

ME589/Geol571 Advanced Topics

Geology and Economics of Strategic and Critical Minerals

Virginia T. McLemore

CLASS REQUIREMENTS

Goals in this class

- Importance, geology, mining, processing of strategic and critical minerals
- What is involved from exploration thru production thru marketing
 - Reports, field notes, presentations
 - Where to look for information
 - Research needed
- Sustainable development
 - We can mine within public concerns
 - Social license to operate

Class

- The class will meet one day per week for 120 minutes
- Remaining time spent on field trips or in occasional extra discussion sessions (SME meetings, other presentations, guest speakers)
- May require extra time for the project presentations

Lectures found on my web site
<http://geoinfo.nmt.edu/staff/mclemore/home.html>

Textbooks

- Kogel, J.E, Trivedi, N.C., Barker, J.M., and Krukowski, S.T., 2006 , ed., Industrial Minerals and Rocks, 7th edition: Society for Mining, Metallurgy, and Exploration, Littleton, Colorado (use McLemore member #0154600 as recommendation) to get this price (save more \$ than membership costs plus you should all be members of SME anyway)
- Committee on Critical Mineral Impacts of the U.S. Economy, 2008, Minerals, Critical Minerals, and the U.S. Economy: Committee on Earth Resources, National Research Council, ISBN: 0-309-11283-4, 264 p., download from http://www.nap.edu/catalog.php?record_id=12034#toc
- Papers as assigned

**Critical Mineral Resources of the United States—
Economic and Environmental Geology and
Prospects for Future Supply**



Professional Paper 1802

U.S. Department of the Interior
U.S. Geological Survey

<https://pubs.er.usgs.gov/publication/pp1802>

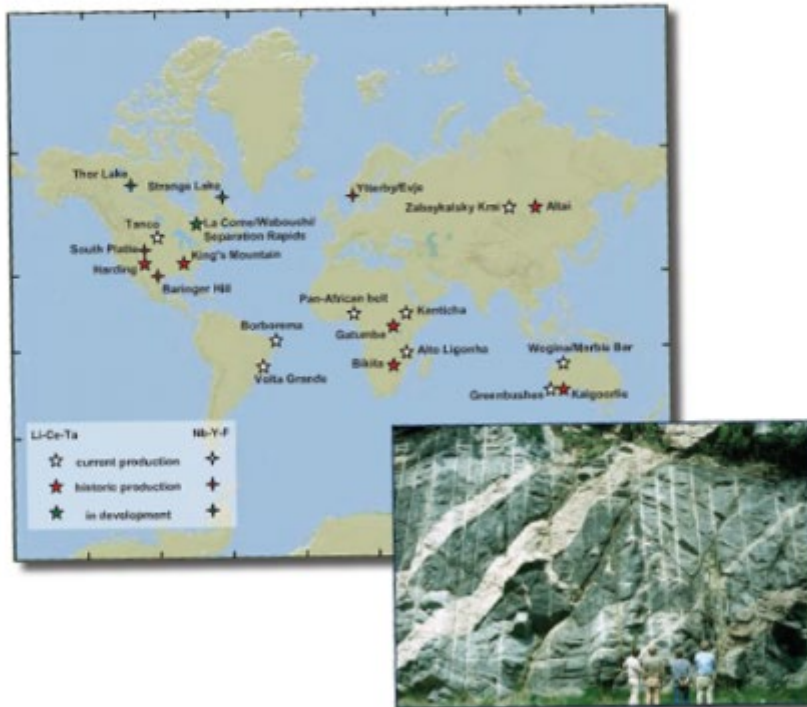


www.segweb.org

REVIEWS IN ECONOMIC GEOLOGY

Volume 18

RARE EARTH AND CRITICAL ELEMENTS IN ORE DEPOSITS



Editors

Philip L. Verplanck and Murray W. Hitzman

SOCIETY OF ECONOMIC GEOLOGISTS, INC.

<https://www.segweb.org/store/detail.aspx?id=REV18-DISC>

U.S. Department of the Interior
U.S. Geological Survey

MINERAL COMMODITY SUMMARIES 2019

Abrasives	Floorspar	Mercury	Silicon
Aluminum	Gallium	Mica	Silver
Antimony	Garnet	Molybdenum	Soda Ash
Arsenic	Gemstones	Nickel	Stone
Asbestos	Germanium	Niobium	Strontium
Berite	Gold	Nitrogen	Sulfur
Bauxite	Graphite	Palladium	Talc
Beryllium	Gypsum	Pest	Tantalum
Bismuth	Hafnium	Perlite	Tellurium
Boron	Helium	Phosphate Rock	Thallium
Bromine	Iodine	Platinum	Thorium
Cadmium	Iron and Steel	Potash	Tin
Cement	Iron Ore	Pumice	Titanium
Cesium	Iron Oxide Pigments	Quartz Crystal	Tungsten
Chromium	Kyanite	Rare Earths	Vanadium
Clays	Lead	Rhenium	Vermiculite
Cobalt	Lime	Rubidium	Wollastonite
Copper	Lithium	Salt	Yttrium
Diamond	Magnesium	Sand and Gravel	Zeolite
Diatomite	Manganese	Scandium	Zinc
Feldspar		Selenium	Zirconium

<https://www.usgs.gov/centers/nmic/mineral-commodity-summaries>

Class Details

- Exams: Midterm and Final—both are take home exams that will emphasize short answer and essay questions.
- Presentation before Feb 17 (SME talk/poster, paper, other)
- Term project—you are required to do a term/research project that will involve some original work.
- Field trips—there will be 2 or more field trips and a trip report on each trip will be required.
- Team work and group projects/reports are encouraged, but midterm and final will be on your own.

Grades

- Midterm 25%
- Final (comprehensive) 30%
- Lab exercises 5%
- Presentation 5%
- Term project 20%
- Field trip reports 10%
- Class Participation 5%

Sources of data

- Internet
- <http://minerals.usgs.gov/minerals/pubs/commodity/myb/>
- <http://www.minerals.com/>
- Societies (SME, others)

- Some slides from Jon Price, State Geologist Emeritus, Nevada Bureau of Mines and Geology

Wikipedia

- Use sparingly
- Some of the information on Wikipedia is incorrect
- Some of your best data and sources of information are in the library and not in electronic form
- Be aware of using copyrighted material—get permission

Term Project

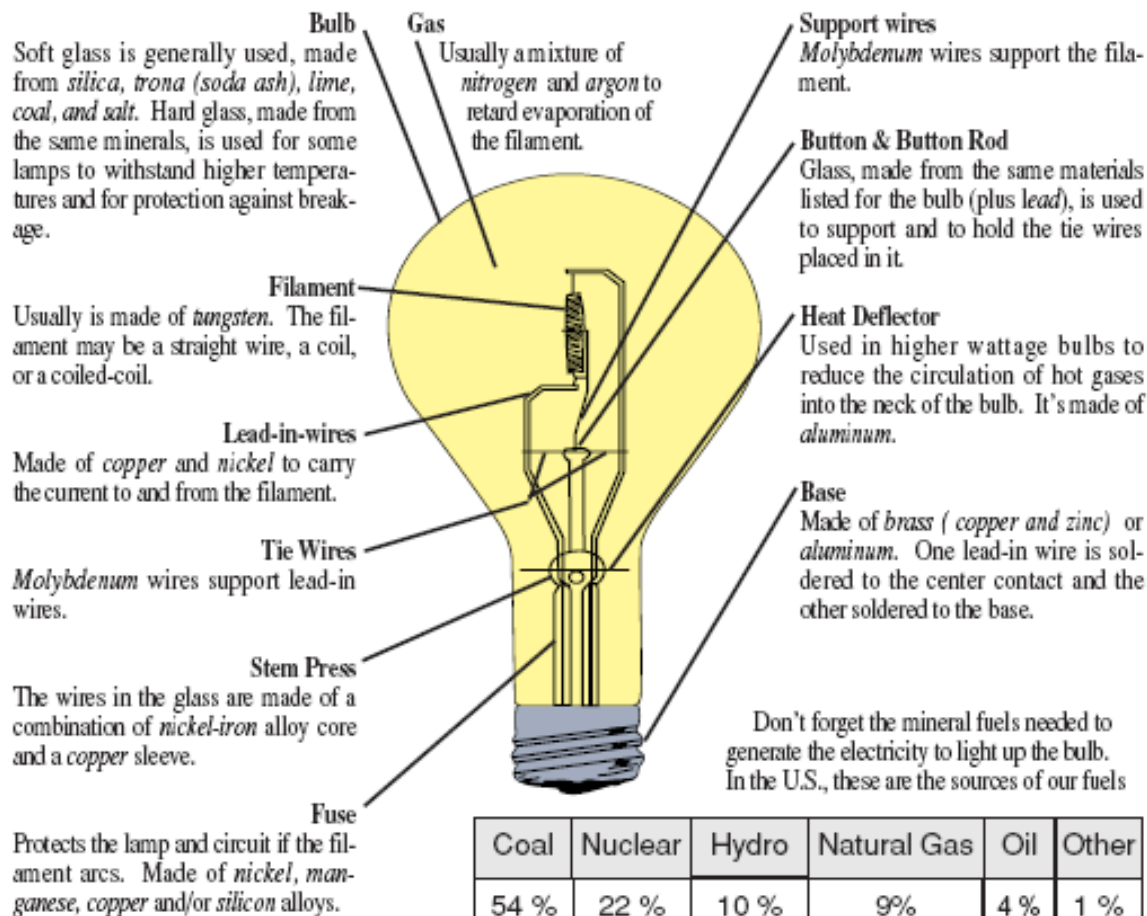
- Lesson plan, poster, and web site on importance of a specific commodity
- Mineral resource potential of specific mineral in a geographic area
- Flow/life cycle of a commodity in our society
- Related to your thesis work
- Sampling and Analytical procedures for a commodity/element
- Detailed analysis of a commodity

Dig A Little Deeper

How Many Minerals and Metals Does It Take to Make A Light Bulb?



Science: What makes the bulb work? Predict: Design light bulbs for the future.



Math/Art: Explore shapes & sizes. Light bulb picture collage.

For information about minerals in society, go to:
Mineral Information Institute, www.mii.org

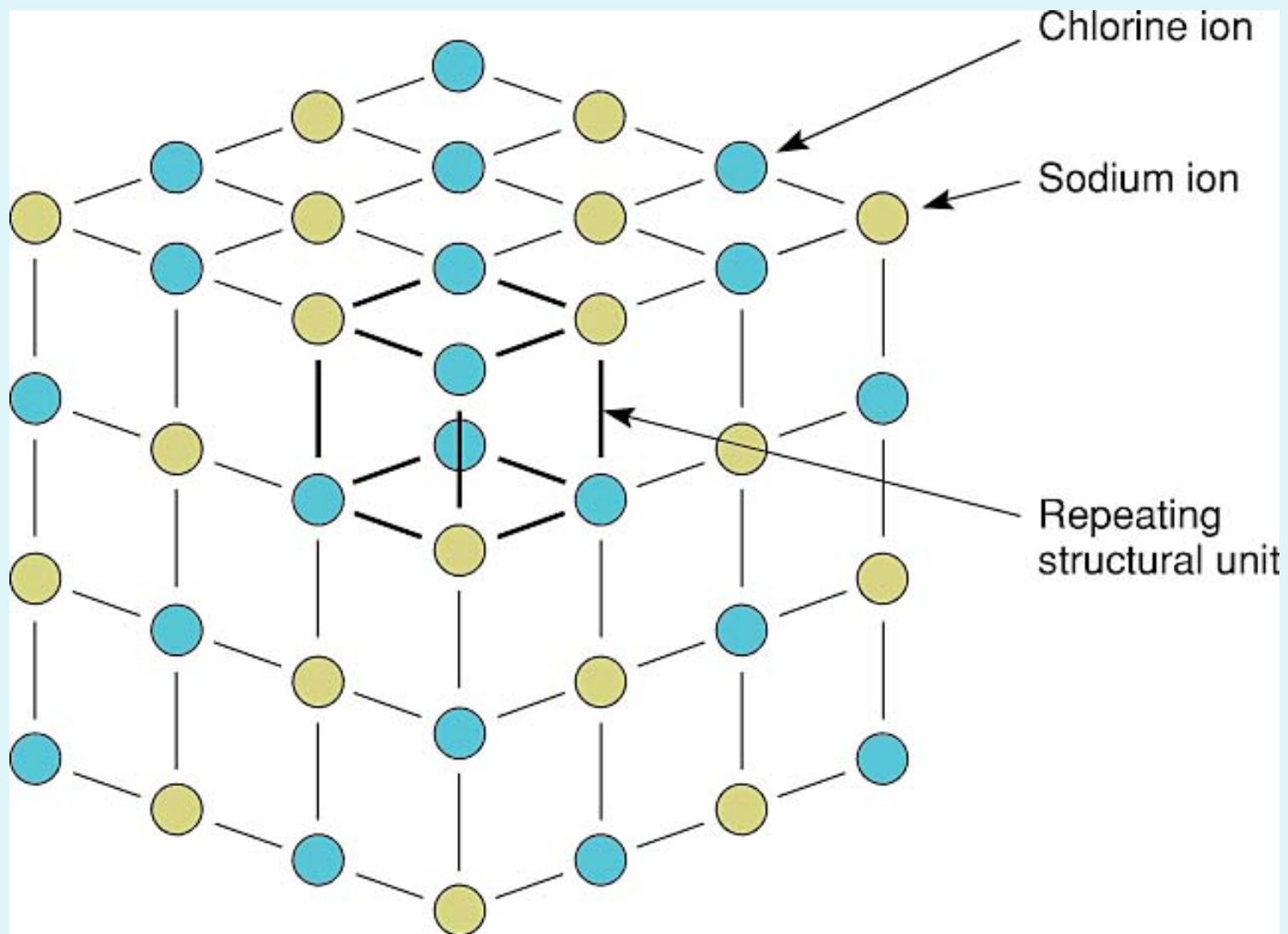
Geography: Research & ID the states and countries producing these minerals.

STRATEGIC OR CRITICAL MINERALS

What is a mineral?

What is a mineral?

- Naturally occurring
- Inorganic
- Solid
- Homogeneous
- Crystalline material
- With a unique chemical element or compound with a set chemical formula
- Usually obtained from the ground



A crystal is composed of a structural unit that is repeated in three dimensions. This is the basic structural unit of a crystal of sodium chloride, the mineral halite.

Another definition

Definition of Minerals

In industry, *minerals* refer to any rock, mineral, or other naturally occurring material of economic value, including metals, industrial minerals, energy minerals, gemstones, aggregates, and synthetic materials sold as commodities.

