Introduction to Extractive Metallurgy

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Course Outlines

Chapter 1 : Introduction (1 lecture)
Chapter 2: Mineral dressing (1 lecture)
Chapter 3: Pyrometallurgy (2 lectures)
Chapter 4: Hydrometallurgy (2 lectures)
Chapter 5: Electrometallurgy (1 lecture)
Chapter 6: Copper Extractive Metallurgy (3 lectures)
Chapter 7: Iron Extractive Metallurgy (2 lectures)
Chapter 8 : Mercury Extractive metallurgy (1 Lecture)
Chapter 9: Rare Earth Extractive Metallurgy (1 lecture)
Chapter 10: Aluminium Extractive Metallurgy (2 Lectures)
Chapter 11: Gold Extractive Metallurgy (2 Lectures)
Chapter 12: Tin Extractive Metallurgy (1 lecture)
Chapter 13: Titanium Extractive Metallurgy (1 lecture)
Chapter 14: Zinc Extractive Metallurgy (1 lecture)

References

1. **Fathi Habashi, Handbook of extractive metallurgy, Volume 2, Wiley-VCH, 1997 - Technology & Engineering - 2426 pages**

2. **C.K. Gupta, Extractive metallurgy of rare earth, CRC press, 2003**

3. **Alain Vignes , Extractive Metallurgy 1, 2011, Wiley-ISTE**

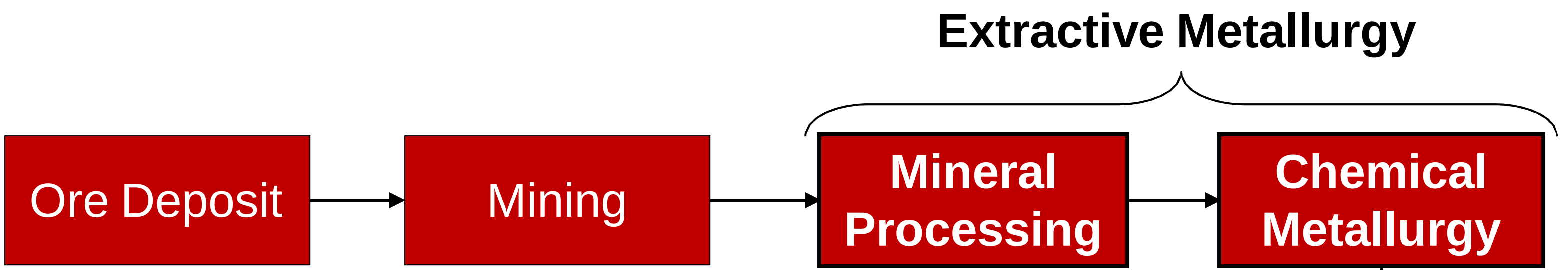
4. **Alain Vignes , Extractive Metallurgy 2, 2011, Wiley-ISTE**

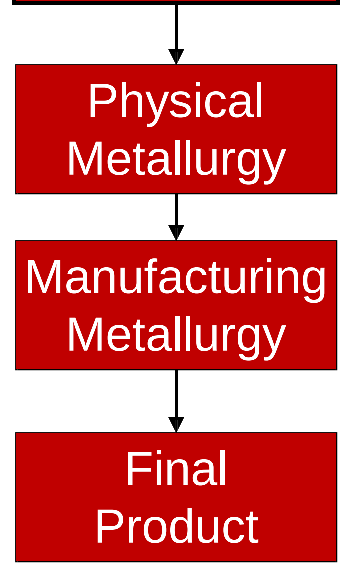
5. **Alain Vignes , Extractive Metallurgy 3, 2011, Wiley-ISTE**

6. **Fathi Habashi,, Principles of Extractive Metallurgy, January 1, 1986 by CRC Press**

7. **Fathi Habashi, Metals from Ores: An Introduction to Extractive Metallurgy, 2003**

