Moreover, processes involving mixing and separation, manmade as much as natural, can also be measured in terms of exergy loss, even if there are no energy losses. In addition, as the exergy of a fuel is approximately equal to its high heating value, one can reference exergy in terms of toe (tonnes of oil equivalent) or any other conventional energy unit, whilst maintaining the scale used by a practitioner. It also permits the addition of different kinds of resources and supports dynamic or cost benefit analysis as is done with money.

For calculating exergy resources, the reference environment (R.E.) deserves special attention. In this respect, the baseline used to assess mineral resources is an imaginary degraded planet named Thanatia, where all mineral resources have been extracted and dispersed, i.e. there are no concentrated mineral deposits (Valero and Valero, 2014). Thanatia constitutes a coherent baseline to evaluate the loss of mineral endowment on Earth and the speed of its exhaustion. It does not consider the end of the world or represents a dead planet but rather its commercial climax. Using this model as a reference, any regional or global planetary state can be assessed as an exergy departure from Thanatia, as long as one knows the physicochemical parameters which characterise the two systems. This allows for the exergy calculation of any resource. Thus abiotic resources, which were previously considered finite but countless, are converted, at least theoretically, into finite and countable. Their thermodynamic value is a measure of their exergy distance from depletion.

Thermodynamic rarity of minerals

Exergy is a measure of the degree of thermodynamic distinction and in this sense it is a measure of an object's rarity (Valero and Valero, 2014). Something other than commonness is rare, and the rarer something is, the greater its distinction. It is therefore not surprising that "thermodynamic rarity" is stated in exergy terms. Consequently, a mineral's thermodynamic rarity is defined as "the actual amount of exergy resources needed to obtain a mineral commodity from Thanatia to the prefixed commercial conditions using the current best available technologies" (Valero and Valero, 2015).

Rarity thus becomes a quantifiable thermodynamic property measured in kJ. Thermodynamic rarity is composed of two complementary parts: 1) the so called, exergy replacement costs or natural bonus, which is a hidden or avoided cost that Man saves for having minerals concentrated in mines and not dispersed throughout the crust and is calculated as the exergy required to replace minerals from Thanatia to the current state present in Nature- from Thanatia at x_c concentration to the concentration in the mines at x_M in Fig.1), and 2) the real costs, i.e. the actual amount of resources needed to convert a mineral into a commodity via extraction, beneficiation, smelting and refining (see Fig. 1).

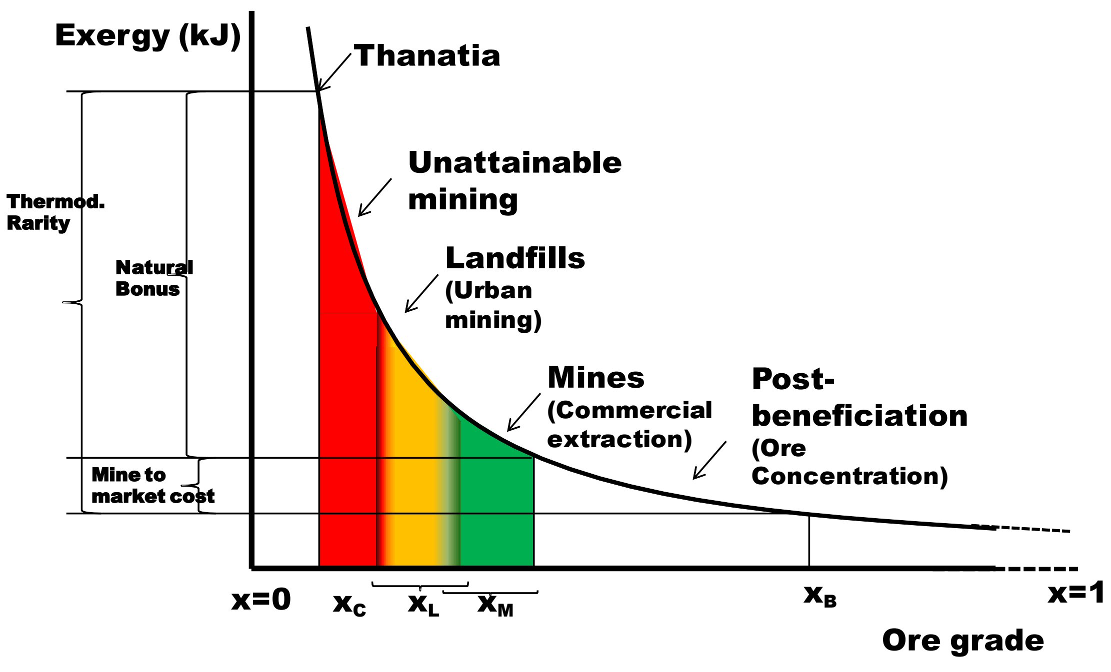

Fig.1: The concept of Thermodynamic rarity (Valero and Valero, 2015).