1. Metals - rare, difficult to find, expensive
2. Energy minerals – coal, oil and natural gas
3. Industrial minerals - non-metallic, such as salt, china clay, fluorspar
 - occur in large quantities in a few places
 - require specialised processing and are expensive
4. Construction minerals - sand and gravel, crushed rock, brick clay
 - deposits are extensive and common
 - transportation is economical over short distances only

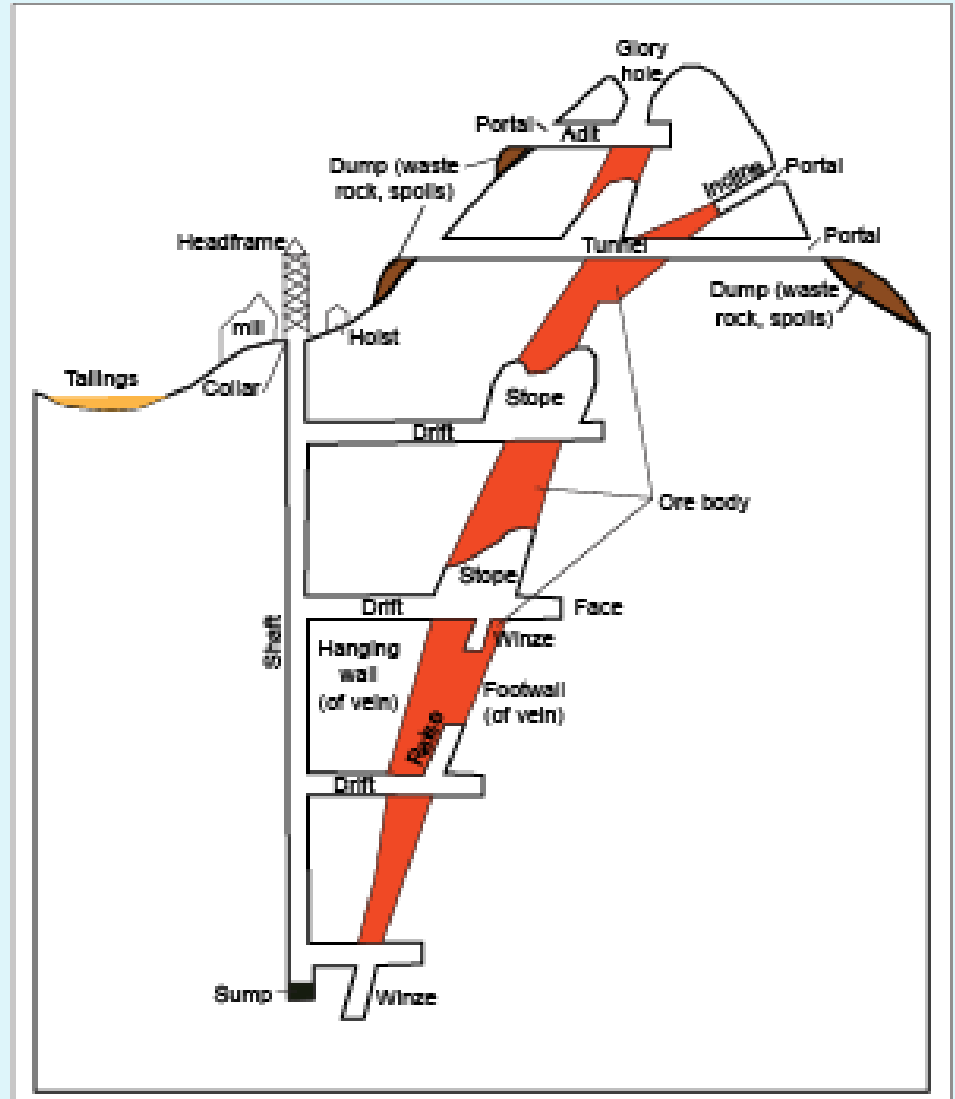
A mineral occurrence is any locality where a useful mineral or material is found.

A mineral prospect is any occurrence that has been developed by underground or by above ground techniques, or by subsurface drilling to determine the extent of mineralization.

The terms **mineral occurrence** and **mineral prospect** do not have any resource or economic implications.

Definition of mine

any opening or excavation in the ground for extracting minerals, even if no actual production occurred, mine feature



A mineral deposit is any occurrence of a valuable commodity or mineral that is of sufficient size and grade (concentration) that has potential for economic development under past, present, or future favorable conditions.

An **ore deposit** is a well-defined mineral deposit that has been tested and found to be of sufficient size, grade, and accessibility to be extracted (i.e. mined) and processed at a profit at a specific time. Thus, the size and grade of an ore deposit changes as the economic conditions change. **Ore refers to industrial minerals as well as metals.**

Mineral Deposits versus Ore Bodies

mineral deposit \neq ore body

ore body = reserves

mineral deposit = \pm reserves
+ unmineable
+ uneconomic
+ mined

What is a rock?

What is a rock?

- Naturally occurring
- Solid
- Homogeneous or heterogeneous
- Usually obtained from the ground
- Usually made up of one or more minerals
- Any naturally formed material composed of one or more minerals having some degree of chemical and mineralogic constancy

What are industrial minerals?

What are industrial minerals?

- Any rock, mineral, or other naturally occurring material of economic value, excluding metals, energy minerals, and gemstones
- One of the nonmetallics
- Includes aggregates

CLASSIFICATION OF MINERAL RESOURCES ON U.S. FEDERAL LAND

Locatable Minerals are whatever is recognized as a valuable mineral by standard authorities, whether metallic or other substance, when found on public land open to mineral entry in quality and quantity sufficient to render a claim valuable on account of the mineral content, under the United States Mining Law of 1872. Specifically excluded from location are the leasable minerals, common varieties, and salable minerals.

Leasable Minerals The passage of the Mineral Leasing Act of 1920, as amended from time to time, places the following minerals under the leasing law: oil, gas, coal, oil shale, sodium, potassium, phosphate, native asphalt, solid or semisolid bitumen, bituminous rock, oil-impregnated rock or sand, and sulfur in Louisiana and New Mexico.

Salable Minerals The Materials

Act of 1947, as amended, removes petrified wood, common varieties of sand, stone, gravel, pumice, pumicite, cinders, and some clay from location and leasing. These materials may be acquired by purchase only.

Other terms

Canadian Instrument 43-101

- Set of rules and guidelines for reporting information relating to a mineral property in order to present these results to the Canadian stock exchange
 - created after the Bre-X scandal to protect investors from unsubstantiated mineral project disclosures
 - gold reserves at (Bre-X's) Busang were alleged to be 200 million ounces (6,200 t), or up to 8% of the entire world's gold reserves
FRAUD
- Similar to JORC (joint ore reserves committee code, Australia)
- South African Code for the Reporting of Mineral Resources and Mineral Reserves (SAMREC)

Other terms

- Adjacent property
 - Company has no interest
 - Boundary close to project
 - Geologic characteristics similar to project
- Advanced property
 - Mineral reserves
 - Minerals resources with a PEA or feasibility study
- Early stage exploration property

Qualified person (43-101)

- engineer/geoscientist with a university degree, or equivalent accreditation, in an area of geoscience, or engineering, relating to mineral exploration or mining
- has at least five years of experience
- has experience relevant to the subject matter of the mineral project and the technical report
- is in good standing with a professional association

What are strategic and critical minerals?

Strategic and critical minerals

- Minerals needed for military, industrial or commercial purposes that are essential to renewable energy, national defense equipment, medical devices, electronics, agricultural production and common household items
- Minerals that are essential for use but subject to potential supply disruptions
- Minerals that perform an essential function for which few or no satisfactory substitutes exist
- The absence of which would cause economic or social consequences
- 33-50% minerals are classified as such

Presidential Executive Order No. 13817

“a mineral (1) identified to be a nonfuel mineral or mineral material essential to the economic and national security of the United States, (2) from a supply chain that is vulnerable to disruption, and (3) that serves an essential function in the manufacturing of a product, the absence of which would have substantial consequences for the U.S. economy or national security”

➤ Demand

- Material composition increasingly complex
- Potential rapid growth in demand for some minerals

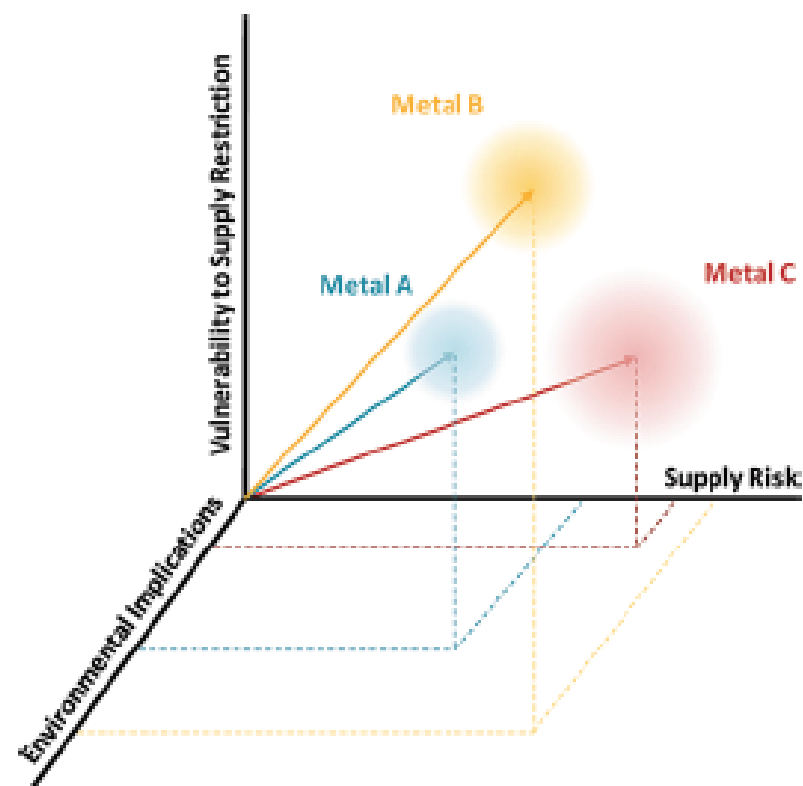
➤ Supply

- Seemingly increasingly fragile
- More fragmented supply chains, US import dependence, export restrictions on primary raw materials, resource nationalism, increased industry concentration

Criticality is context specific:

- ◆ What is critical for a given manufacturer or product may not be critical for another, what is critical for a state may not be critical for a country, and what is critical for national defense may be different than what is necessary to make a television brighter or less expensive.
- ◆ Recent studies have expanded the scope of criticality to include environmental and technological factors.

Graedel, T. E.; Barr, R.; Chandler, C.; Chase, T.; Choi, J.; Christoffersen, L.; Friedlander, E.; Henly, C.; Nassar, N. T.; Schechner, D.; Warren, S.; Yang, M.; Zhu, C., 2012, Methodology of metal criticality determination: Environ. Sci. Technol., 46, 1063-1070.



What are the differences between
critical and strategic?

Differences between critical and strategic

- Minerals for military uses are strategic
- Minerals for which a threat to supply could involve harm to the economy are critical
- A critical mineral may or may not be strategic, while a strategic mineral will always be critical

History of strategic and critical minerals

- 1918: end of WW1 Harbord List developed
- 1938: Naval Appropriations Act
- 1939: Strategic Minerals Act
- 1940 Reconstruction Finance Corp formed to acquire and transport materials
- 1944: Surplus Property Act authorized strategic materials stockpile
- Became the Defense National Stockpile Center (DNSC)
- 1992: Congress ordered DNSC to sell the bulk of the stockpiles

What are green technologies?

What are green technologies?



- Environmental technologies or clean technologies
- Future and existing technologies that conserve energy and natural resources and curb the negative impacts of human involvement, i.e. environmental friendly (modified from Wikipedia)
 - Alternative power (wind turbines, solar energy)
 - Hybrid and electric cars
 - Batteries
 - Magnets
- Other technologies
 - Water purification
 - Desalination
 - Carbon capture and storage



Why are minerals so important?

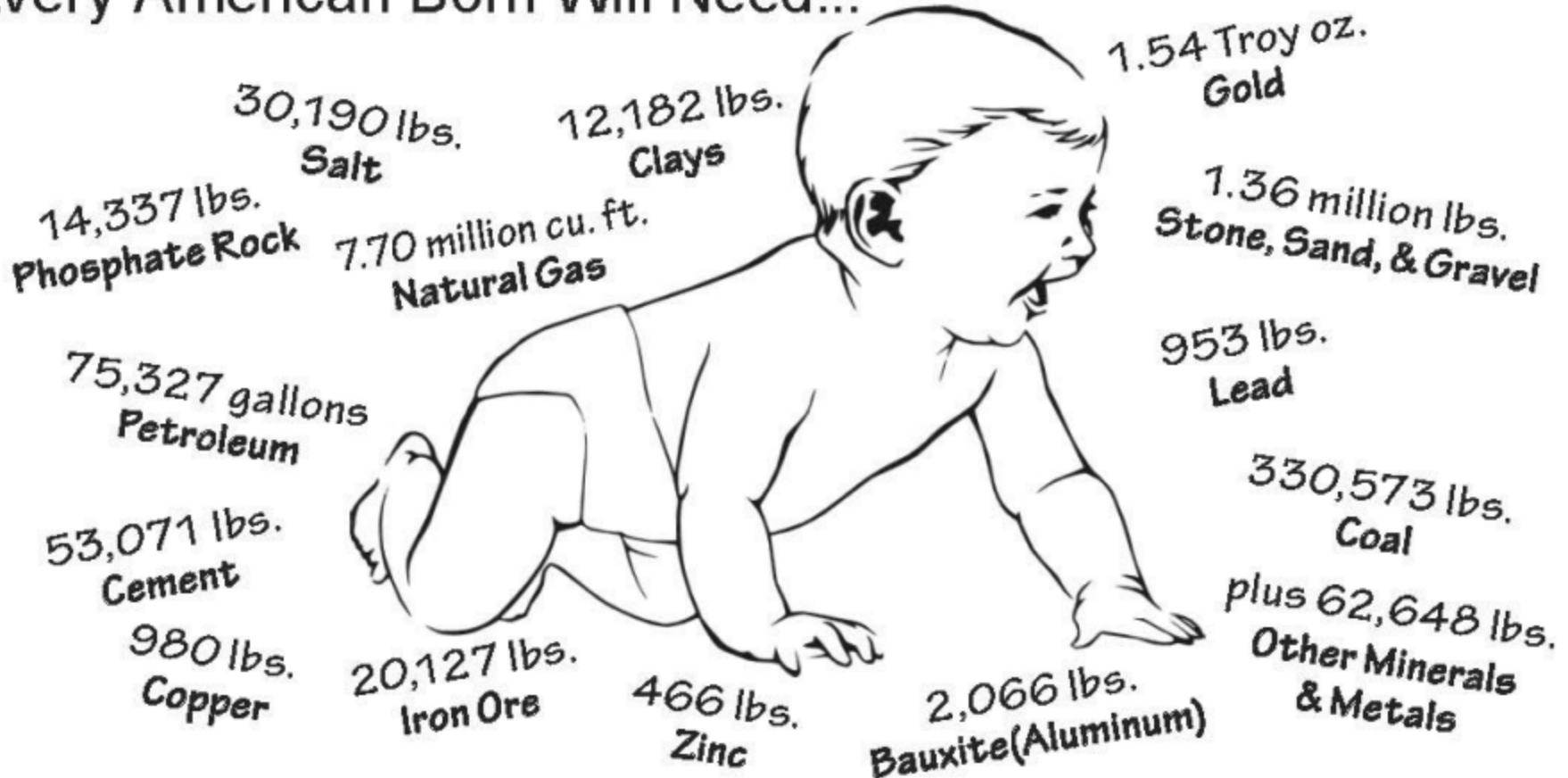
Why are minerals so important?

Your world is made of them!

The average American uses about two million pounds of industrial minerals, such as limestone, clay, and aggregate, over the period of a lifetime.

Building blocks of our way of life

Every American Born Will Need...