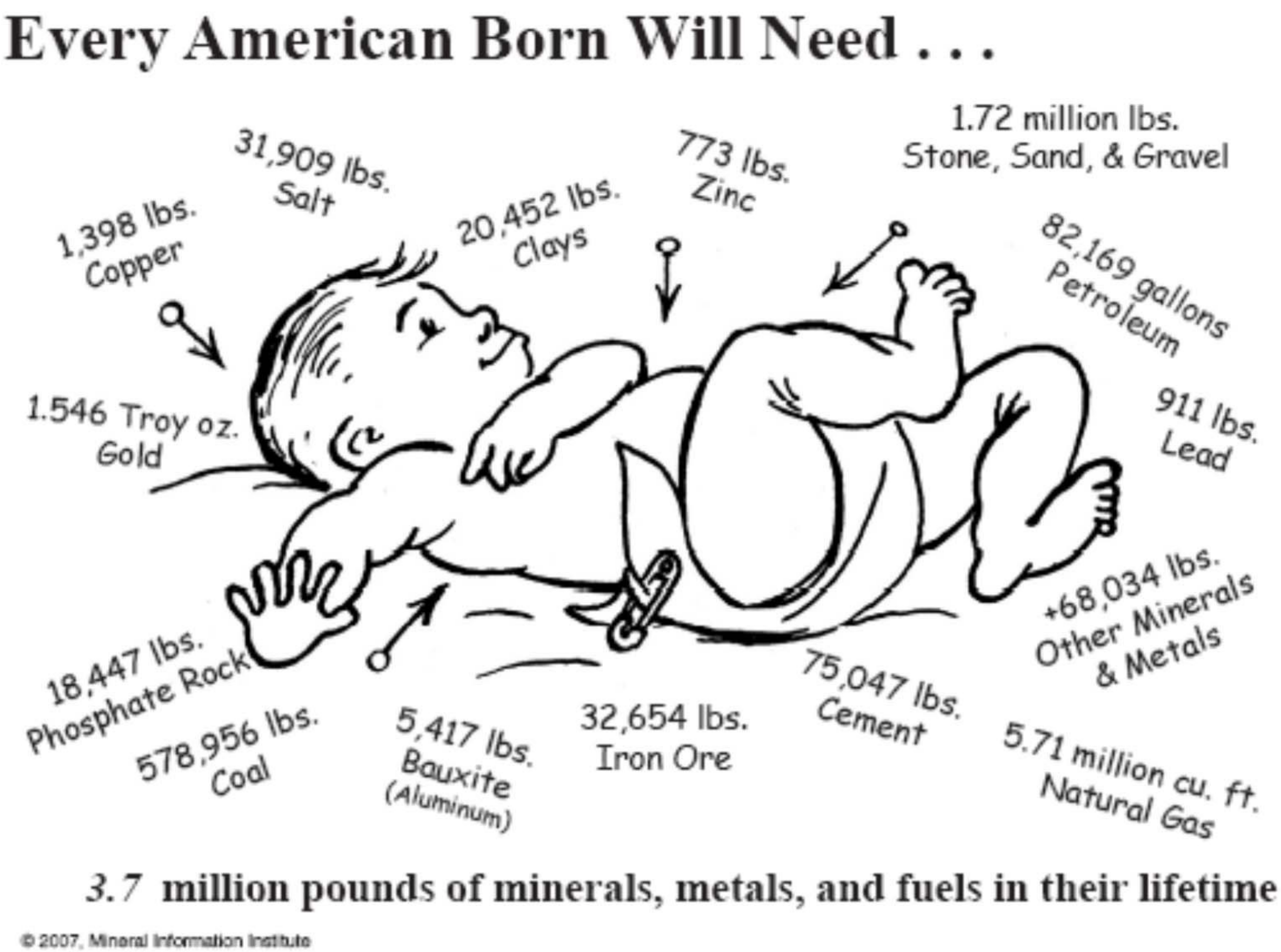
Getting Metals to Market





- Geologist finds a deposit with a metal mineral concentration that is economic to mine.
- Mining Engineers determine best way to recovery minerals while excluding some waste rock.
- Metallurgical Engineers separate valuable minerals from waste rock, extract metals for the minerals, treat the metal to achieve accessible properties, manufacture the metal into a useful final product.

How important is extractive metallurgy?



How Much More Do We Need?

