The Impact of Recycling on the Useful Life of Minerals in Products.

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Life forms on Earth have relied on recycling of minerals for billions of years, but most life forms require dispersal of minerals and nutrients in the form of decaying flora and fauna etc., whereas humans in an industrial society require concentrations of minerals for its technology and the stuff it creates. Georgescu-Roegen in his book "The Entropy Law and the Economic Process" (1971) pointed out that mineral resources required for technology will ultimately become dispersed regardless of our efforts to recycle. 100% recycling is a physical impossibility because higher recycling rates of materials require progressively more energy which ultimately limits the practical level of recycling (Mills 2020).

Figure 1 shows the recycling process and the inevitable energy and material loss to the environment.

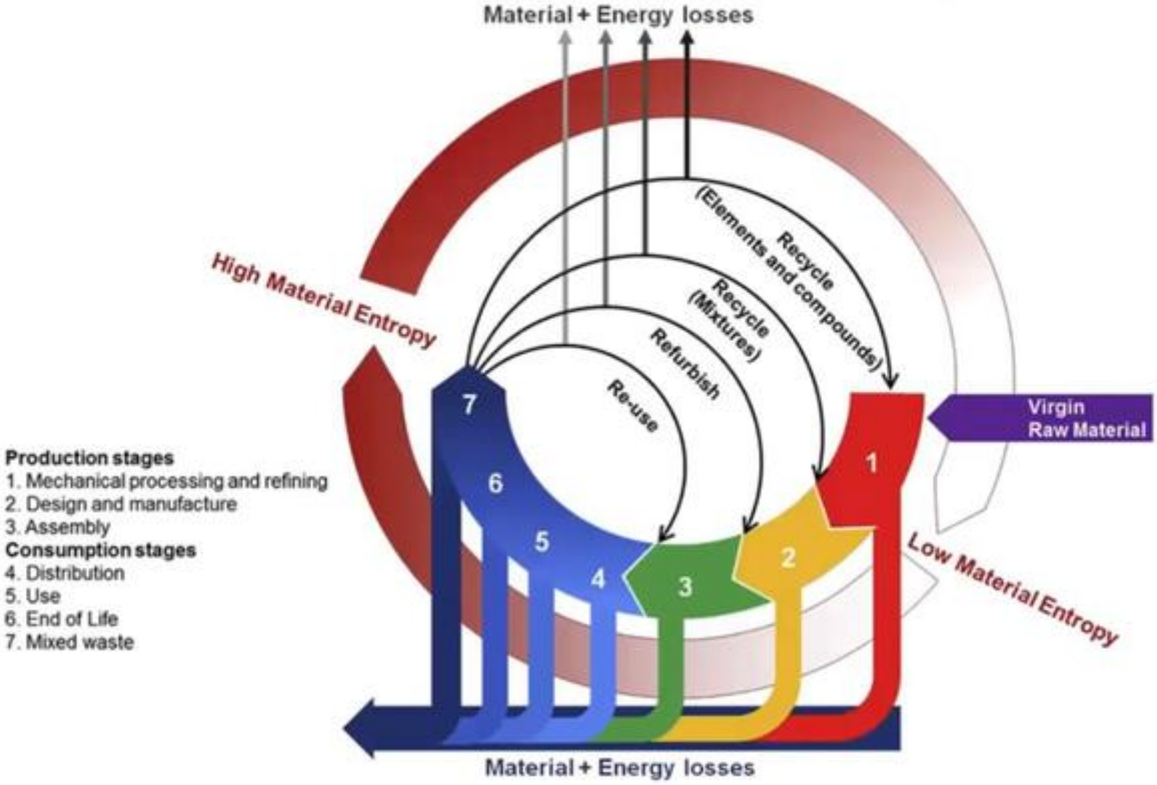

Figure 1: Recycling and Inevitable Energy & Material Loss to the Environment

Figure 2 shows current recycling rates of metals. Only a few metals have a recycling rate of over 50%. According to the United Nations Environmental Programme (UNEP 2011), iron and steel have an end-of-life recycling rate of 70-90%. The recycling rate of lead in the United States reached 76 percent in 2019. These values represent the highest end-of-life recycling rates among all the industrially-used metals. Some rare metals necessary for the production of batteries not only have a very low recycling rate, but are also scarce and are already a supply risk (Michaux 2019).