3.19 million pounds of minerals, metals, and fuels in their lifetime

Every Year— 38,052 pounds of new minerals must be provided for every person in the United States to make the things we use every day



8,509 lbs. **Stone** used to make roads, buildings, bridges, landscaping, and for numerous chemical and construction uses



5,599 lbs. **Sand & Gravel** used to make concrete, asphalt, roads, blocks and bricks



496 lbs. **Cement** used to make roads, sidewalks, bridges, buildings, schools and houses



357 lbs. **Iron Ore** used to make steel— buildings; cars, trucks, planes, trains; other construction; containers



421 lbs. **Salt** used in various chemicals; highway deicing; food & agriculture



217 lbs. **Phosphate Rock** used to make fertilizers to grow food; and as animal feed supplements



164 lbs. **Clays** used to make floor & wall tile; dinnerware; kitty litter; bricks and cement; paper



65 lbs. **Aluminum (Bauxite)** used to make buildings, beverage containers, autos, and airplanes



12 lbs. **Copper** used in buildings; electrical and electronic parts; plumbing; transportation



11 lbs. **Lead** 87% used for batteries for transportation; also used in electrical, communications and TV screens



6 lbs. **Zinc** used to make metals rust resistant, various metals and alloys, paint, rubber, skin creams, health care and nutrition



36 lbs. **Soda Ash** used to make all kinds of glass; in powdered detergents; medicines; as a food additive; photography; water treatment



5 lbs. **Manganese** used to make almost all steels for construction, machinery and transportation



332 lbs. **Other Nonmetals** have numerous uses: glass, chemicals, soaps, paper, computers, cell phones



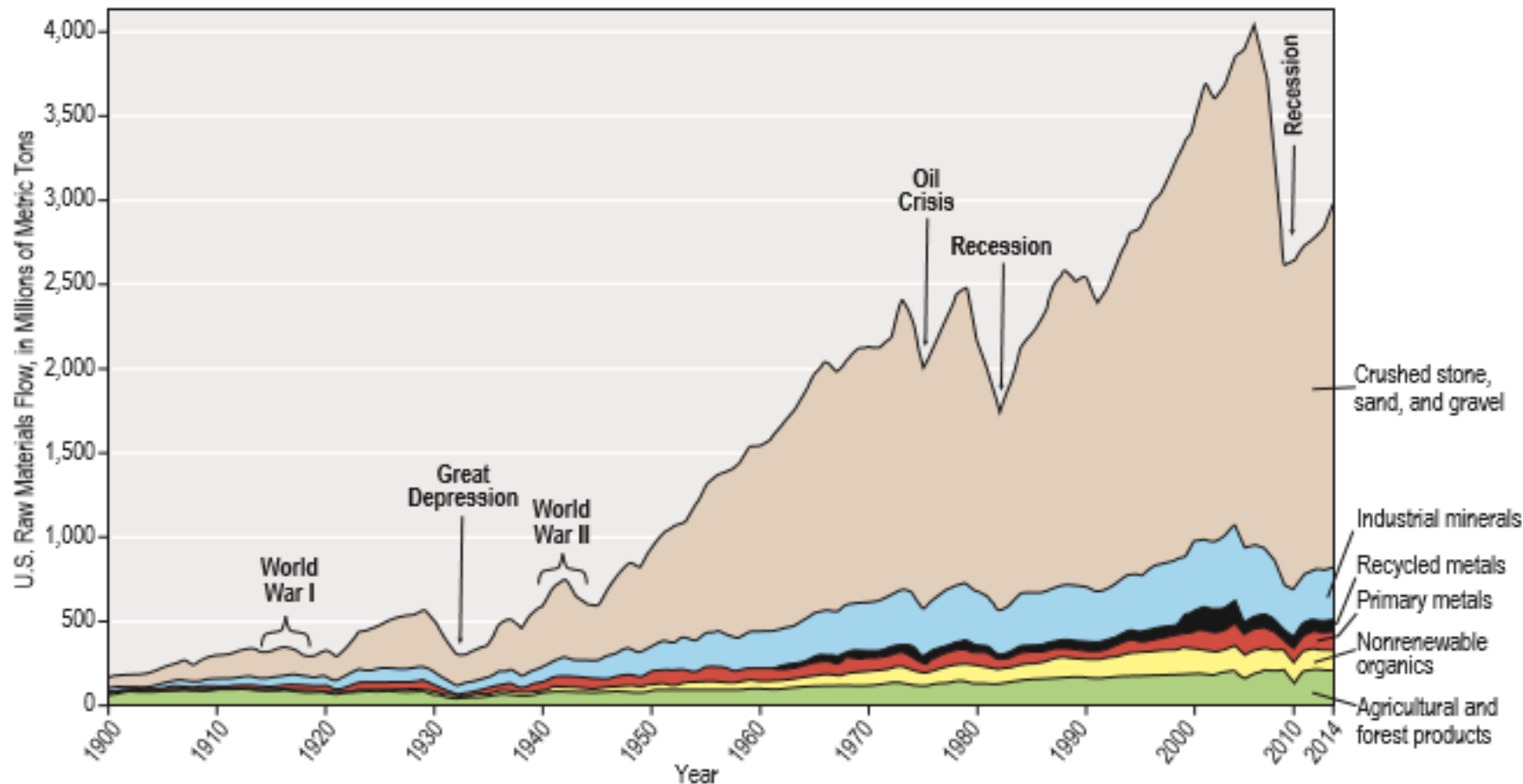
24 lbs. **Other Metals** have the same uses as nonmetals but also electronics, TV and video equipment, recreation equipment, and more

Including These Energy Fuels

• 951 gallons of **Petroleum** • 6,792 lbs. of **Coal** • 80,905 cu. ft. of **Natural Gas** • 1/4 lb. of **Uranium**

To generate the energy each person uses in one year—

U.S. flow of raw materials by weight 1900-2014. The use of raw materials in the U.S. increased dramatically during the last 100 years (modified from Wagner, 2002).



Elements in Computer Chips (National Research Council, 2007)

elements needed in 1980s
 additional elements needed today

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac															
			Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	
			Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	

Geologically, most minerals

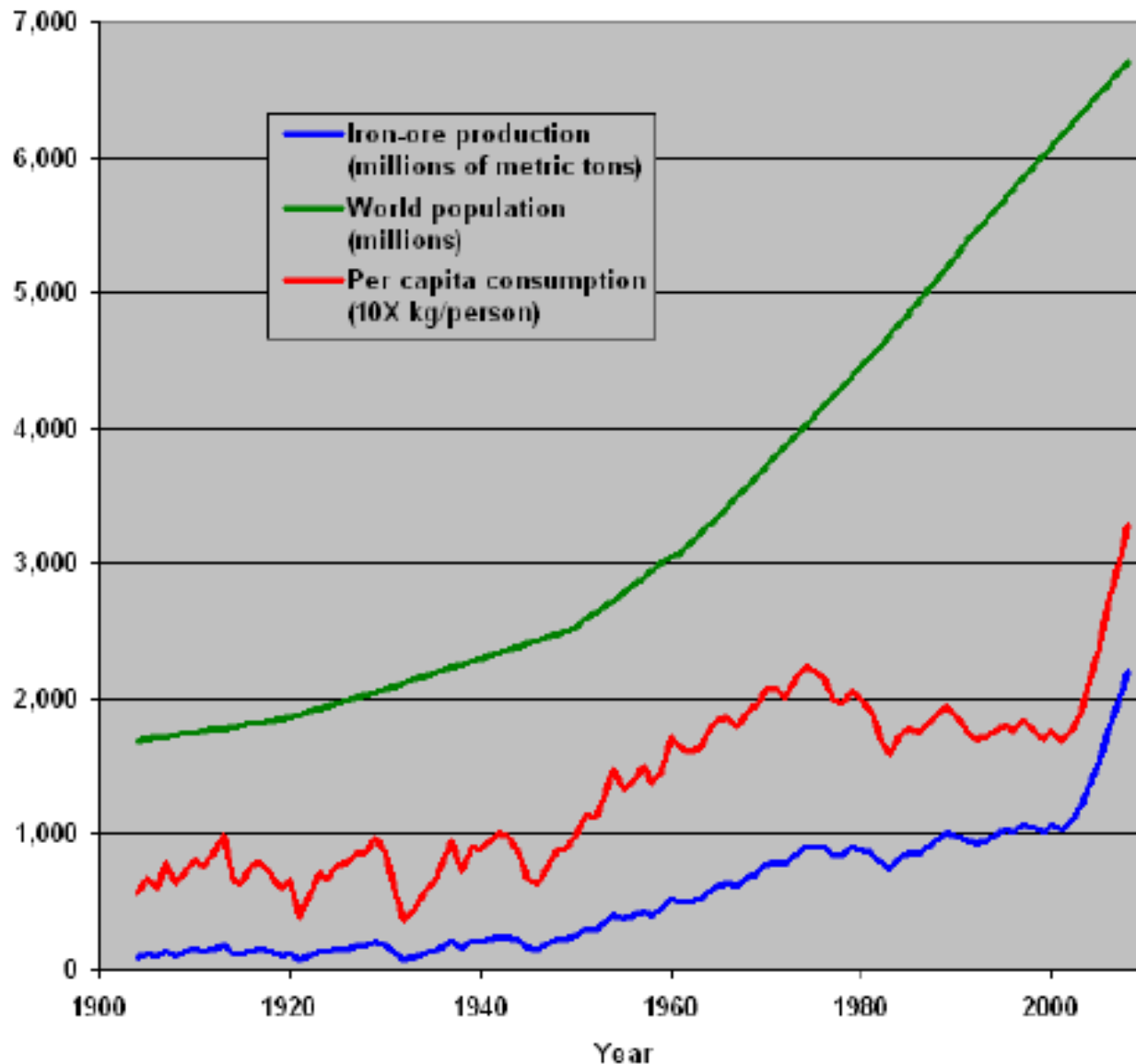
- are widespread
- have enormous reserves
- are easy accessible

The main challenge is provide society with its needs, protect future resources, limit alteration of the landscape, and affect local communities as little as possible (i.e. sustainable development).

DEMAND

Demand is growing partly because world population is increasing, and partly because standards of living (measured by per capita consumption) are increasing.

Iron



~4X more population than 100 years ago

~14X more production than 100 years ago

~4X more per capita consumption than 100 years ago

Production statistics mostly from USGS/USBM

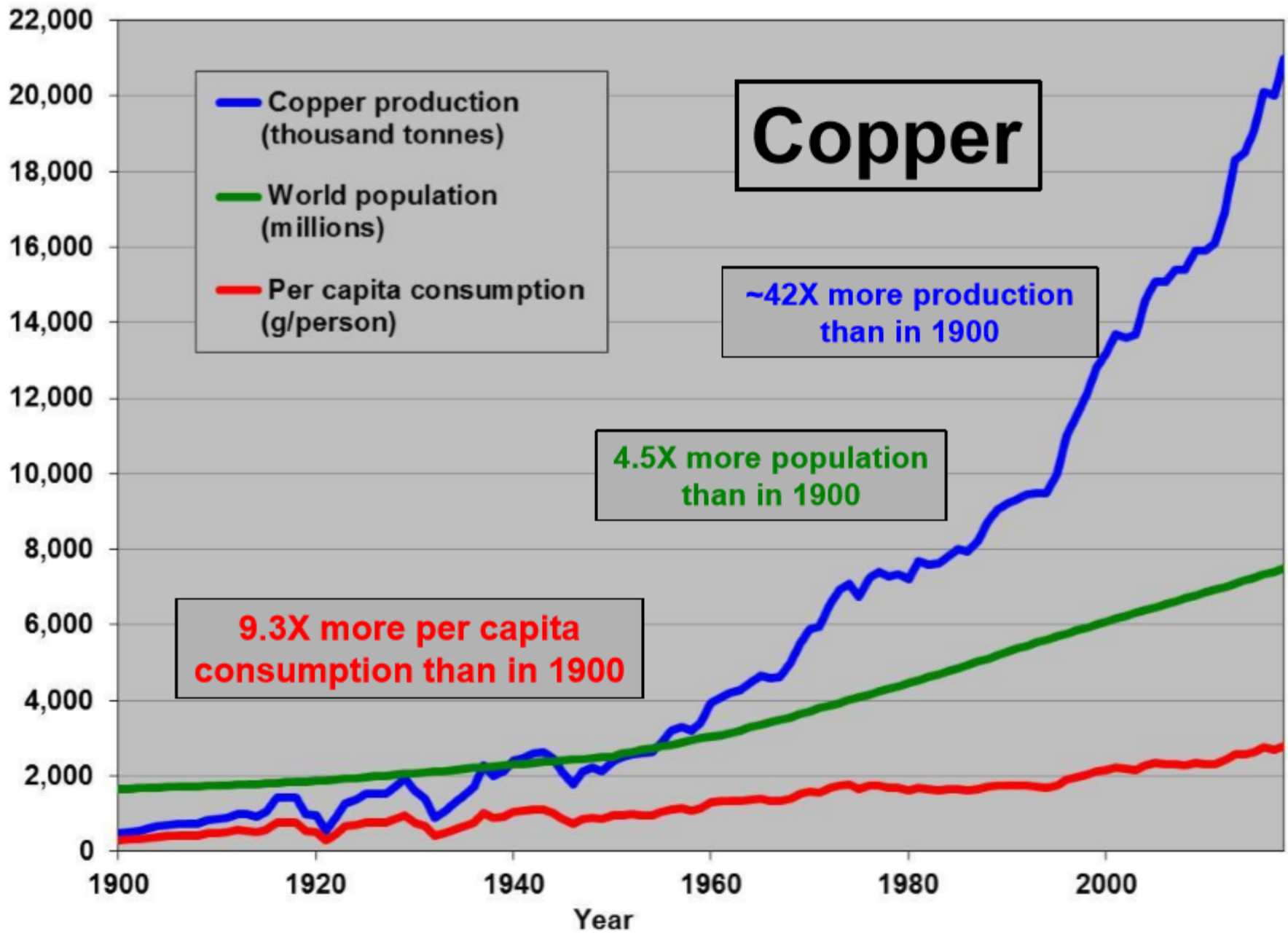
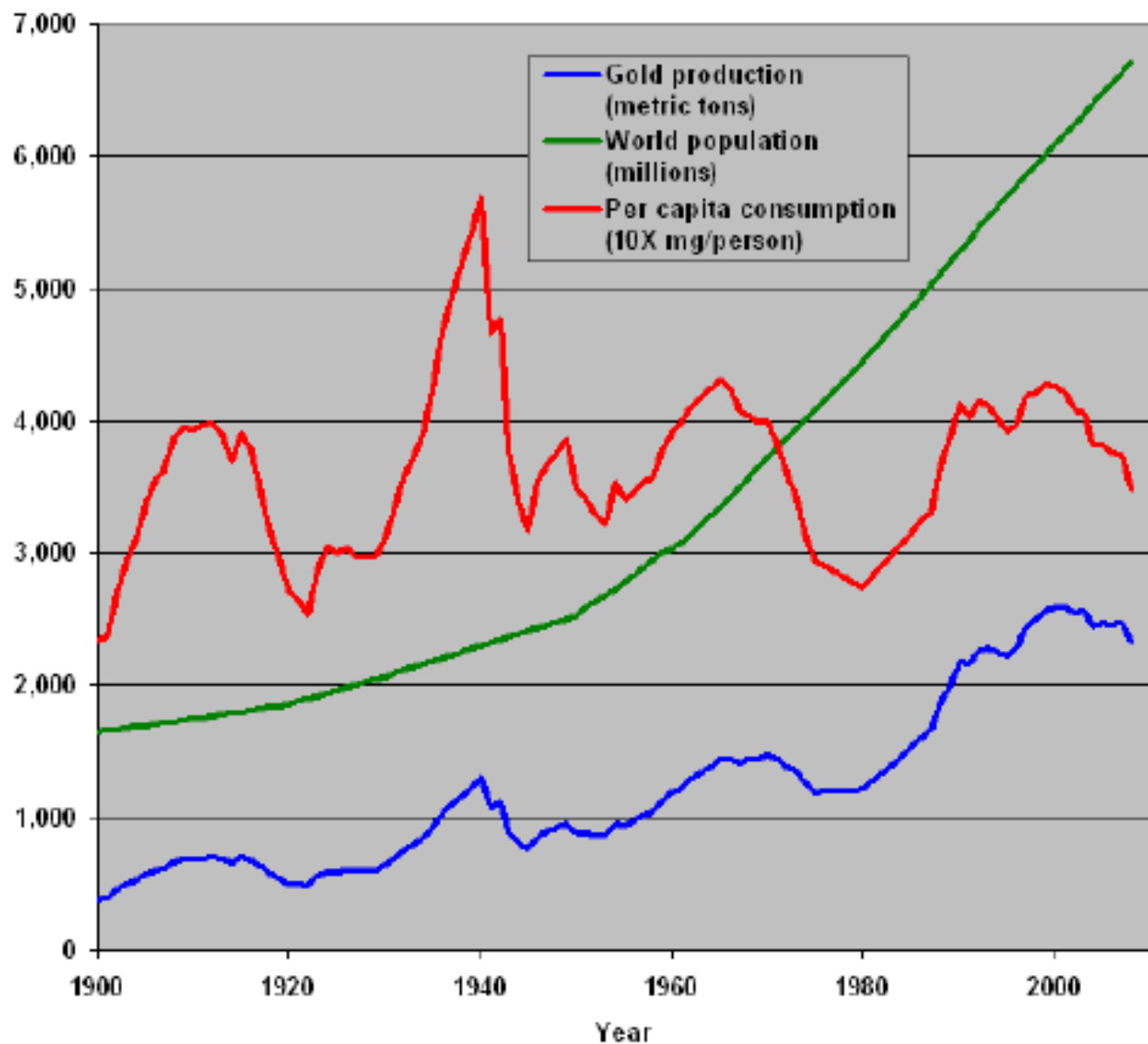




Photo copyrighted by Michael Collier, from the AGI website, Rio Tinto/Kennecott Utah Copper mine; the remaining resource as of 16 May 2008 = 3.06 million metric tons of Cu

Global copper production in 2018 (21 million metric tons) exceeded over 100 years of production from the Bingham Canyon mine (~17 million metric tons).