- If China (1.3 billion population) were to reach US Consumption…

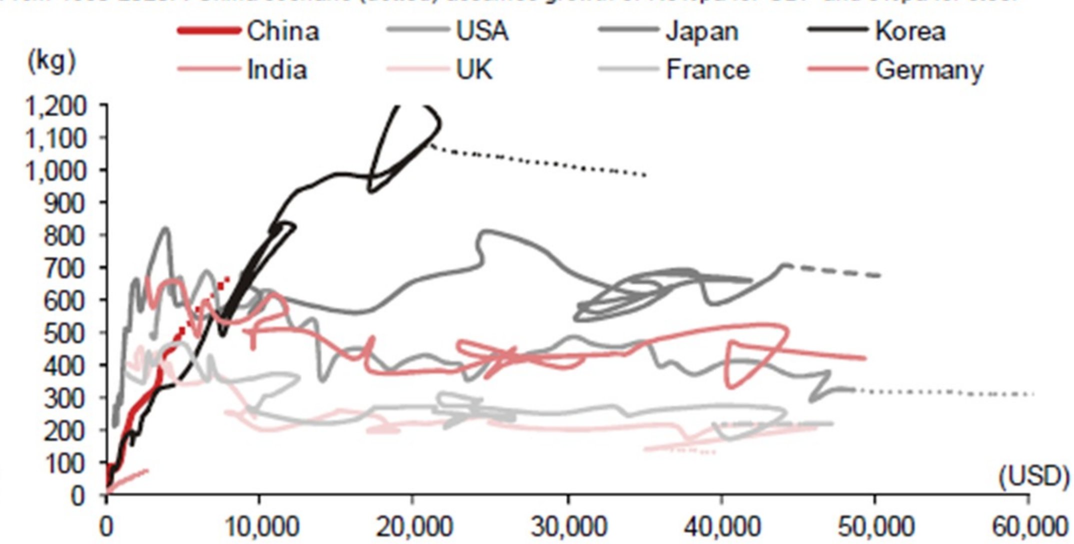
Steel:	286 million tons est. 2008 total – 1.4 billion tons
Copper:	14 billon pounds est. 2005 total – 33 billion lbs
Aluminum:	34 billion pounds est. 2005 total – 70 billion lbs

- What about India (1.1 billion population)?

Gross domestic product (GDP) at purchasing power parity (PPP) per capita = the value of all final goods and services produced within a country in a given year divided by the average population for the same year

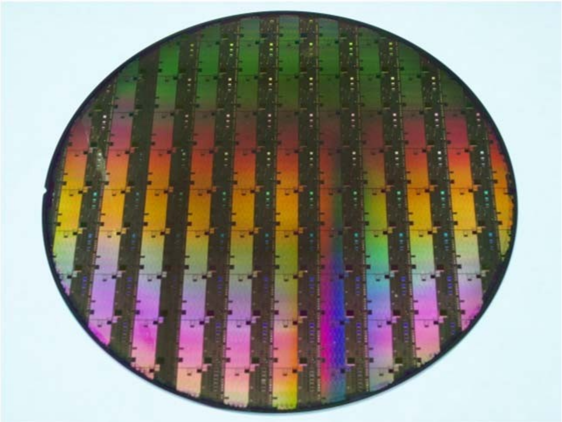
Fig. 5: Steel consumption per capita (kg/person) vs. GDP per capita (USD/person)

From 1960-2020F: China scenario (dotted) assumes growth of 7.5%pa for GDP and 5%pa for steel



Source: World Steel Association, IMF, Nomura estimates

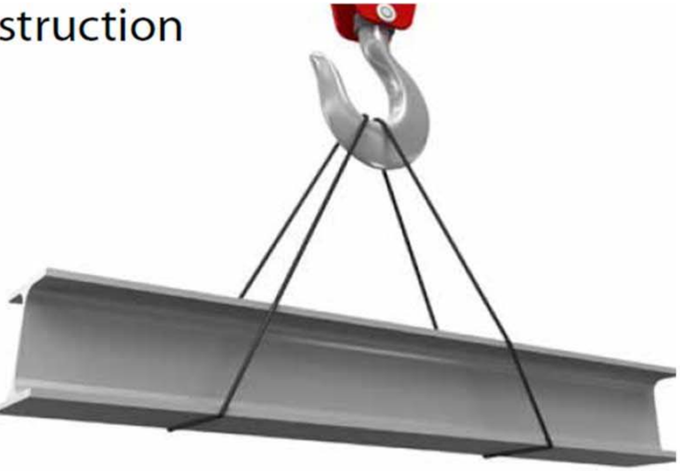
Where do we use these resources?



- Everything we use – whether ancient or modern comes from the earth.
- If it wasn't grown, it was mined.
- If it was mined it was processed into a useful product – whether coal for a furnace or microelectronics for a computer.

Where do we use these resources?