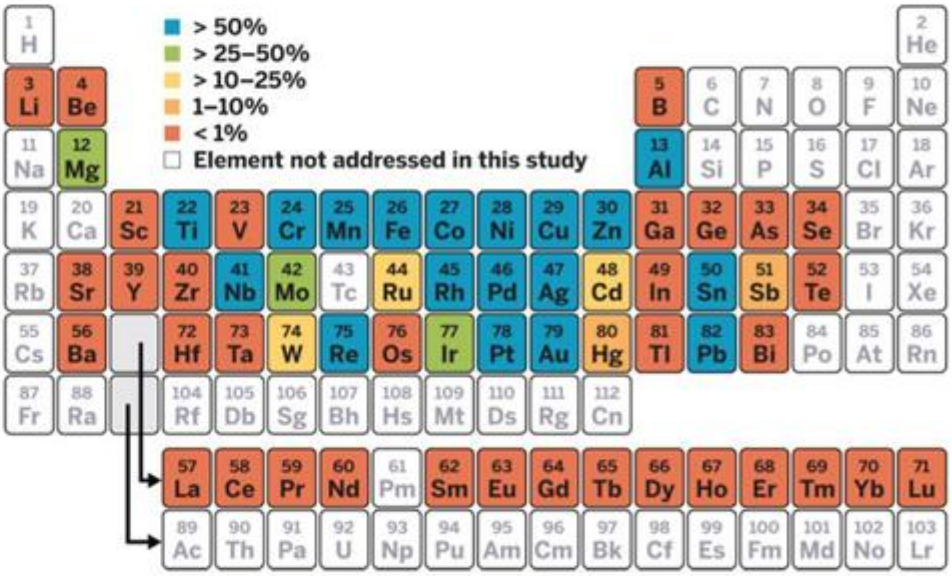

Figure 8. Recycling rates of metals (Source: United Nations Environment Programme, Recycling Rates of Metals (2011) / C&EN May 30, 2011) (Copyright License: https://creativecommons.org/licenses/by-nc-sa/4.0/)

Figure 2: Recycling Rates of Metals (Michaux 2019)

Assume that all metals have a recycling rate of 90%. After only 6 and 7 cycles of recycling, 53% and then 48% of the original material is available for reuse. The half-life is therefore, say, 7 cycles. Assume the time in use is 30 years - for example, components of photovoltaic panels and wind turbines. The half-life would then be about 200 years. Every 200 years, the original mined material would be halved. After 1,000 years, there would be only 3% of the original mined material in use. The current rates of recycling of many metals nowhere match 90% and higher rates of recycling do not bode well for the long-term future because higher rates of recycling require progressively more energy than lower rates. Some metals require more energy to recycle than other metals at any chosen rate of recycling.

The converse of half-life is the doubling time, the time for an entity undergoing exponential growth to double in size (see SCAN website page on exponential growth). When use of a resource grows exponentially, the use of resources over the last doubling time is equal to the sum total of use over all previous doubling times. Any growth in the mining of resources compounds the shortening in the time frame during which it is physically possible to mine that resource. A higher technological society can be sustained for a longer period when there is no growth in the mining of resources.

The grades of mined materials have steadily decreased, especially since the 1930s as shown in Figure 3. Without extraordinary advances in mining and refining technology, the 10% of world energy consumption currently used for mineral extraction and processing would rise as lower grade and more remote deposits are mined (Mudd 2009). Very low concentrations of minerals and metals are too energy costly to concentrate for use. The energy costs of recycling will eventually exceed that of mining low concentrations of metals and minerals still in the ground. Energy is required for many other purposes other than mining and recycling of minerals and use of energy has a hierarchy of necessary uses. In the long-term future, society will need to accept that some minerals are too energy costly to continue using in its technology.