Demand for nearly every mineral (and energy) commodity is high.



Gold

~same per capita consumption as 100 years ago

~4X more production than 100 years ago

Barrick's Betze pit, 2000

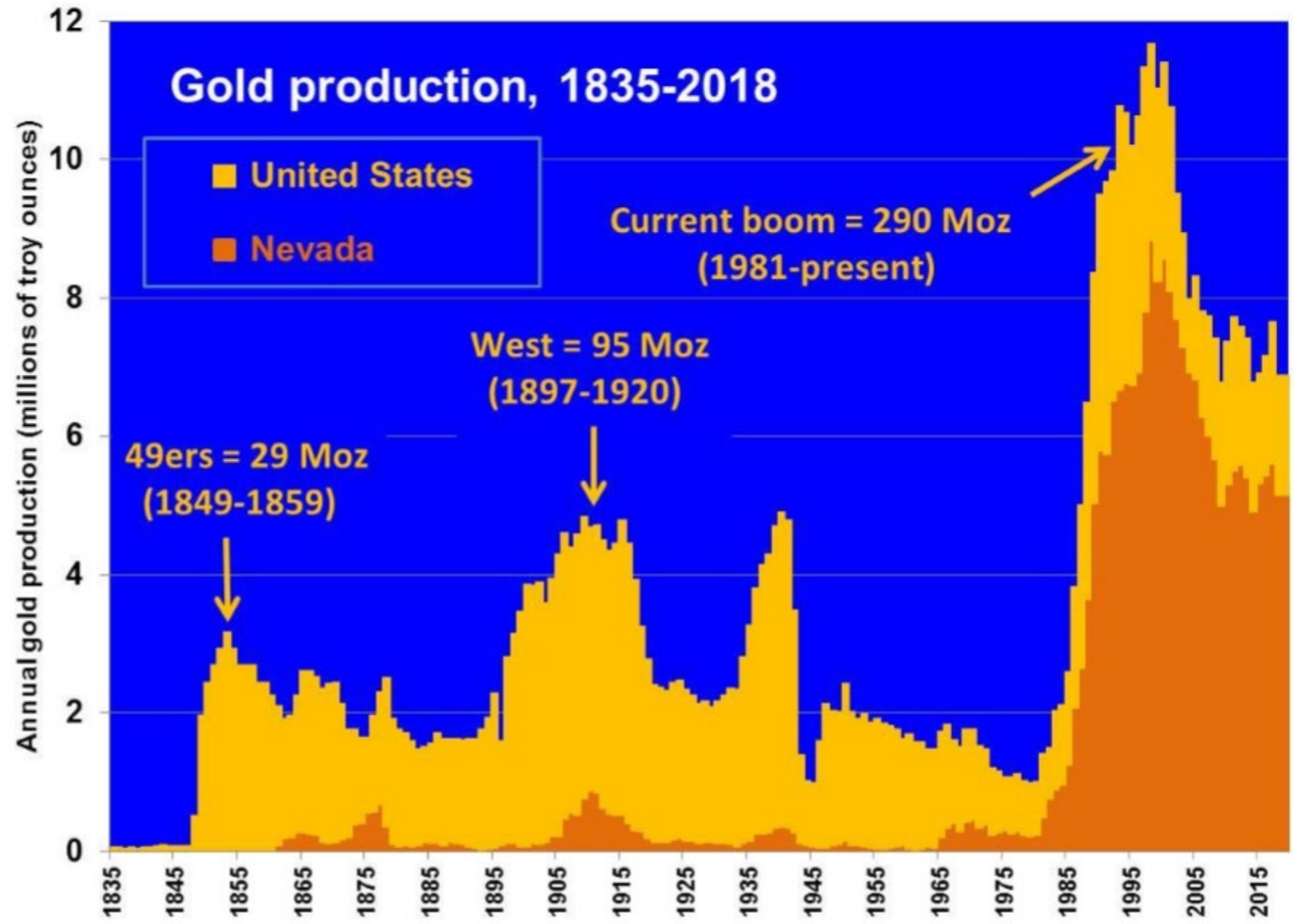


Newmont's Carlin East pit and portal, 2000



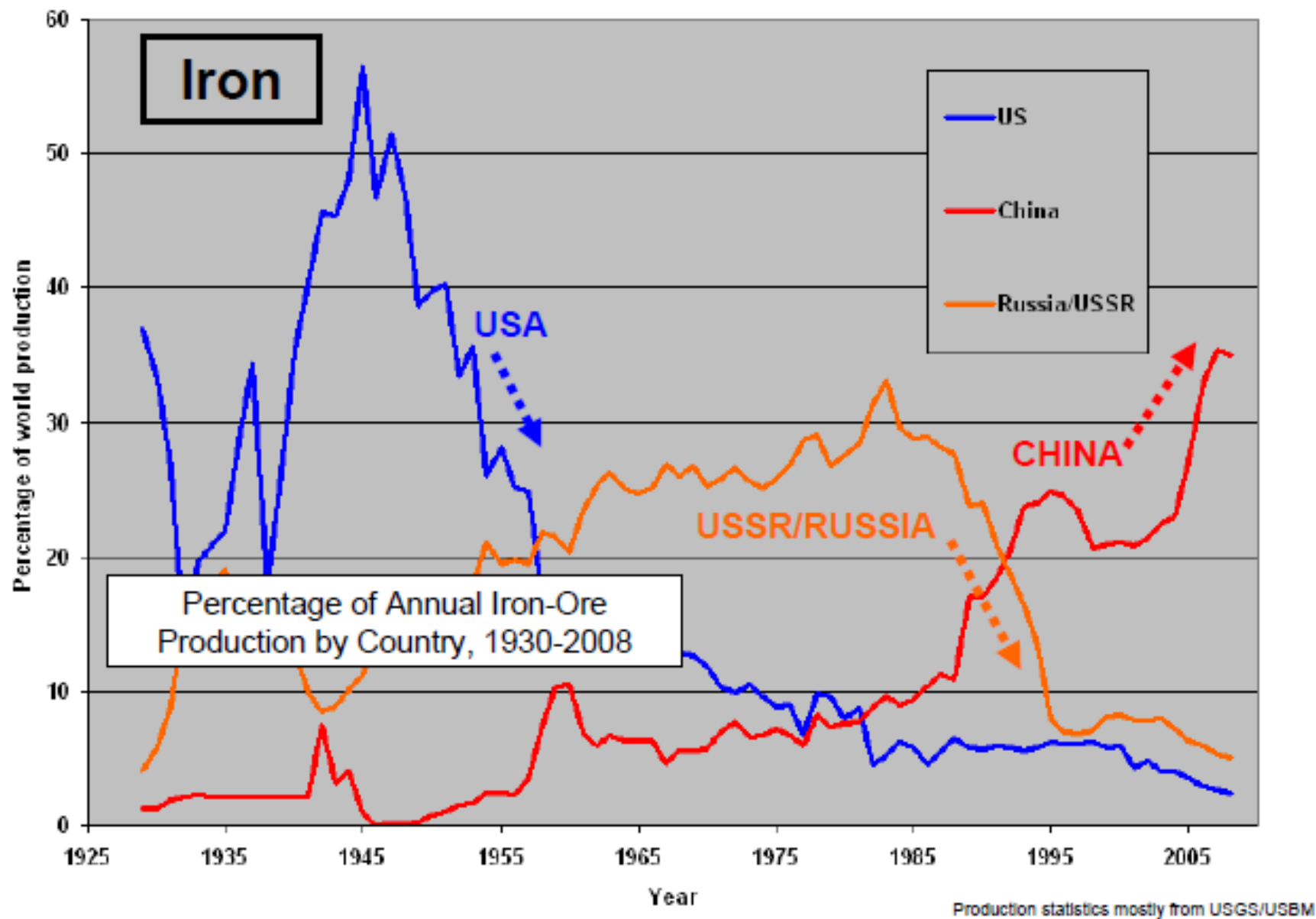
Global gold production in 2018 (3,260 metric tons) exceeded the cumulative production from the Carlin trend in Nevada (~3,000 tons), one of world's top regions.

Gold production, 1835-2018

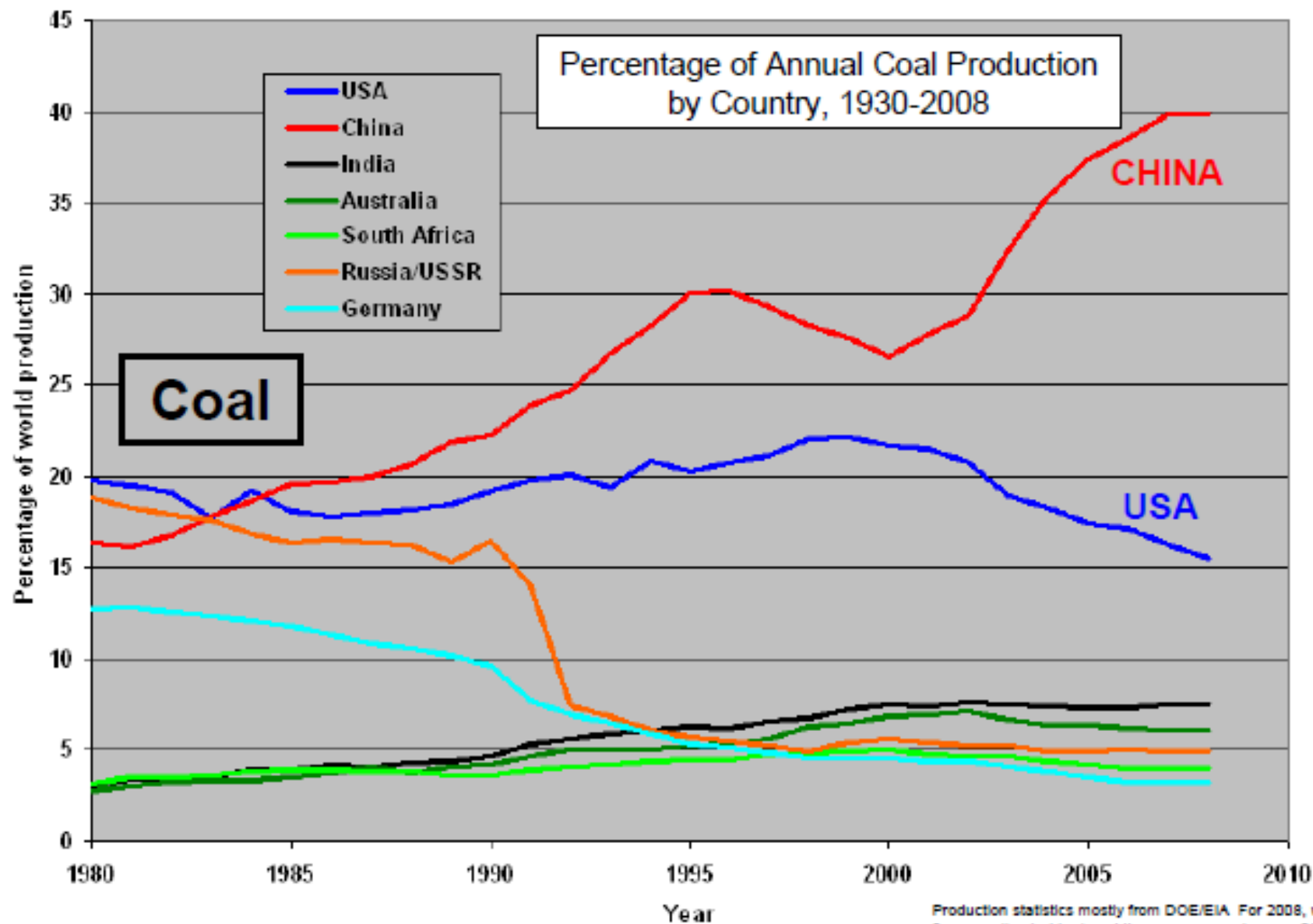


We are in the midst of the biggest gold-mining boom in history.

China has been #1 in iron-ore production since 1992.

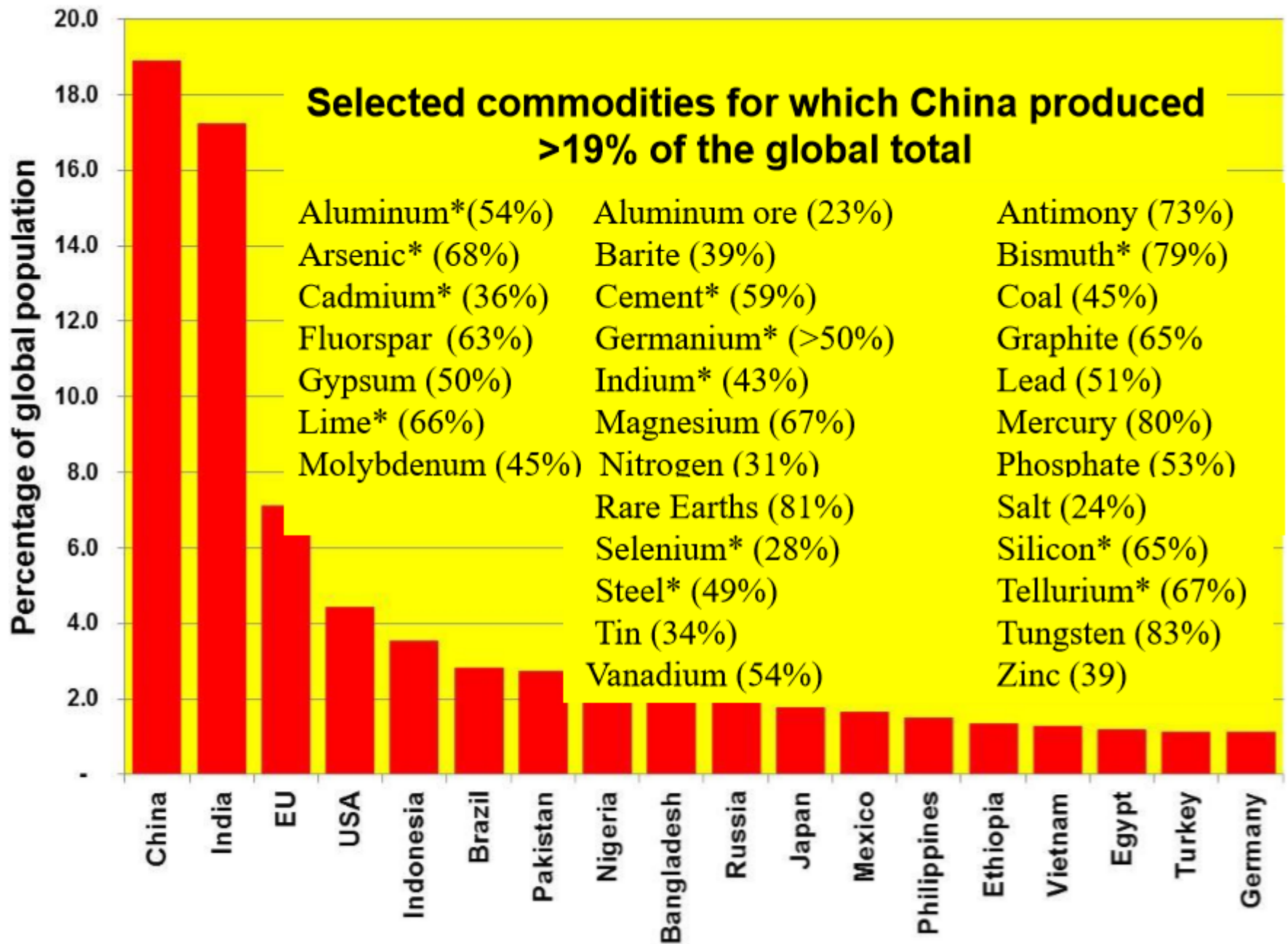


China has been #1 in coal production since 1985.



