

EVOLUTION OF THE DECREASE IN MINERAL EXERGY THROUGHOUT THE 20TH CENTURY. 1) THE CASE OF COPPER IN THE US

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Evolution of the decrease in mineral Exergy throughout the 20th century.
1) The case of US Copper

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AIM OF THE PAPER:

1. To show the usefulness of exergy as an indicator for assessing the degradation of mineral resources on earth and measuring scarcity.
2. To calculate the exergy decrease of US copper mines due to copper production throughout the 20th century.

INTRODUCTION

- The economical evaluation of natural resources rarely take into account physical characteristics that make them valuable: a particular composition and a specific concentration. (Scarcity increases but prices do not!)
- But they can be evaluated from a thermodynamic point of view in terms of exergy.
- Thermodynamic value of a natural resource: the minimum work (exergy) needed to produce it with a specific structure and concentration from common materials in the environment.

THE EXERGY OF MINERALS

- The minimum theoretical work that nature should invest to provide minerals at a specific composition from a degraded earth is equal to the standard chemical exergy:

$$b_{ch} = \Delta G_f + \sum_e n_e b_{che}$$

- The chemical exergy is proportional to the consumption rate of the mineral.

THE EXERGY OF MINERALS

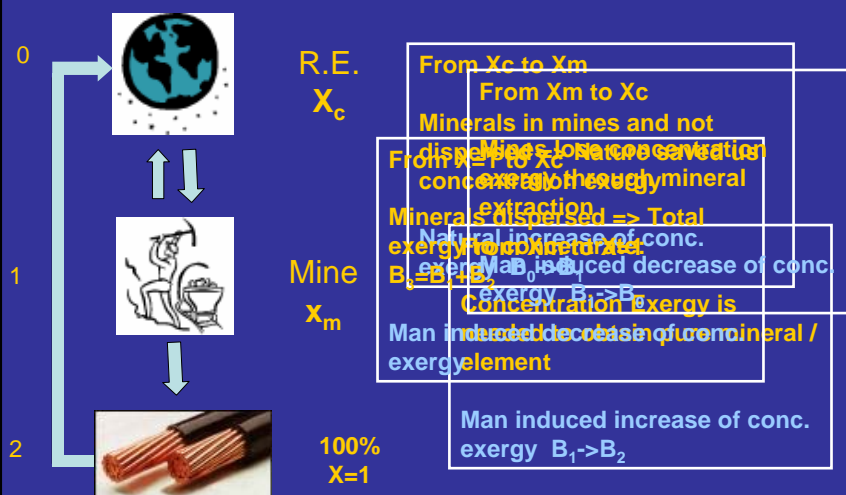
- The minimum theoretical work needed to concentrate a substance from an ideal mixture of two components is given by:

$$b_c = -RT_0 \left\{ \ln x_i + \frac{(1-x_i)}{x_i} \ln(1-x_i) \right\}$$

- The concentration exergy is not lineary dependent on the consumption rate. It is right this component what makes exergy a more realistic measure of magnitude than mass.

THE EXERGY OF MINERALS

Hence by means of exergy, we can integrate in just one indicator all the characteristics that describe a natural resource: composition, concentration and of course quantity, by multiplying the unitary exergies with the tonnes of the resource considered.

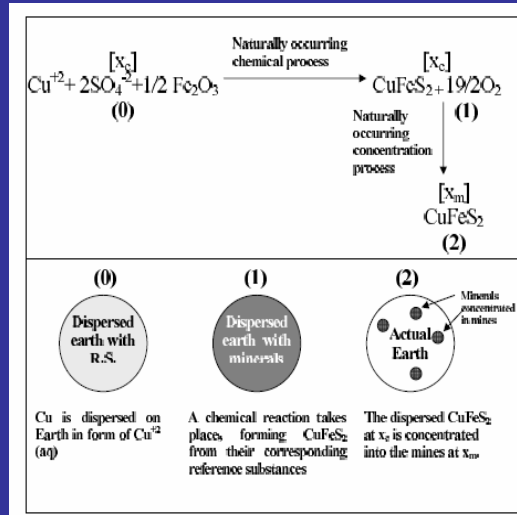


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THE EXERGY DECREASE OF COPPER MINES

- Hypothetical processes for obtaining the mineral from R.E. to mine.

- Assumption: the overall copper is found in the mines as chalcopyrite.



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THE EXERGY OF MINERALS

- Exergy accounts for a minimum, however the real processes designed by man are far from ideal conditions. We would ignore technological limits which are much more costly!

- We must include the real physical processes in the thermodynamic evaluation of resources.