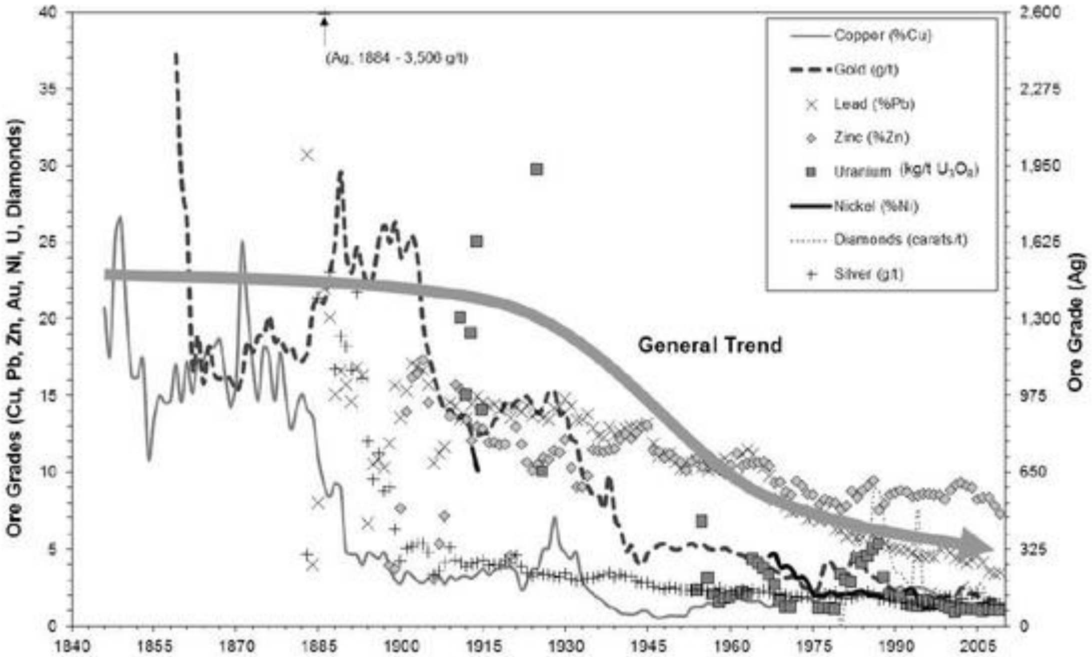

Figure 16. Grade of mined minerals has been decreasing (Source: Mudd 2009- updated 2012, Analyst- Gavin Mudd)

Figure 3: Decreasing Grades of Mined Materials (Mudd 2009, updated Mudd 2012)

A balance of longevity in use and the rate of recycling is necessary to reduce the energy costs of keeping minerals and metals in use over each generation of the population. This balance needs to be weighed up against the energy costs of mining for new minerals and metals and the extent of their scarcity.

Figure 4: Balancing Rate of Recycling & Longevity Against Mining for Minerals & Metals

Metals and minerals which are ultimately dispersed to the environment after use represent the loss of resources which cannot be used by future generations. If our species of humankind should continue to exist in the far distant future, then future levels of technology will inevitably decline due to the inability to concentrate dispersed minerals and metals. Humans will have the choices of accepting a declining level of technology and a corresponding declining physical consumption standard of living or reducing their population to maintain the same per capita use of minerals. Ultimately, the prospect for humans is a return to being hunter-gatherers. This life style does not necessarily need to be brutish and short so long as humans in the distant future are able to retain essential repositories of knowledge.

Humankind has so far squandered a large proportion of minerals in the ground for a large and increasing population over a relatively short period of time with consequences for future generations. Nicholas Georgescu--Roegen stated in his book "The Entropy Law and the Economic process" on page 304:

> "Population pressure and technological progress bring ceteris paribus the career of the human species nearer to its end only because both factors cause a speedier decumulation of its dowry. The sun will continue to shine on the earth, perhaps, almost as bright as today even after the extinction of mankind and will feed with low entropy other species, those with no ambition whatsoever. For we must not doubt that, man’s nature being what it is, the destiny of the human species is to choose a truly great but brief, not a long and dull, career."

We have a moral duty to ensure that the useful life of minerals in our products are optimised as much as possible. The useful life of minerals mined from the ground for use in products can be increased by recycling before inevitably going back into the ground as waste. The following is a simple formula which adds up the useful life of minerals per kilogram which are recycled and reused in a succession of products. The recycling rate is the percentage of the minerals in the products which are recycled at the end of the useful life of each product.

$$Useful\ Life\ of\ Minerals\ per\ Kilogram = \frac{Useful\ Life\ of\ Product}{1 -\ Recycling\ Rate}$$

If the recycling rate = 0, then the Useful Life of Minerals per Kilogram = the Useful life of the product.
If the Recycling Rate = 50% (0.5), then the Useful Life of Minerals per Kilogram = Twice the Useful life of the Product.
If the Recycling Rate = 95% (0.95), then the Useful Life of Minerals per Kilogram = Twenty times the Useful life of the Product.