Production statistics mostly from DOE/EIA. For 2008, world coal figures estimated to rise at the same percentage as China.

Selected commodities for which China produced >19% of the global total



Data from USGS in 2017, except coal from IEA in 2016.

In production of 44 mineral commodities, China ranks well above all others.

Country	Number of commodities for which this country is the #1 producer	Number of commodities for which this country is among the top 3 producers
China	21	28
USA	4	11
South Africa	4	6
Australia	3	11
Chile	2	4
Congo	2	3
Russia	1	15
Canada	1	5
Kazakhstan	1	4
Brazil, Mexico, & Indonesia	1	2

The World Has Changed

For industry, the changes in the world are creating opportunities for:

exploration (domestically and worldwide, particularly in areas with potential for large deposits),

development and production (including new technologies for extracting metals from known deposits), and

sustainability (including the future of the environment, local and national economies, social and governmental stability, recycling, and substitutions of other minerals and products).



Round Mountain, NV (2007)

New deposit types are still being found – e.g., Carlin gold (1961), Olympic Dam copper-iron-gold, South Australia (1975), HREE in kaolinite-rich laterite developed on granites in China (2000s) – **and will be found in the future.**

We need to be thinking about ore-forming systems and future resources – USGS Professional Paper 820 (1973).

Some of the challenges in producing critical and strategic minerals



5 Dimensions of Mineral Availability

***WHAT** Questions Must We Ask?*

1

Geologic
Availability



✓ Does the mineral resource exist?

2

Technical
Availability



✓ Can we extract and process it?

3

**Environmental
& Social**
Availability



✓ Can we produce it in environmentally and socially responsible and acceptable ways?

4

Political
Availability



✓ How do governments influence availability through their policy and actions?

5

Economic
Availability



✓ Can we produce it at a cost users are willing and able to pay?

Limits on mineral resource availability

Are more about

- Costs
- Distribution
- Time frame

Than about tons

Some of the challenges in producing critical and strategic minerals

- How much of the minerals do we need?
- Are there enough materials in the pipeline to meet the demand for these technologies and other uses?
- Can any of these be recycled?
- Are there substitutions that can be used?
- Are these minerals environmental friendly—what are the reclamation challenges?
 - REE and Be are nearly always associated with U and Th and the wastes from mining REE and Be will have to accommodate radioactivity and radon

Additional challenges in producing these technologies

- Are any of these minerals “conflict minerals”, i.e. minerals that fall under the Conflict Minerals Trade Act (H.R. 4128)
 - Minerals that provide major revenue to armed fractions for violence, such as that occurring in the Democratic Republic of Congo (GSA, Nov. 2010)

- **Many critical elements are produced entirely as by-products of the refining of major metals**
 - **Tellurium (copper)**
 - **Indium & germanium (zinc)**
 - **Gallium (aluminum)**
 - **Rhenium (molybdenum)**
 - **Cobalt (copper, nickel)**
- **Prices are artificially low (economy of scope) until the co-production saturates**
- **By-product does not drive production of main product, even at high prices**
- **Price demand inelasticity**

Coproduction Issues - Rhenium

- Rhenium is produced as a by-product of molybdenum – there are no primary rhenium producers.
- It is used in producing specialty steels.

Rhenium

- Atomic number 75
- 0.05-1 ppb in crust
- combustion chambers, turbine blades, and exhaust nozzles of jet engines
- US \$4,575 per kg (2011)
- By-product of molybdenum and copper production
- Found in molybdenite

Salient Statistics—United States:

	<u>2014</u>	<u>2015</u>	<u>2016</u>	<u>2017</u>	<u>2018^e</u>
Production ¹	8,510	7,900	8,440	8,200	8,300
Imports for consumption ²	25,000	31,800	31,900	34,500	42,000
Exports	NA	NA	NA	NA	NA
Consumption, apparent ³	33,500	39,700	40,300	42,700	51,000
Price, average value, dollars per kilogram, gross weight: ⁴					
Metal pellets, 99.99% pure	2,980	2,670	2,030	1,550	1,500
Ammonium perrhenate	3,080	2,820	2,510	1,530	1,400
Employment, number	Small	Small	Small	Small	Small
Net import reliance ⁵ as a percentage of apparent consumption	75	80	79	81	84

World Mine Production and Reserves: The reserves estimate for the United States was revised based on company reports.

	Mine production⁶		Reserves⁷
	<u>2017</u>	<u>2018^e</u>	
United States	8,200	8,300	400,000
Armenia	300	260	95,000
Canada	—	—	32,000
Chile ⁸	27,000	27,000	1,300,000
China	2,500	2,500	NA
Kazakhstan	1,000	1,200	190,000
Peru	—	—	45,000
Poland	9,300	9,300	NA
Russia	NA	NA	310,000
Uzbekistan	460	500	NA
World total (rounded)	<u>48,800</u>	<u>49,000</u>	<u>2,400,000</u>

- Rhenium changes the phase structure in complex alloys, allowing turbine blades to operate longer at higher temperatures ($>1600^{\circ}\text{C}$) and pressures without deformation
- General Electric discovered that sufficient Re (by-product of molybdenum production) for mass produced turbines might not be available (or extremely expensive).



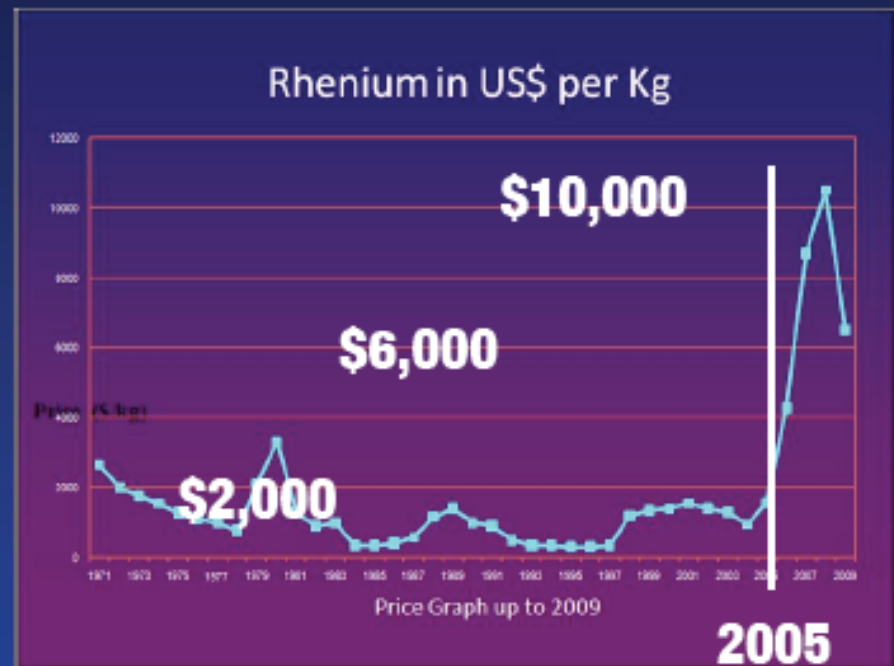
~25 kg Re per
gas turbine

General Electric's Rhenium Story

GE launched a two pronged approach in 2005:

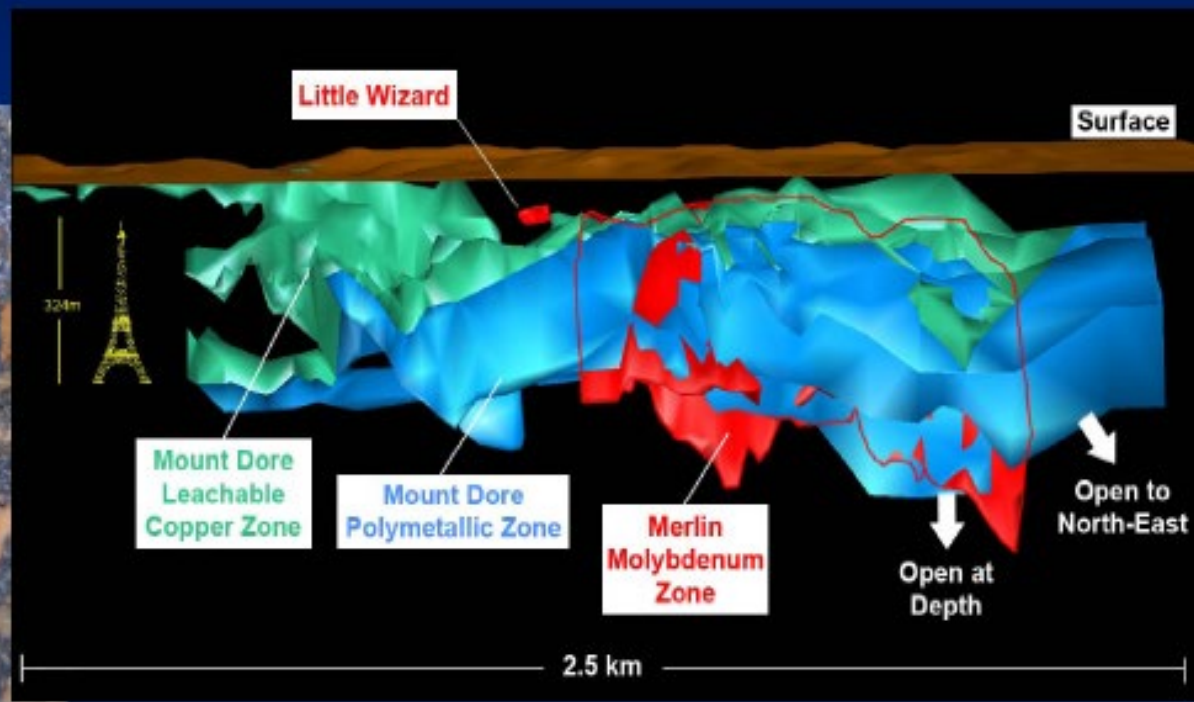
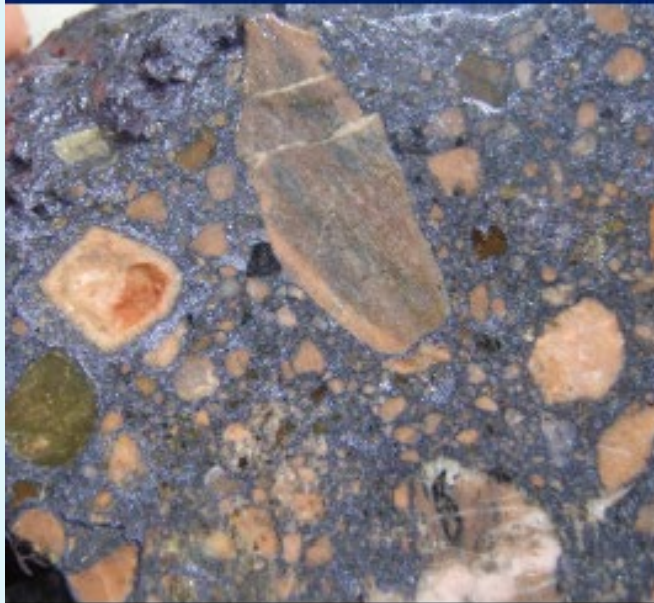
- Recycle pre-consumer scrap to forestall shortage (new supply)
- Develop new alloys with low (zero?) Re (substitution)
- Had success over 5 years*

* Fink, P.J., Miller, J.L., and Konitzer, D.G., 2010, J. Minerals Metals Mater. Soc. 62, 57.



Is there really a shortage of Rhenium?

- Serendipity recently resulted in the discovery of a new type of super high grade moly deposit with a high Re content.
- Merlin, Australia (6.7 Mt @1.34% Mo, 23.2 g/t Re)
- Discovery of additional deposits (if we can develop a geological model for the deposits) should ease fears of Re supply.



MINING'S INFLUENCE IN HISTORIC CULTURES



Arrowhead clipart from www.firstpeople.us

Critical and strategic minerals will change with time.



Avatar



Importance of minerals

- Mining began with prehistoric man who wanted to improve their way of life
- Ancient cultures often settled time after time around areas that provided raw materials
- 300,000-100,000 years ago mining of flint in N France and S England
- Throughout history, wars were fought over natural resources

Important Cultural Eras

- Stone Age (prior to 4000 B.C.)
- Bronze Age (4000 to 5000 B.C.)
- Iron Age (1500 B.C. to 1780 C.E.)
- Steel Age (1780 to 1945)
- Nuclear Age (1945 to the present)

- **Early civilisations:** fundamental importance of nonfuel minerals, metals, and materials technology and applications.
 - Stone Age, Copper Age, Bronze Age, Iron Age
 - Discovery of metals: **innovations and applications**
 - Gold (6000 BC), copper (4200 BC), silver (4000 BC), lead (3500 BC), tin (1750 BC), iron (1500 BC), mercury (750 BC)
- **Information Age:** developments in materials science and engineering, mineral exploration, and processing continue to enable and support the development of new technologies

Table 1.1.1. Chronology of Events Related to Mining

Period—Stage	Near East—Mediterranean—Africa	Central and Northern Europe and Great Britain	North and South America	Australasia
BC				c. 500,000 Use of fire (China)
Paleolithic		300,000–100,000 Surface mining of flint (N. France, S. England)		
c. 20,000	c. 40,000 Hematite mined for ritual painting (Africa)	c. 30,000 Use of fire, lamps, cave art, hunting with projectiles		
Late Paleolithic		End of Ice Age		
	c. 9500 Copper pendant. (Iraq)	c. 10,000 Gold ornaments		

Mining Engineering Handbook

When was the first mine?

Certainly after
agriculture????

How would you find the answer to this question?

When was the first mine?

- Prehistoric man used chert and flint as tools 450,000 years ago
- Nazlet Khater 4 site, Nile Valley, Upper Egypt 33,000 yr
- British flint quarries
- Krzemionki Opatowskie, Southern Poland
 - Upper Palaeolithic
 - Middle and Neolithic (4500 B.C.)
 - Early Bronze Age

When was the first underground mine?