- They are defined as the relationships between the energy provided in the real process of obtaining the resource and the minimum energy required if the process were reversible. k_c and k_r are the exergy coefficients. b^* is the actual exergy, b is the minimum energy required if the process were reversible.

- The real exergy would be then:
 Thermodynamic exergy

$$b^* = b_{ch} * k_c$$

THE EXERGY OF MINERALS

Therefore, the exergy costs can account for one more feature than the exergy indicator, namely the state of technology.

THE EXERGY DECREASE OF COPPER MINES

In year 2000, the total chemical exergy decrease of copper mines was 626,99 ktoe. Minimum consumption rate in 1900: 168 ktoe/year. Maximum in 1998: 1235 ktoe/year.

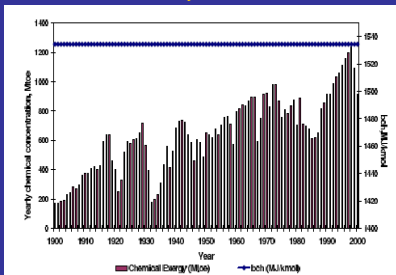


Figure 2: YEARLY CHEMICAL EXERGY CONSUMPTION IN THE U.S. OF CHALCOPYRITE DUE TO COPPER PRODUCTION THROUGHOUT THE 20th CENTURY

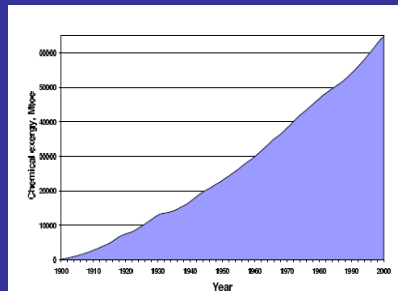


Figure 3: CUMULATIVE CHEMICAL EXERGY DECREASE OF COPPER MINES IN THE U.S. THROUGHOUT THE 20th CENTURY

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THE EXERGY DECREASE OF COPPER MINES

In year 2000, the total chemical exergy decrease of copper mines was 626,99 ktoe. Minimum consumption rate in 1906: 1,92 ktoe/year. Maximum in 2000: 10,77 ktoe/year.

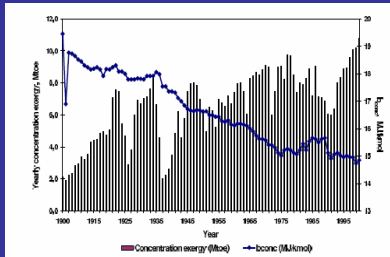


Figure 4: YEARLY CONCENTRATION EXERGY CONSUMPTION IN THE U.S. OF CHALCOPYRITE DUE TO COPPER PRODUCTION THROUGHOUT THE 20th CENTURY

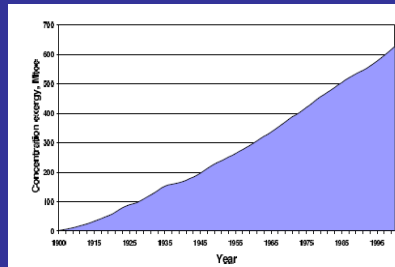
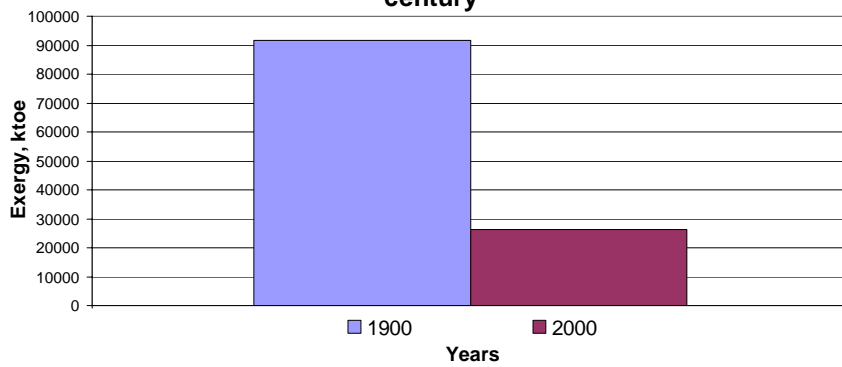


Figure 5: CUMULATIVE CONCENTRATION EXERGY DECREASE OF COPPER MINES IN THE U.S. THROUGHOUT THE 20th CENTURY

The mine has the greatest exergy concentration, when the ore grade is the maximum and becomes lower as the ore grade decreases. Year 1900: $x_m > 0,02 \text{ kg/kg} \Rightarrow bc > 18 \text{ MJ/kmol}$; Year 2000: $x_m < 0,005 \Rightarrow bc < 15 \text{ MJ/kmol}$

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Exergy decrease of US copper reserves in the 20th century



THE EXERGY DECREASE OF COPPER MINES

•Through the unit exergy costs, reversible exergies are converted into real exergies.