Figure 5 shows a graph of the Useful Life of Minerals per Kilogram over a range of recycling rates from zero to 95% for products with a useful life of 20 years and 100 years respectively.

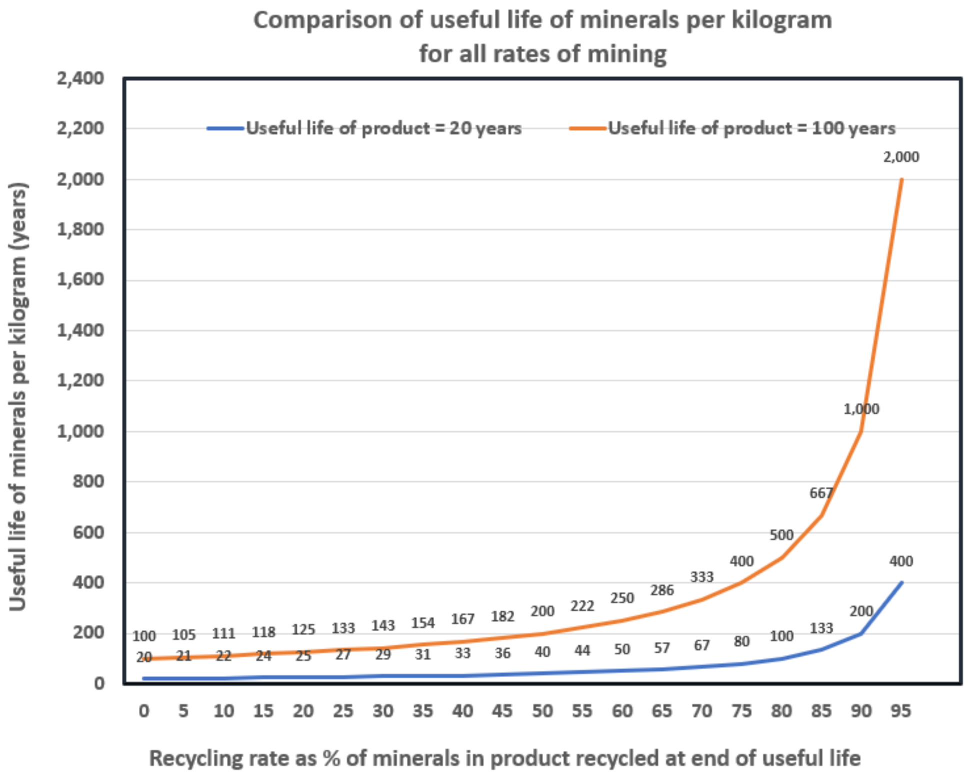

Figure 5: Comparison of Useful Life of Minerals per Kilogram (Johnstone, 2023)

Given the data in the above graph, it would seem that optimisation of the Useful Life of Minerals per Kilogram simply involves increasing the Useful Life of Products and increasing the Rate of Recycling, but it is not that simple. In the case of mobiles, the actual useful life of this product for many people does not match the potential useful life of this product. Many people have bought into a throwaway society mentality and replace their mobiles every three years or so. The potential life of a product can be physically limited due to wear and tear and failure over time. Extending the potential life of products would require the use of more energy and more materials required for production. Likewise, when it comes to increasing the Rate of Recycling. Some products are more easily recycled than others.

Each increase in the Recycling Rate will involve different increases in energy and materials needed to assist higher Recycling Rates. The energy costs of higher recycling rates would eventually become prohibitive because net energy is required for many other products and services necessary to sustain the wellbeing of humankind. The scale of net energy per capita has limits and the production of any single product cannot monopolise the use of limited net energy. Lurking in the background are the increasing energy costs of mining and the impact of waste on the environment.

The graph in Figure 5 does not take into account all the above factors, but can be by using a simple model of recycling as shown in Figure 6. This model has been developed using the dynamic simulation software called Vensim.