- Bomvu Ridge, Swaziland
- Hematite
- 40,000 years old
- crude methods of ground control, ventilation, haulage, hoisting, lighting, and rock breakage

Krzemionki

Opatowskie, Southern Poland

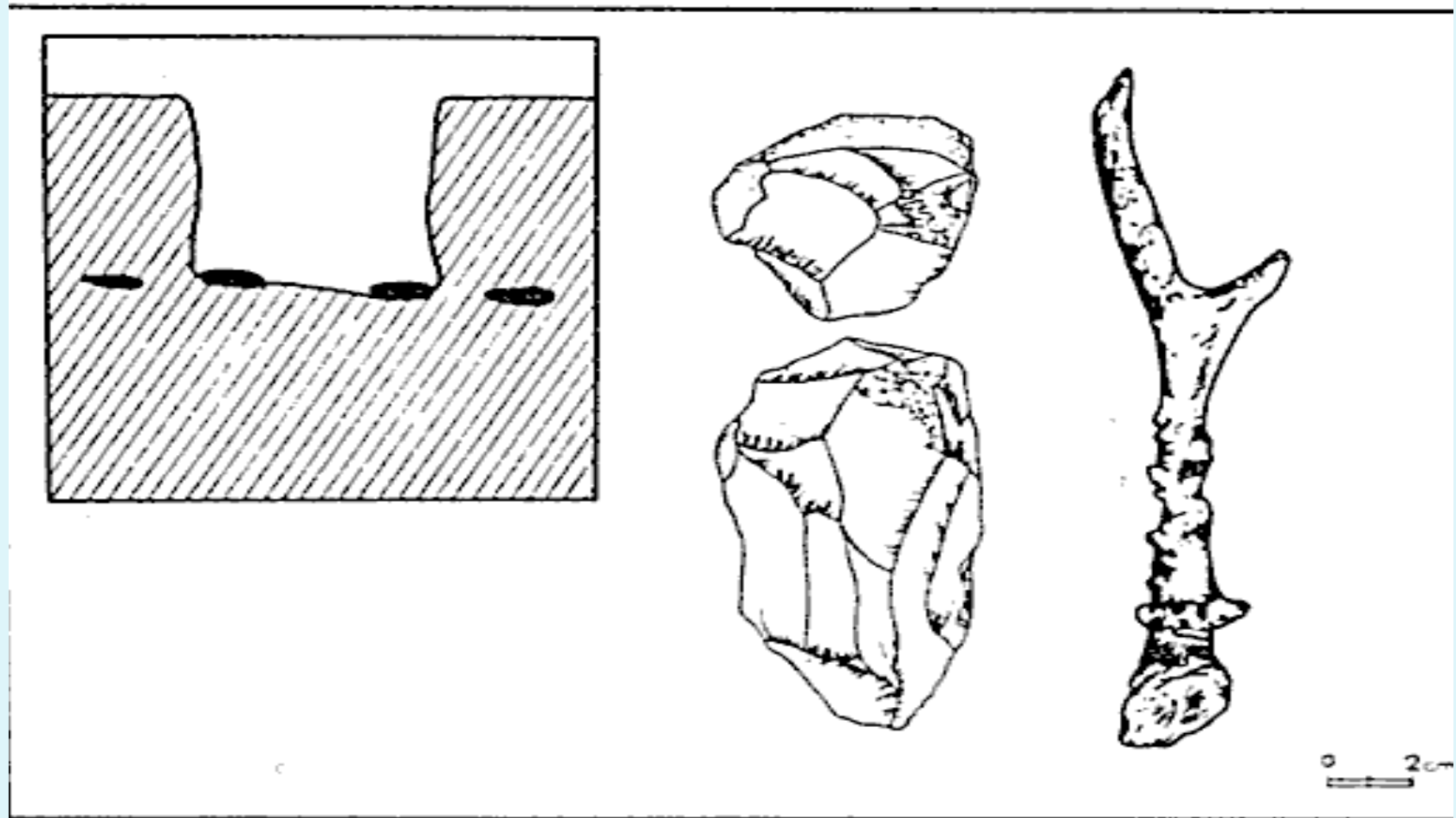


Fig. 1. From the left: scheme of a pit-mine, miner tools.

Krzemionki

Opatowskie, Southern Poland



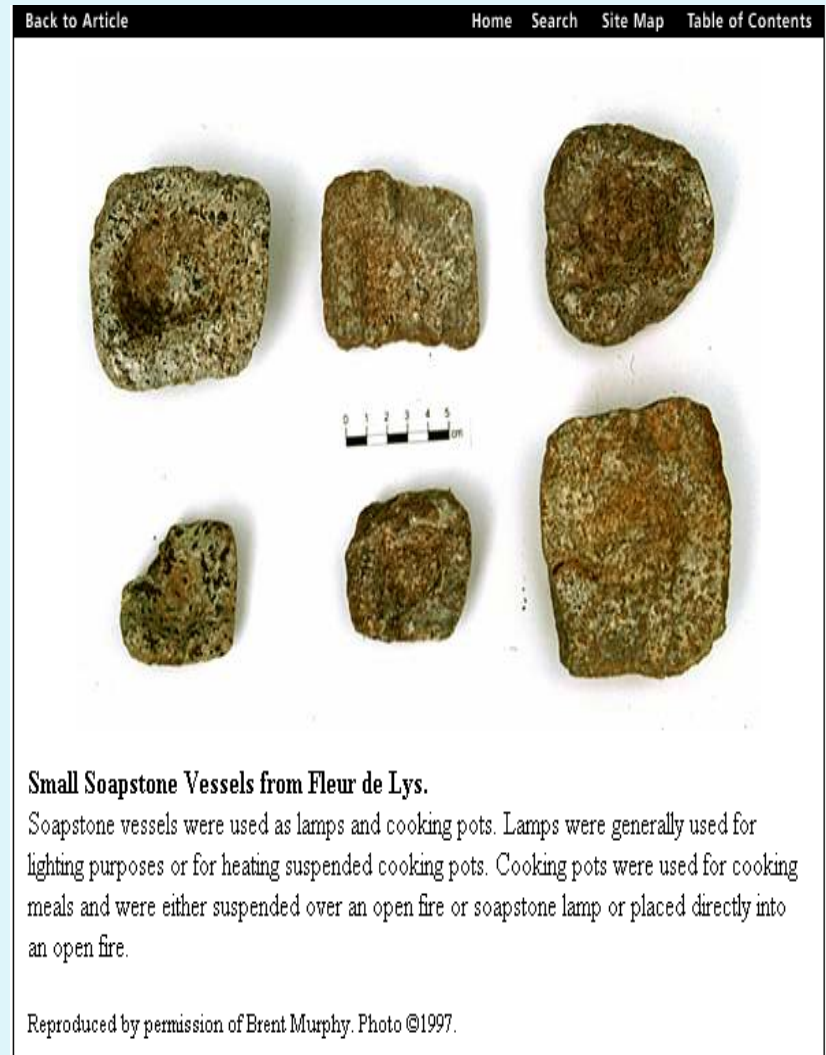
Photo 22. Widok kopalni filarowej.



Photo 26. Widok kopalni filarowej.

When was the first mine?

- Prehistoric man used soapstone
- Fleur de Lys quarry, Newfoundland
- Maritime Archaic peoples used it approximately 4,000 years ago



Old Testament recognized the land of Ophir (Zimbabwe), which was somewhere in Africa, as a source of gold

African mining sites

- Zimbabwe 20,000 to 26,000 BC
- Swaziland 50,000 BC

Other uses of minerals in ancient societies

- Egyptians replaced water clocks with sand hour glasses
- Greek and Romans made concrete-like structures that are still standing today
- Building stones used in many ancient cultures

Lets look at a commodity in
more detail

SALT

- NaCl
- table salt
- essential to life (man 2-5 gr/day)
- salt was used as a preservative, tanning leather, stock, mining
- salt was used to preserve Egyptian mummies



SALT

- Trade in salt was very important; salt was valuable enough to be used as currency in some areas.
 - Salt cakes
- The Latin phrase "salarium argentum," "salt money," referred to part of the payment made to Roman soldiers.
- <http://www-geology.ucdavis.edu/~gel115/salt.html>

- Greek worshippers consecrated salt in their rituals
- in the Old and New Testaments, covenants were sealed with salt
- Jewish "KASHRUT" [hygiene] tradition and law, involves the dehydration of meat for its preservation
- Catholic Church used salt in purifying rituals
- Buddhist believed salt repels evil spirits
- Pueblo people worship the Salt Mother



Blocks of pure salt cut from the earth sit stacked in rows awaiting carriers in Taoudenni, as a miner removes earth from his pit mine.



Caravans across the Sahara basin carrying salt across the desert to the trading centers of Karta, Bambara, Cairo and Timbuktu.

<http://www.cheethamsalt.com.au/>

Salt Harvesting at Geelong in the 1920's



Salt is harvested manually by shovels.....



and lifted onto conveyer belts.....

Mining salt
in 1920s at
The
Cheetham
Salt mine,
Australia

[http://www.cheethams
alt.com.au/](http://www.cheethamsalt.com.au/)

The star of David used to crystallise salt in salt pans in Mexico, La Concordia - from "Maya Salt Production and Trade - Antony P. Andrews " courtesy Gertrude Blom.



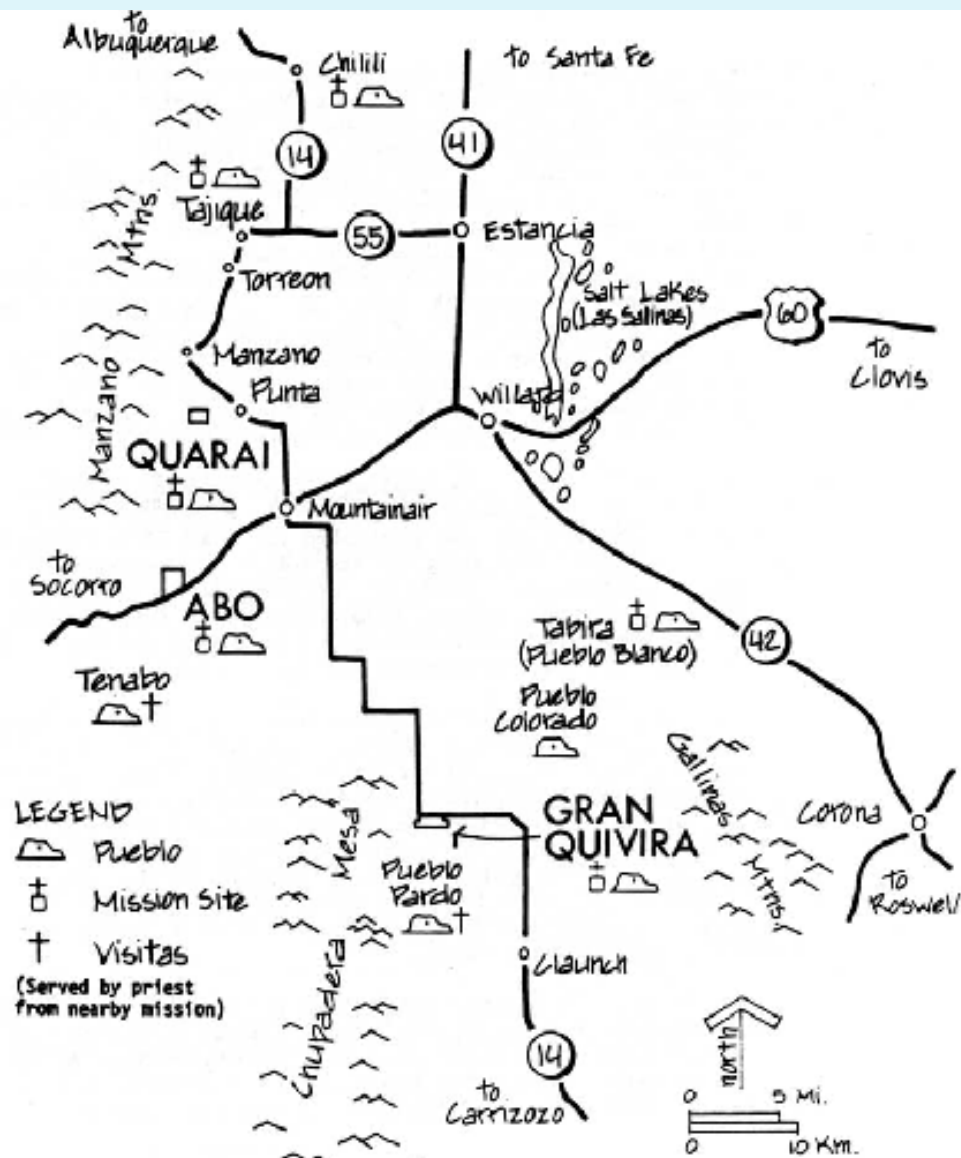
http://salt.org.il/frame_rel.html

Salt in Austria

- Heilbad Durnnberg
- 750-150 BC
- 200 people worked the deposits
- wealth of this small settlement is clearly evidenced by the clusters of graves which surrounded the various rectangular houses

Estancia Basin in central New Mexico

- Salt basin, few areas with edible salt
- central to Indian Pueblos—Abo, Gran Quivira, Salinas, a total of 10 Piro pueblos
- important in trade by 13th century
- Spanish conquest, built churches, and demanded more salt
- Spanish shipped salt to Mexico for use in processing silver



the salinas basin

SALINAS NATIONAL MONUMENT • NEW MEXICO
 U.S. DEPT. OF THE INTERIOR • NATIONAL PARK SERVICE

313/80.017
 SEPT. 83/SWRD

<http://www.nps.gov/sapu/hsr/fig1.jpg>

Salt and Silver Processing

- Patio process developed in 1557 in Pachuca, Hidalgo, Mexico
- silver ores crushed in arrastras to a fine slime
- mixed with salt, water, copper sulfate, mercury
- spread onto a patio and allowed to dry in the sun
- silver could then amalgamate with mercury and thus be recovered

End of an Era

- by the late 1670s the entire Salinas District, as the Spanish had named it, was depopulated
 - Apache raids increased
 - Famine
 - Poor harvests
 - Pueblo revolt in 1680

Salient Statistics—United States:¹

	<u>2014</u>	<u>2015</u>	<u>2016</u>	<u>2017</u>	<u>2018^e</u>
Production	45,300	45,100	41,700	^e 40,000	42,000
Sold or used by producers	46,000	42,800	40,200	^e 38,000	41,000
Imports for consumption	20,200	21,600	12,100	12,600	17,000
Exports	935	830	716	1,120	950
Consumption:					
Apparent ²	65,300	63,600	51,600	^e 49,000	57,000
Reported	55,600	52,300	48,400	^e 48,000	51,000
Price, average value of bulk, pellets and packaged salt, dollars per ton, f.o.b. mine and plant:					
Vacuum and open pan salt	180.61	188.87	197.78	^e 200.00	200.00
Solar salt	75.35	102.04	99.69	^e 100.00	100.00
Rock salt	48.11	56.32	56.74	^e 55.00	58.00
Salt in brine	9.08	10.27	8.29	^e 10.00	10.00
Employment, mine and plant, number ^e	4,200	4,200	4,000	4,100	4,100
Net import reliance ³ as a percentage of apparent consumption	29	33	22	23	28

Recycling: None.**World Production and Reserves:**

	<u>Mine Production^e</u>	
	<u>2017</u>	<u>2018</u>
United States ¹	40,000	42,000
Australia	11,000	12,000
Austria	4,600	4,600
Brazil	7,400	7,500
Canada	12,000	13,000
Chile	8,500	9,500
China	67,000	68,000
France	4,500	4,500
Germany	13,000	13,000
India	28,000	29,000
Mexico	9,000	9,000
Netherlands	6,940	7,000
Pakistan	3,600	3,600
Poland	4,450	4,500
Russia	5,800	5,800
Spain	4,500	4,500
Turkey	5,500	5,500
United Kingdom	5,100	5,100
Other countries	<u>47,200</u>	<u>47,000</u>
World total (rounded)	288,000	300,000

Reserves⁴

Large. Economic and subeconomic deposits of salt are substantial in principal salt-producing countries. The oceans contain a virtually inexhaustible supply of salt.

Is salt a critical/strategic mineral?