Before the appearance of any mining activities, all geological heritage remained in the geosphere, in the form of very concentrated mineral deposits. At that point in time, extraction costs would have been extremely low, whilst replacement costs (i.e. given the highly concentrated nature of all deposits), extremely high. As extraction occurs, mineral deposits become steadily depleted and approach the conditions of Thanatia. Accordingly, the exergy replacement costs decrease, whereas it becomes more energy intensive to extract and refine those depleted deposits. Consequently, the hidden costs are increasingly converted into real ones and at the limit, when all minerals are dispersed into Thanatia, the exergy replacement costs are zero whilst those required to extract, beneficiate and refine are infinite. As long as the Planet is on the green area of Fig. 1, commercial extraction will preferably occur over the so called "urban mining", i.e. reclaiming resources from the technosphere (from landfills). Slowly however, the ore grade in mines x_M will approach the concentration of many metals in landfills, a moment at which urban mining will become definitely a cost-effective alternative.

With the thermodynamic rarity concept, in addition to account for the yearly exergy loss through mineral depletion, it becomes easy to rank minerals according to their scarcity on Earth and the cost-effectiveness (in exergy terms) to extract and beneficiate minerals from mines. Figure 2 shows thermodynamic rarity values of some main ores of elements, classified into the critical ones, marked in red and having thermodynamic rarity values greater than 10,000 GJ/ton, in orange (10,000-1,000 GJ/ton), yellow (1,000-100 GJ/ton) and the least critical ones in green (100 GJ/ton).

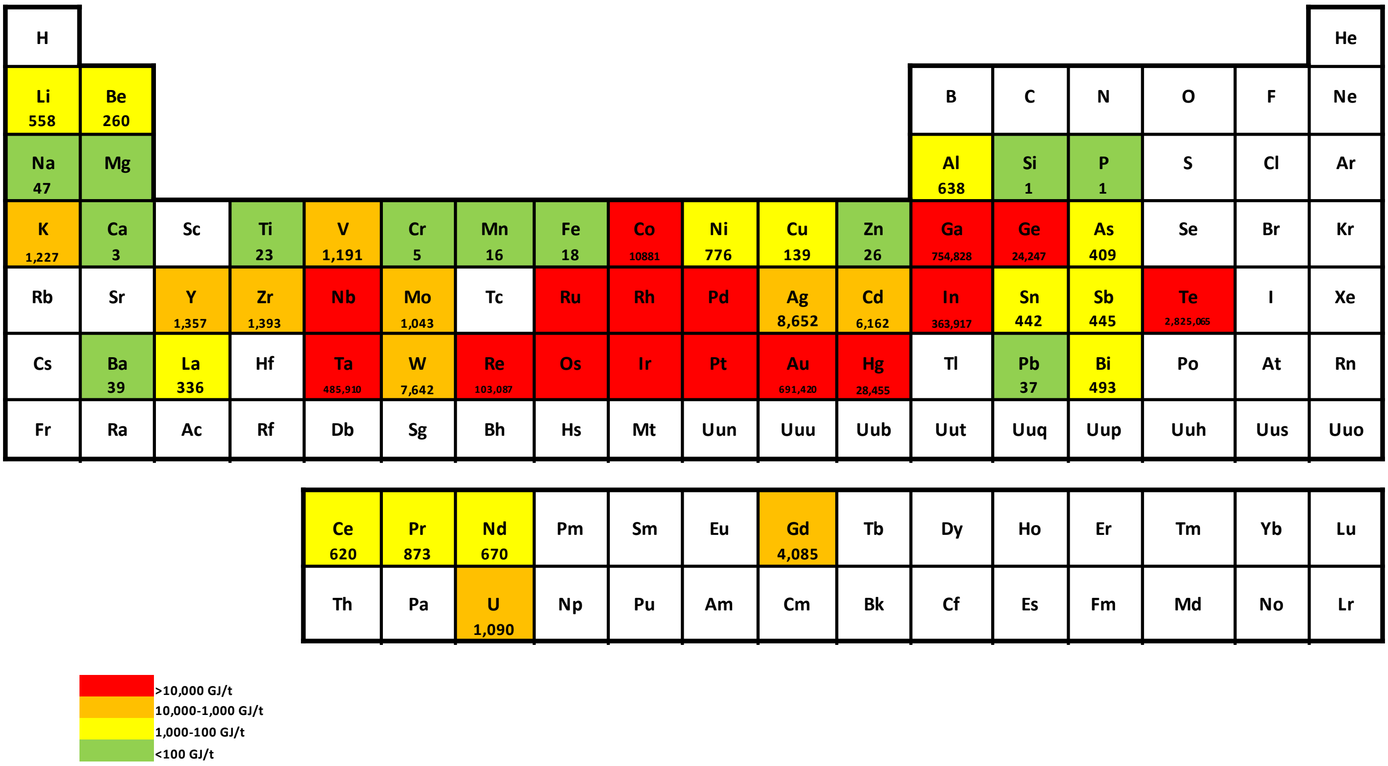

Fig.2: Thermodynamic rarity of some main ores of elements. Valero, Valero and von Gries (2016)

The thermodynamic rarity concept, provides a quantitative tool to assess the use of mineral resources through material flow analysis based not only on quantity, but also quality, i.e. it is not the same to extract tones of limestone than grams of gold, for instance. Note that at the moment, conventional MFA only takes into account tonnage, forgetting the quality of minerals.

References

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