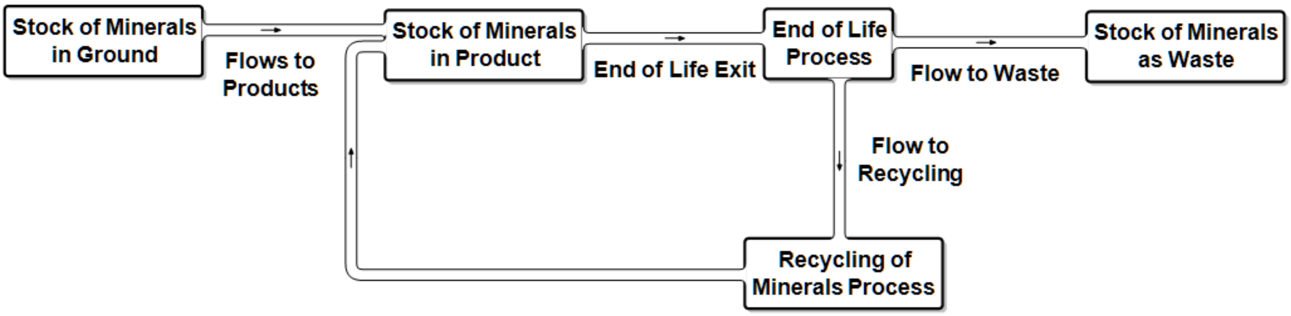

Figure 6: Simple model of Recycling (Johnstone, 2023)

Three separate models have been developed for the scenarios of a constant linear rate of mining, an exponential decay rate of mining, and a Hubbert Curve rate of mining. These models can be viewed on the author's website including an Excel file of the Hubbert Curve which can be used to select a combination of parameters for a symmetrical Hubbert Curve. Slider controls enable variations in the Initial Materials, The Mining Rate, Useful Lifetime of Products, and Recycling Rate. The models show the graphs of the decline of Minerals in Ground, the increase and decline of Minerals in Products (the area under the graph represents the total useful life of products), the increase in Waste Materials, and the increase in Recycled minerals over time. All Minerals in Products decay to zero over time. The website graphs show a time frame of 1,000 years for viewing convenience on a horizontal scale, so this decay cannot be seen in some scenarios for high Recycling Rates. The author has used a 10,000 year time scale in each model to ensure a decay to zero. These more precise models for higher recycling rates are available for download from the above website. A free version of Vensim PLE can be downloaded to run these models.

Using Vensim to model a simple simulation of recycling enables modelling of the energy costs of mining, production of products, and recycling which are not linear over time. The Vensim models use a one year time step and this data can be exported to a CSV file where, within Excel, energy costs over time can be incorporated at each time step for mining, production, and recycling. The same applies for the environmental costs of waste.

Obtaining estimates of the above energy costs will take time and effort. In the meantime, there are immediate actions we can undertake to reduce our impact on the environment. Figure 7 shows the waste hierarchy of human settlements. Actions further up the hierarchy reduce impacts on the environment and enable a higher level of technology for future generations.

Figure 7: The Waste Hierarchy

Disposal of some waste is inevitable. For modern civilisations to exist at a technology level way beyond the stone tools of the hunter-gatherer, there will always be waste which flows out of the economy into the environment. The environment can accommodate a degree of waste, but we need to ensure the level of our waste does not exceed the environment's capacity to assimilate that waste. We need to use benign technology. We also need to question whether higher levels of technology provide greater levels of happiness and wellbeing

Before accepting disposal of materials, we should Recover and Repurpose materials as much as possible, followed by Recycling and Reusing materials in a replacement or different form. The most effective way to reduce waste is to Refuse to use materials for unnecessary and extravagant purposes. By doing so, we Reduce our use of materials.

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UNEP (2011) Assessing Mineral Resources in Society: Metal Stocks & Recycling Rates. https://www.resourcepanel.org/reports/recycling-rates-metals

ADDITIONAL READING

Allwood, J. and J. Cullen. (2012) *Sustainable materials with both eyes open*. http://www.withbotheyesopen.com

“This evidence-based survey presents a holistic vision of options for a sustainable future by going beyond efficient and clean production to the inclusion of material efficiency and the reduction of demand. Beginning with an all-encompassing examination of the uses of the five most important materials—steel, aluminium, cement, plastic, and paper—this exploration delves into the entire lifecycle of these materials, from smelting and goods manufacture to final recycling. Through evidence drawn from this analysis and real-world commercial enterprises, the study submits creative solutions for achieving manufacturing efficiencies and the same functionality or services using less material, and identifies potential economic outcomes from these scenarios.”