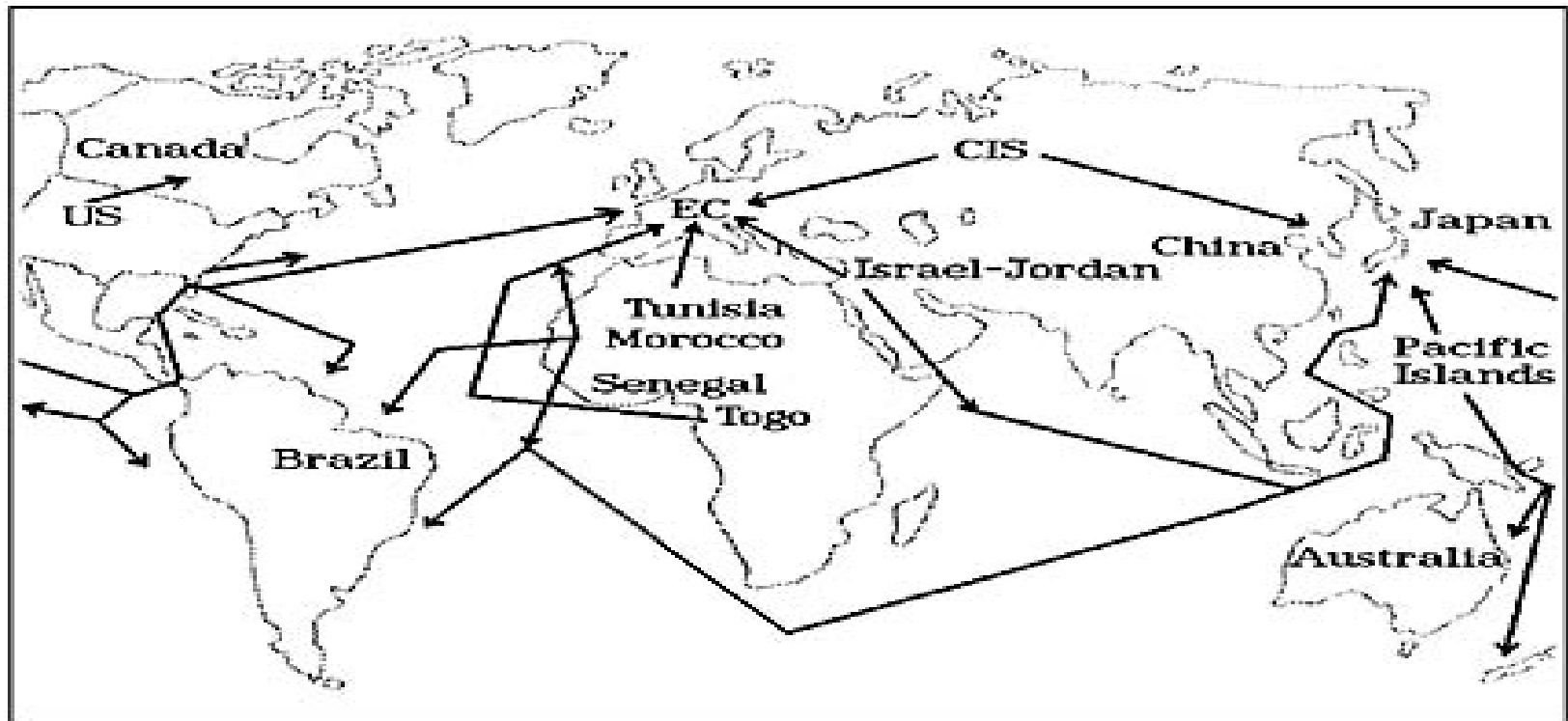
What has changed from Prehistoric times to today?

Need for more commodities

Technology

Global market

Fig. 1. Trade patterns in phosphate rock.



Environmental concerns

Mineral availability

Long term mineral availability (>10 Yr)

- Geologic (does the mineral resource exist)
- Technical (can we extract and process it)
- Environmental and social (can we mine and process it in environmentally and socially acceptable ways)
- Political (how does politics influence)
- Economic (can we mine and produce it at a cost the markets will pay)

Short- and medium-term availability

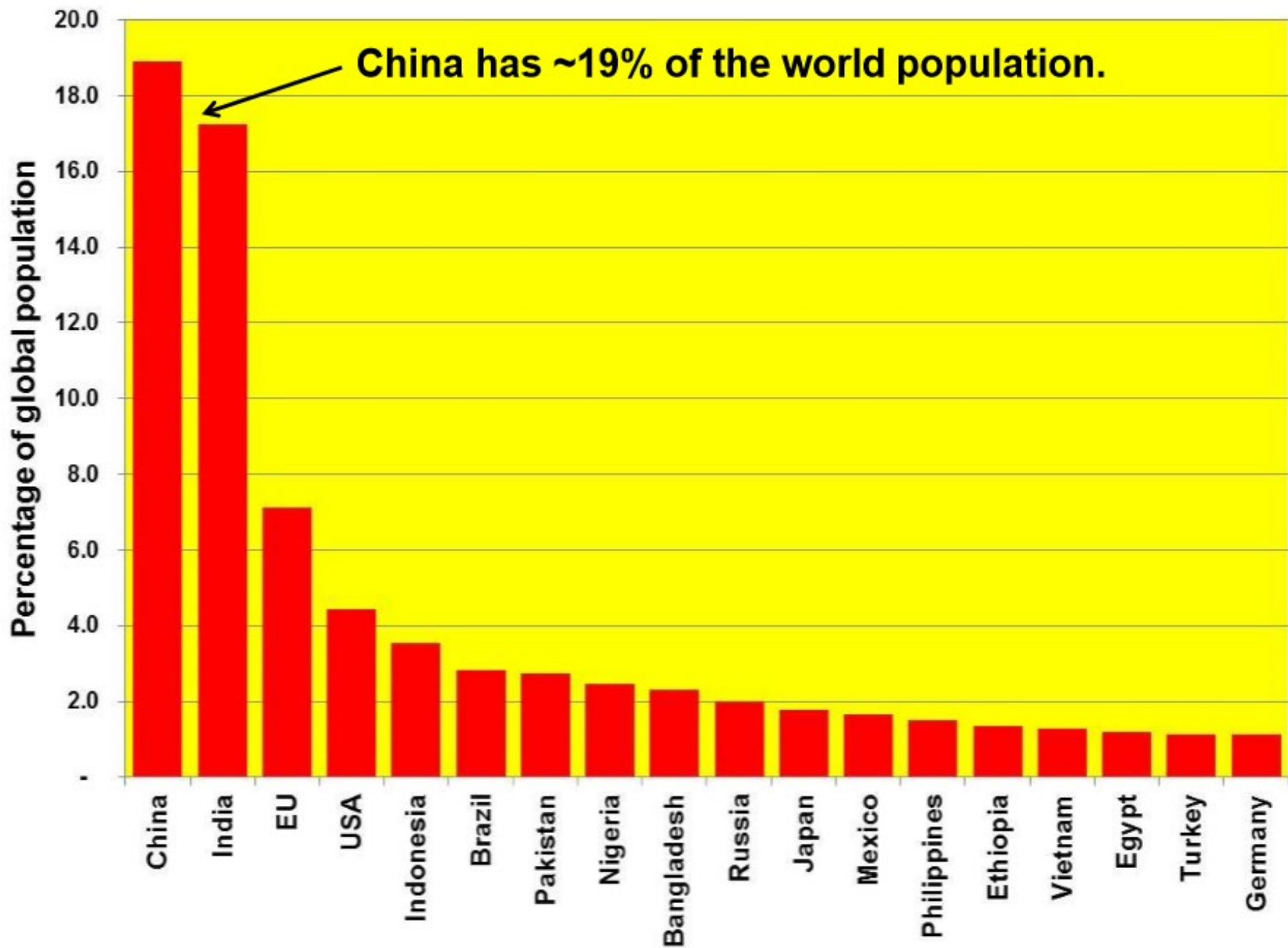
- Significant or unexpected increase in demand
- Small markets
- Production from a small number of mines, companies, or markets
- Minerals whose supply consist significant of byproduct production (i.e. Ga byproduct of bauxite mining)
- Markets for which there is no significant recovery from old scrap

Global challenges

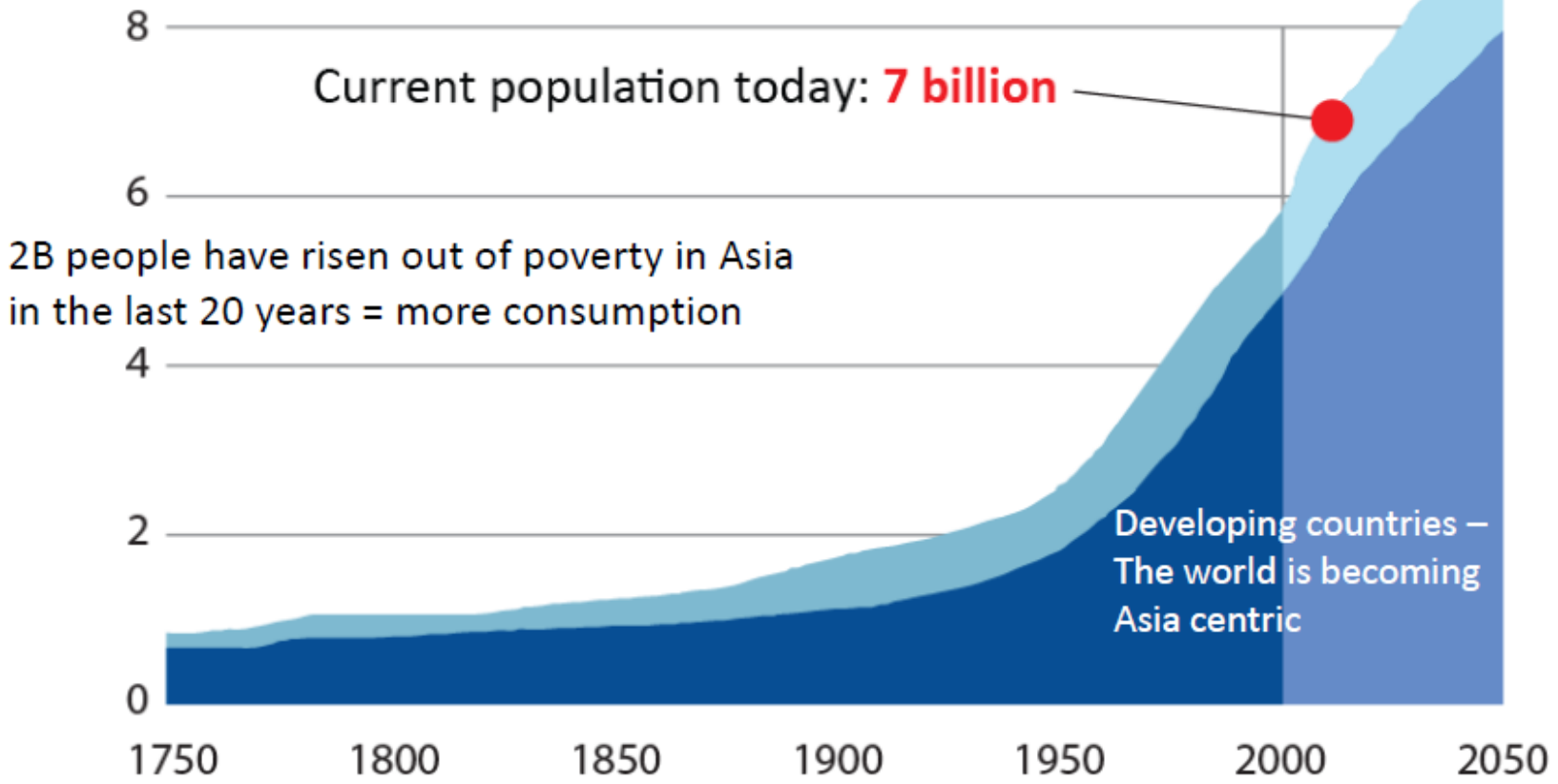
- The small volumes of strategic/critical minerals utilized makes them price sensitive
- New producers need a reliable, long-term buyer
- Long-term buyers require a fixed price, but operating costs are variable
- Monopolies/oligopolies can drive out marginal producers by over-supplying the market until the competition is eliminated

Other factors

- Population
- Food

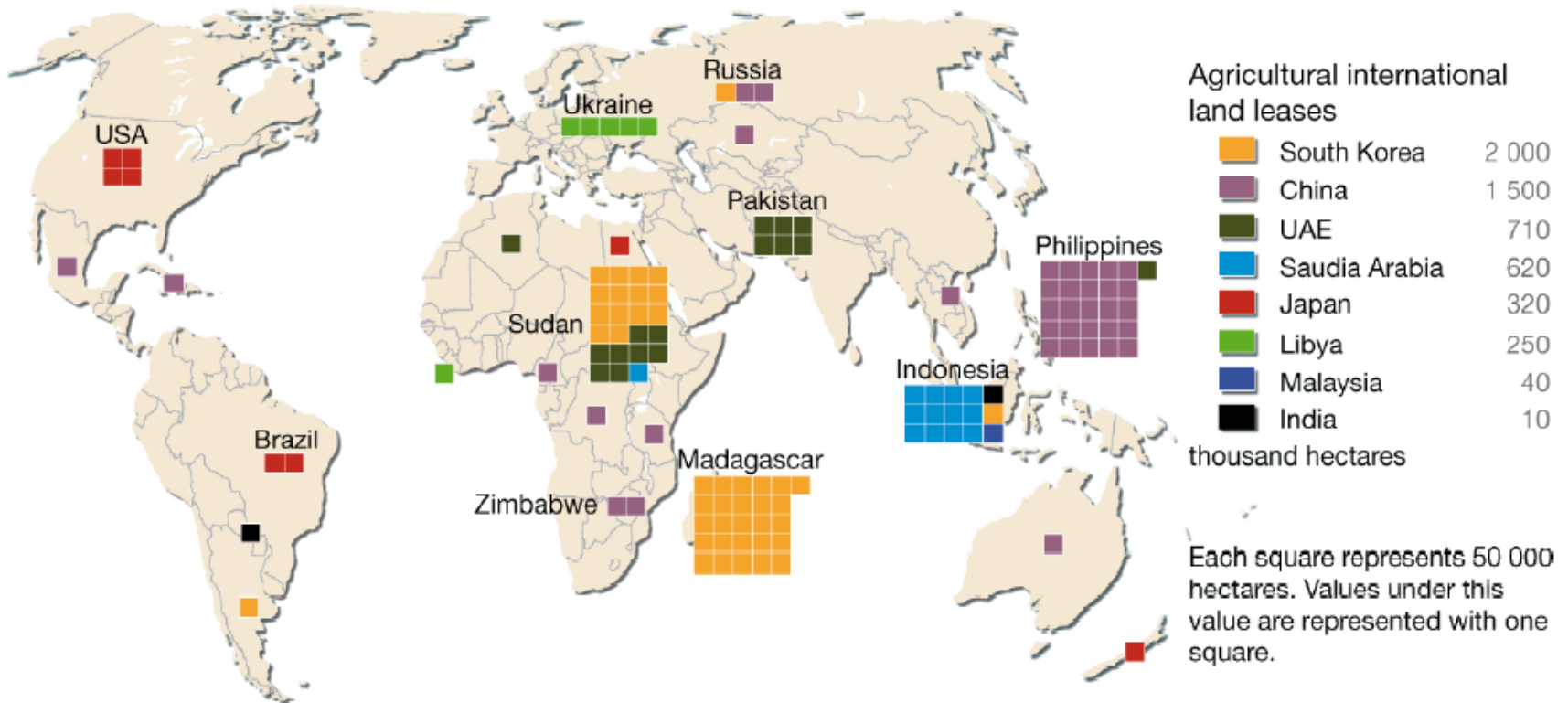


Global population,
estimates and projections (billions)



UNEP

Food Security



UNEP

What minerals are considered critical and strategic minerals?