• $k_{ch}=10$; $k_c=385,61$ Source: Valero and Botero 2000

•The US copper exergy reserves and reserve base have been reduced to more than one third and to more than one half respectively.

•Years: 24 reserves and 48 reserve base. At current consumption rates.

Year	RESERVES		BASE RESERVE	
	1900	2000	1900	2000
Minimum exergy, ktoe				
b_{ch}	90776,24	25959,14	116735,38	51918,29
b_c	878,11	251,12	1129,22	502,23
b_t	91654,35	26210,26	117864,61	52420,52
Non-reversible exergy, ktoe				
b_{ch}^*	907762,40	259591,43	1167353,83	519182,87
b_c^*	338607,04	96832,59	435439,63	193665,18
b_t^*	1246369,44	356424,02	1602793,46	712848,05

Amount of US copper extracted in 20th century= 102,6 Mt

US population: 300 Mill.
People



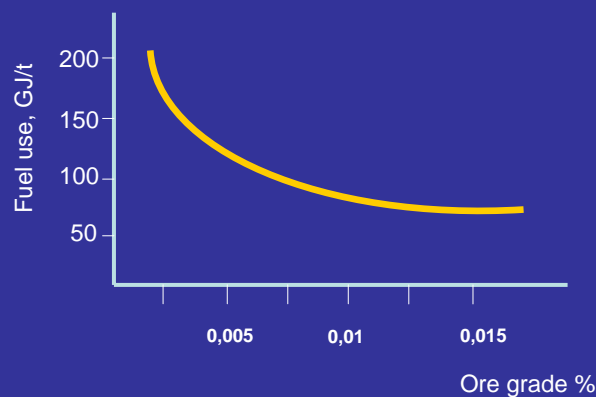
342 kg/hab in the US

World population: 6.500
Mill. People



15,7 kg US copper/hab in the world

- The United States accounted for about 8% of world production and retained its position as the world's second leading mine producer. Chile is the leading mine producer and accounts for more than 37% of total world production (Year 2000).
- U.S. Geological Survey estimates indicated world copper reserves of 470 Mt and a copper reserve base of 940 Mt. The United States had about 7% each of the world's copper reserves and reserve base.
- In the 20th century, the US extracted about 1/4th of current world reserves.



Adapted from Chapman and Roberts 1983

- Cummulative exergy footprint:
- Each US citizen has a “backpack” of 342kg of Copper.
- Which means a cummulative copper exergy consumption of: 889Mtoe/300Mhabitants=> aprox. 3 toe/US citizen.

- Cummulative exergy footprint:

$$Ft^* = \sum_{\text{Year 1900}}^{\text{Year 2000}} M_i (b_{c,i} * k_{c,i} + b_{ch,i} * k_{ch,i})$$

CONCLUSIONS AND DISCUSSION:

- In many cases, the lack of information about the state of natural resources on earth is the key factor for which natural goods are being extracted in an unsustainable way. Appropriate indicators for the scarcity of these goods must be found and exergy could be one of them.
- Through exergy, we can assess the three components that describe a natural resource: quantity, chemical composition and its particular concentration. Furthermore, through the exergy costs we can take into account the state of technology for obtaining the particular resource. Hence, instead of needing three or four different inventories for each of the features of a resource, we would need just one, compiling the whole information.
- As in the case of fossil fuels, the Hubbert peak effect could be applied for mineral resources with exergy. For mineral resources, it is not only important the quantity extracted, but also the quality of the remaining ores (that is not the case for fossil fuels and therefore exergy is better for this case than mass).

CONCLUSIONS AND DISCUSSION:

- As a case study, we have determined the exergy decrease of US copper mines due to copper extraction throughout the 20th century:
 - During the past century, the US extracted the equivalent exergy of 2,5 and 1,2 times of their current national exergy reserves and base reserve of their copper mines, respectively.
 - Similar numbers are expected for other substances. These results indicate the high degree of unsustainability of the mining industry.

DRAWBACKS

The principal drawback is the lack of information. A great amount of information needs to be compiled: world trends of natural resources production and consumption, trends of ore grades and technological developments. Unfortunately, this data is not always available and requires a lot of effort to gather it. Exergy will not be able to compete against mass until more information is available.

THANK YOU VERY MUCH FOR YOUR
ATTENTION!

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