Construction



Infrastructure
150 Mt
14 %

For infrastructure: 24 % of steel is in structural sections; 54 % is reinforcing bars; 6 % is hot rolled train rails (providing a strong, wear and fatigue resistant contact surface); 16 % is in pipes formed by welding rolled steel, with high corrosion and fatigue resistance, and high strength to resist internal pressure and installation stresses.

Buildings
433 Mt
42 %

25 % of the steel in buildings is in structural sections, mainly hot rolled sections but also some welded plate. Sections form a strong, stiff structural frame. 44 % is in reinforcing bars, adding tensile strength and stiffness to concrete. Steel is used because it binds well to concrete, has a similar thermal expansion coefficient and is strong and relatively cheap. 31 % is in sheet products such as cold-formed purlins for portal frame buildings and as exterior cladding.

Metal products

Metal goods
134 Mt
12 %

Other metal goods include a multitude of products, from baths and chairs to filing cabinets and barbed wire. 30 % of steel entering this product group is hot rolled coil; 20 % is hot rolled bar; and the remainder is either plate, narrow strip, or cast iron.

Consumer packaging
9 Mt
1 %

Steel use in packaging is dominated by tin-plated rolled steel, which doesn't corrode. 60 % of this steel is made into food cans, providing durable packaging for the subsequent cooking and distribution. 40 % is used for aerosols.

Domestic appliances
29 Mt
3 %

Appliances are dominated by white goods (up to 70 %). The vast majority of steel used here is cold rolled coil, often galvanized or painted. Most of this steel is used for panelling. Other applications including washing machine tubs (welded rolled steel strip), motors, expanders in fridge/freezers and cast parts for transmissions.

- We make over 1000Mt of steel products every year, equivalent to a 1 meter square band of steel wrapped around the equator more than three times.

Where do we obtain mineral and metal resources?

- We obtain these resources from the earth, which contains an abundance of various elements within the thin layer of the earth’s crust.

Abundance of elements in the Earth's Crust

Element	Abundance (%)	Element	Abundance (%)
Oxygen	46.4	Vanadium	0.014
Silicon	28.2	Chromium	0.010
Aluminum	8.2	Nickel	0.0075
Iron	5.6	Zinc	0.0070
Calcium	4.1	Copper	0.0055
Sodium	2.4	Cobalt	0.0025
Magnesium	2.3	Lead	0.0013
Potassium	2.1	Uranium	0.00027
Titanium	0.57	Tin	0.00020
Manganese	0.095	Tungsten	0.00015
Barium	0.043	Mercury	0.000008
Strontium	0.038	Silver	0.000007
Rare Earths	0.023	Gold	< 0.000005
Zirconium	0.017	Platinum metals	< 0.000005

B. A. Wills, "Mineral Processing Technology," 3rd ed., Pergamon Press, Oxford, 1985

Abundance of elements in the Earth's Crust

- Most metals are found in the form of minerals within the earth's crust. For example:
  - Aluminum (Al) is often found with oxygen (O) and hydrogen (H) in gibbsite ($Al(OH)_3$)
  - Copper (Cu) is often found with iron (Fe) and sulfur (S) in chalcopyrite ($CuFeS_2$)
  - Iron (Fe) is often found with oxygen (O) in hematite (Fe_2O_3)

Abundance of elements in the Earth's Crust

- Where in the earth's crust can these resources be obtained?

  - We recover these resources from locations in the earth's crust where they are concentrated in ore bodies.

  - **Enrichment Factor** is used to describe bodies of mineral ore. It is defined as the minimum factor by which the weight percent of mineral in an orebody is greater than the average occurrence of that mineral in the Earth's crust.

Abundance of elements in the Earth's Crust

- Enrichment Factors that relate to the **economic viability** of an orebody are largely determined by the following:
  - **The value of the mineral** (the higher the value of the recovered mineral the more expensive the recovery process can be in order to obtain it - this could include processing larger amounts of ore)
  - **The level of the technology available to recover the mineral** (any advances in technology may allow ores with lower wt% mineral to be exploited for the same cost)
  - **The cost of refining the mineral once recovered** (this may require the bulk of the price demanded by the final product, so leaving little margin for the initial recovery of the mineral)
  - **Other macro-economic factors** (such as fuel prices if the mineral requires a large amount of transportation or energy prices if the recovery and refinement process is inherently energy intensive)

Metallic Ore	Approximate **enrichment factor** from natural occurrence to form economical ore body
Aluminum	4
Chromium	3,000
Cobalt	2,000
Copper	140
Gold	2,000
Iron	5
Lead	2,000
Manganese	380
Molybdenum	1,700
Nickel	175
Silver	1,500
Tin	1,000
Titanium	7
Tungsten	6,500
Uranium	500
Zinc	350

William Dennen, Mineral Resources: Geology Exploration, and Development, Taylor & Francis, New York, 1989.