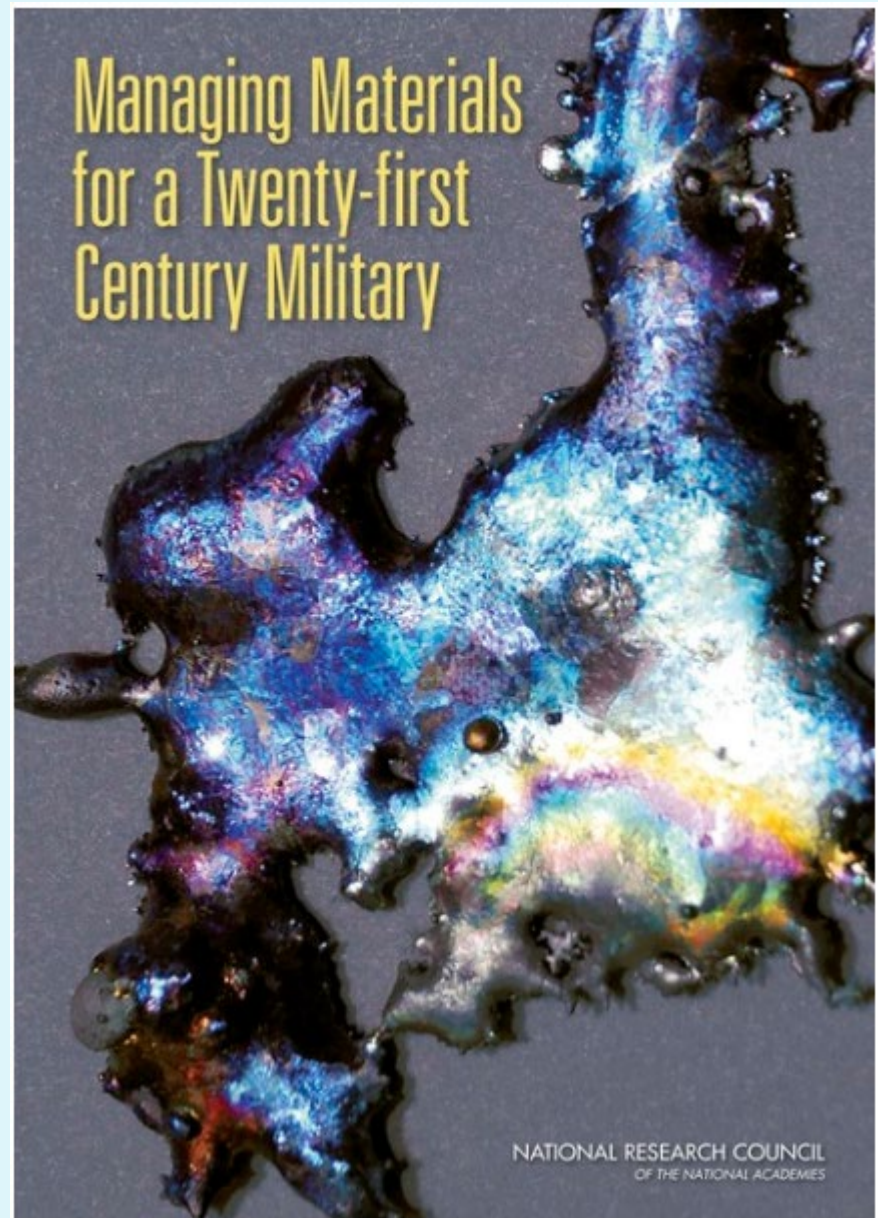
Certainly petroleum!

But it is not on the list

Why?

DOD

- REE
- U
- Be
- Cr
- Co
- Mn
- Ge
- PGM
- Ta
- Sn
- W
- Zn
- Al
- Bi
- B
- Cd
- Cu
- F
- Ga
- Hf
- In
- Pb



http://www.nap.edu/catalog.php?record_id=12028

Strategic and critical minerals for the U.S. (Long, 2009; Long et al., 2010)

- Antimony
- Barite
- Chromite
- Cobalt
- Fluorite
- Gallium
- Graphite
- Indium
- PGE (platinum group elements)
- REE (rare earth elements)
- Rhenium
- Tantalum
- Titanium
- Tungsten
- Yttrium
- Niobium

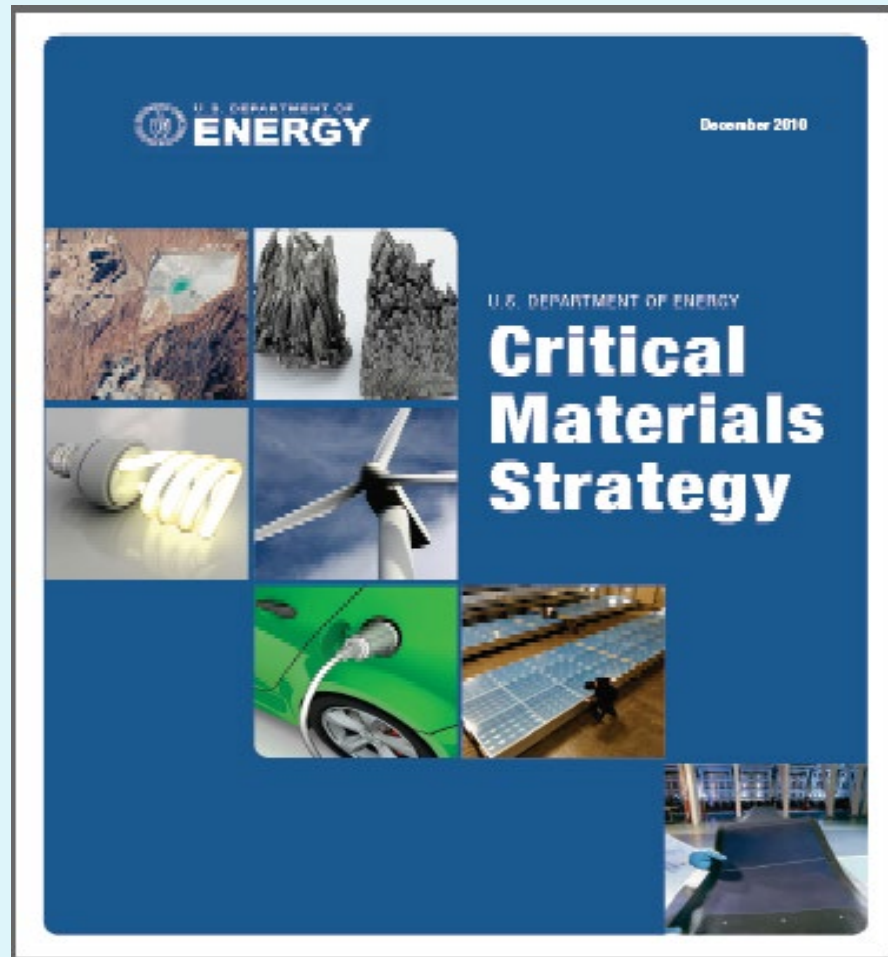
Green minor metals—basis for cleaner technology innovation

- Indium
- Germanium
- Tantalum
- PGM
- Tellurium
- Cobalt
- Lithium
- Gallium
- REE



Minerals required for clean energy technologies

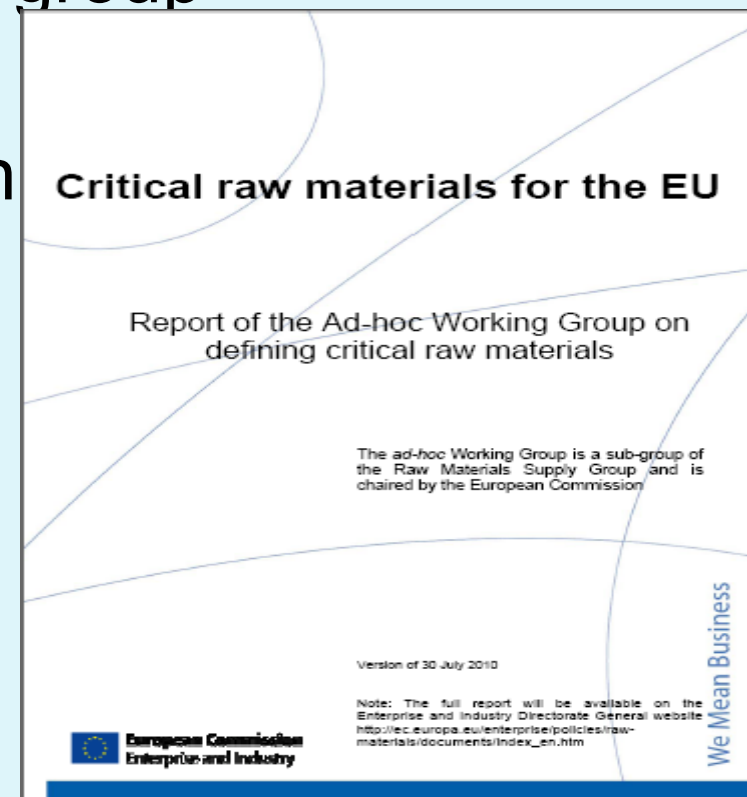
- Lithium
- Cobalt
- Gallium
- REE, Y
- Indium
- Tellurium



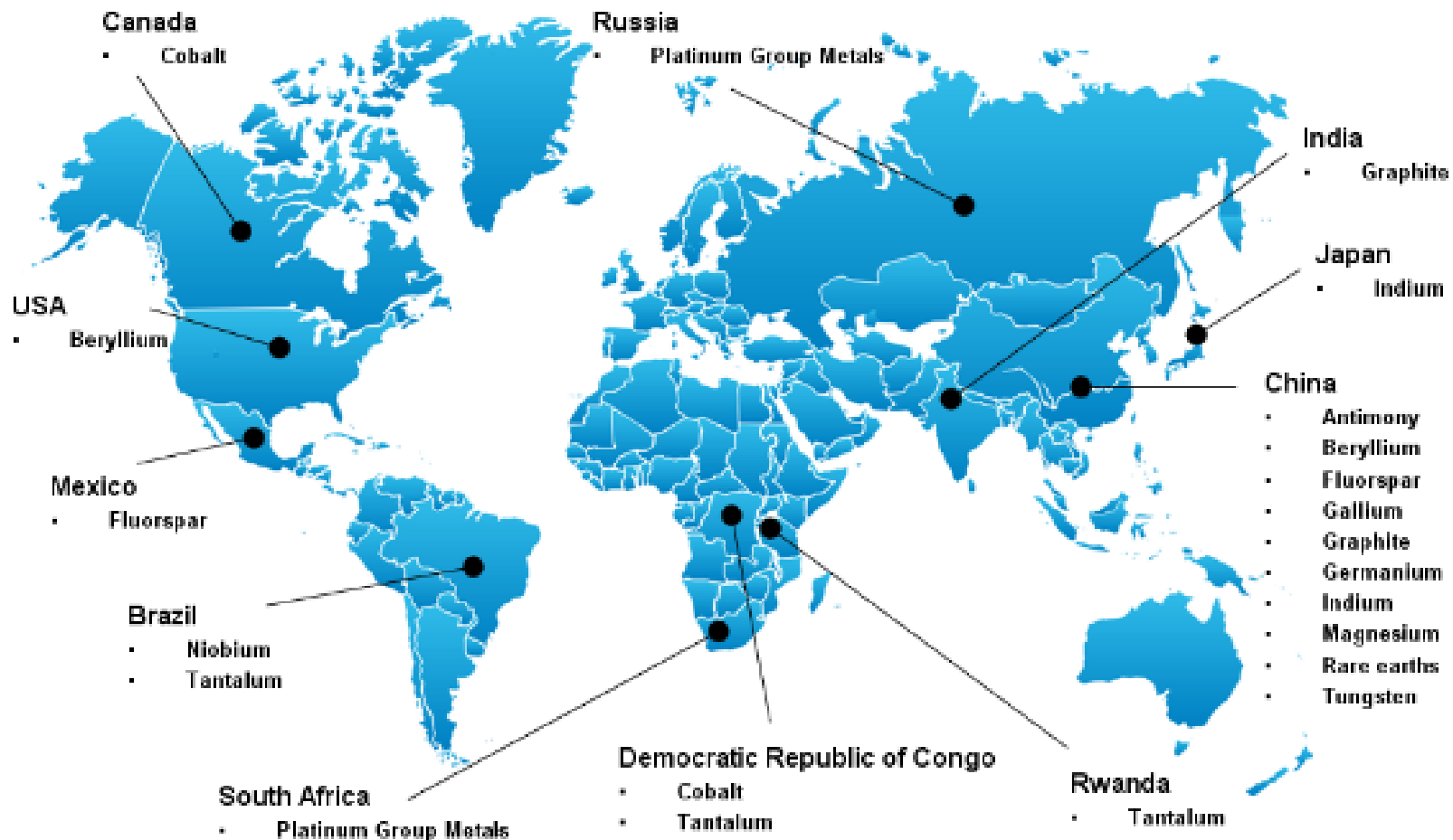
<http://www.energy.gov/news/documents/criticalmaterialsstrategy.pdf>

Strategic minerals for the European Union

- Antimony
- Beryllium
- Cobalt
- Fluorspar
- Gallium
- Germanium
- Graphite
- Indium
- Magnesium
- Niobium
- PGM (platinum group metals)
- REE (rare earth elements)
- Tantalum
- Tungsten



Production concentration of critical raw mineral materials



http://europa.eu/rapid/press-release_MEMO-10-263_en.htm?locale=en

Raw material	Production 2006 (t)	Demand from emerging technologies 2006 (t)	Demand from emerging technologies 2030 (t)	Indicator1) 2006	Indicator1) 2030
Gallium	152 6)	28	603	0,18	3,97
Indium	581	234	1.911	0,40	3,29
Germanium	100	28	220	0,28	2,20
Neodymium (rare earth)	16.800	4.000	27.900	0,23	1,66
Platinum (PGM)	255	very small	345	0	1,35
Tantalum	1.384	551	1.410	0,40	1,02
Silver	19.051	5.342	15.823	0,28	0,83
Cobalt	62.279	12.820	26.860	0,21	0,43
Palladium (PGM)	267	23	77	0,09	0,29
Titanium	7.211.000 2)	15.397	58.148	0,08	0,29
Copper	15.093.000	1.410.000	3.696.070	0,09	0,24

http://europa.eu/rapid/press-release_MEMO-10-263_en.htm?locale=en

Critical Minerals 2018

- Aluminum (bauxite), used in almost all sectors of the economy
- Antimony, used in batteries and flame retardants
- Arsenic, used in lumber preservatives, pesticides, and semi-conductors
- Barite, used in cement and petroleum industries
- Beryllium, used as an alloying agent in aerospace and defense industries
- Bismuth, used in medical and atomic research
- Cesium, used in research and development
- Chromium, used primarily in stainless steel and other alloys
- Cobalt, used in rechargeable batteries and superalloys
- Fluorspar, used in the manufacture of aluminum, gasoline, and uranium fuel
- Gallium, used for integrated circuits and optical devices like LEDs
- Germanium, used for fiber optics and night vision applications
- Graphite (natural), used for lubricants, batteries, and fuel cells
- Hafnium, used for nuclear control rods, alloys, and high-temperature ceramics
- Helium, used for MRIs, lifting agent, and research
- Indium, mostly used in LCD screens
- Lithium, used primarily for batteries

Critical Minerals 2018

- Magnesium, used in furnace linings for manufacturing steel and ceramics
- Manganese, used in steelmaking
- Niobium, used mostly in steel alloys
- Platinum group metals, used for catalytic agents
- Potash, primarily used as a fertilizer
- Rare earth elements group, primarily used in batteries and electronics
- Rhenium, used for lead-free gasoline and superalloys
- Rubidium, used for research and development in electronics
- Scandium, used for alloys and fuel cells
- Strontium, used for pyrotechnics and ceramic magnets
- Tantalum, used in electronic components, mostly capacitors
- Tellurium, used in steelmaking and solar cells
- Tin, used as protective coatings and alloys for steel
- Titanium, overwhelmingly used as a white pigment or metal alloys
- Tungsten, primarily used to make wear-resistant metals
- Uranium, mostly used for nuclear fuel
- Vanadium, primarily used for titanium alloys
- Zirconium, used in the high-temperature ceramics industries

Assignment

- Mineral deposit models (Cox and Singer, 1986, <http://pubs.usgs.gov/bul/b1693/Tlbc.pdf>)
- The classification of ore deposits (Noble, 1955)
- Principles of a resource/reserve classification for minerals
(<http://pubs.usgs.gov/circ/1980/0831/report.pdf>)
- NATIONAL INSTRUMENT 43-101, *STANDARDS OF DISCLOSURE FOR MINERAL PROJECTS*
(http://web.cim.org/standards/documents/Block484_Doc111.pdf)