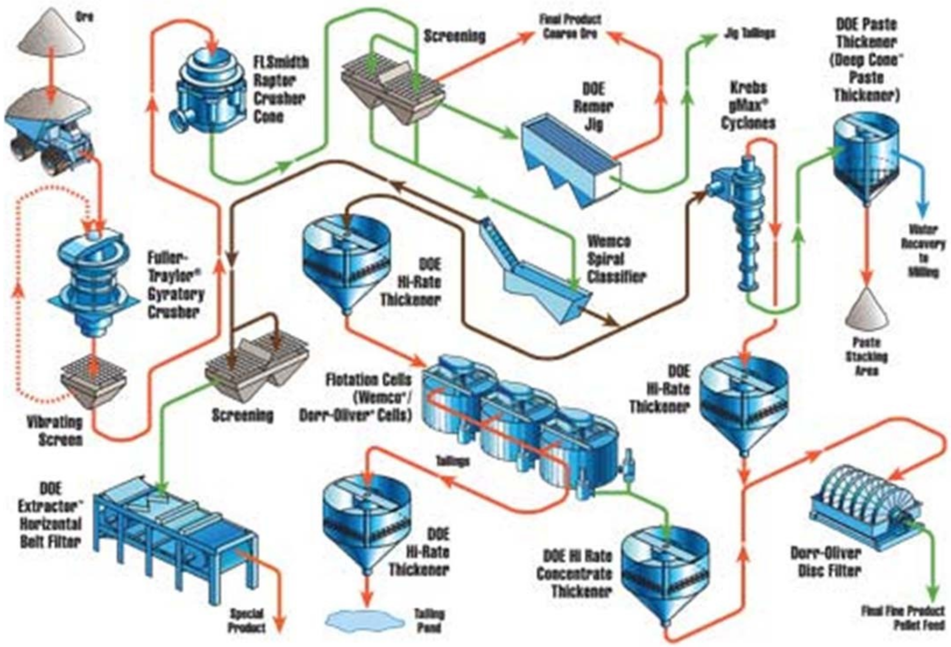
What causes ore bodies to form?

- Geological events such as earthquakes, volcanic eruptions, erosion, natural leaching are often necessary to form mineral deposits.
- These events concentrate mineral in locations that are accessible to mining.
- Such events are often associated with the formation of mountains, and it is not just a coincidence that most mine sites are located in mountains.

How do we obtain these resources?

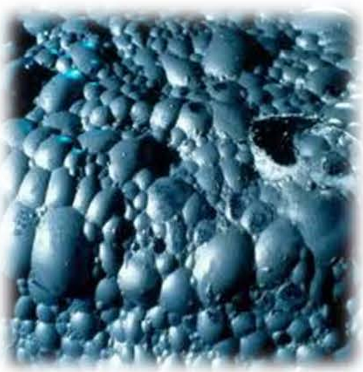
- We obtain these resources by utilizing appropriate mining and extractive metallurgical processes.

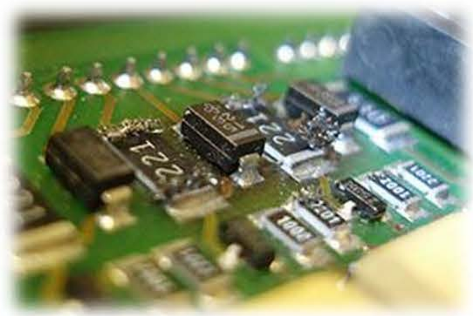
Iron Ore Processing Flowsheet, FLSmidth Minerals



What is extractive metallurgy?

- Extractive metallurgy is the branch of metallurgical engineering that is associated with the separation of valuable minerals or metals from specific resources such as run-of-mine ores and recyclable materials as well as their recovery into saleable raw material products.



What is extractive metallurgy?

- Extractive metallurgy consists of two main divisions:
  - **Particle Processing**
    (also known as ***Mineral Processing***)
  - **Chemical Processing**
    (also known as ***Chemical Metallurgy***)