CRITICAL ELEMENTS FOR ENERGY

Elisabeth M. Price & Jonathan G. Price, Nevada Mining Association's Education Committee, updated 3 November 2023

Using the periodic table and data on uses, production, and prices of the elements.

INTRODUCTION

The periodic table of the elements summarizes information about the properties of elements, including the physical states and chemical reactivity. This brief activity encourages the student to use the periodic table to discover the locations of elements and the symbols of those important to "green" energy (defined as energy produced from renewable sources or energy produced with little or no emission of carbon dioxide).

OBJECTIVE

Students will survey the periodic table to find elements important for transportation, heating, and the generation, transmission, and storage of electricity; examine the properties of the elements; and look for patterns in the properties, as reflected in patterns of the periodic table. Students will discuss global sources for the elements and the projected amounts needed for society.

MATERIALS

- One large copy of the periodic table per group (or use the individual periodic table found on the web).
    - Table should show state of matter, chemical symbol, and chemical name.
- Table (included in this file) labeled "Critical Elements for Energy Technologies" (alternatively, use the latest edition of the U.S. Geological Survey's Mineral Commodity Summaries, available online at http://minerals.usgs.gov/minerals/). The table lists countries that are the major sources of the elements and how they are used in energy technologies.
- World map to place symbols for elements produced in leading countries (examples are included in this file).
- Small adhesive dots or post-it strips (on which to write element symbols) to place onto world map (alternatively, use a pencil and write the chemical symbols on the blank world map; alternatively, project the map on the classroom board and write symbols there with erasable markers). Also use these post-it strips to write the electric energy production approach (fossil fuels, hydro, solar, wind, geothermal, nuclear, biomass, tidal) and post these on the periodic table for each element needed for this approach.

PROCEDURE AND QUESTIONS TO ANSWER

1) Students discuss and list metals and other elements needed for transportation, heating, and generation, storage, and transmission of electricity.
2) Where are elements located on the periodic table? [Write the electrical energy production approach (fossil fuel, hydro, solar, wind, geothermal, nuclear, etc.) on post-it strips and have the students place these on the periodic table.]
3) What properties would make the element useful for the generation, storage, or transmission of electricity?
4) What makes the elements "green" or not?

5) Are there properties of the elements that might cause environmental problems?
6) Students determine where the elements are produced. (This is generally where they are mined, although for some, we have data only on where they are recovered at smelters or refineries.)
   a) Write symbols of “green” elements on the adhesive dots.
   b) Using the tables of “Critical Elements for Energy Technologies” and the map of the world, place dots labeling the elements onto the map on the countries in which the elements are presently mined or in some cases refined.
   c) Discuss ways this information might be important to the production of energy in the US.
   d) Discuss why China is a major producer of more elements than any other country (use the population chart at the end of this file to stimulate the discussion).

   Another approach is to assign one or more elements of the 44 elements (or 48 commodities) in the tables to each student. Have them either use the handout, the U.S. Geological Survey’s Mineral Commodity Summaries (latest annual report), or search the web to identify major uses of each element and the countries that are the leading producers. Have the students identify the elements that would be needed to generate electricity from coal, natural gas, oil, solar, wind, nuclear, dammed water, tides, biomass, and geothermal resources. Then have the students use a world map to mark the countries that are the major producers (say the top one or the top three) for each element. Use the chemical symbols for marking the maps. Discuss the apparent uneven distribution of mineral resources.

7) Discuss why some elements are used more than others.
   a) Which of the major mineral commodities are used the most, as measured by the amount of global production? (List the top ten by weight.)
   b) How does abundance in the Earth’s crust correlate with which mineral commodities are used the most? Why do you think there is this correlation?
8) Discuss why some elements are more expensive than others.
   a) What are the most expensive elements? (List the top ten on the basis of dollars per kilogram.)
   b) How does abundance in the Earth’s crust correlate with which elements are most expensive? Why do you think there is this correlation? What are the anomalies?

TEACHER NOTES

Consult the table, "Critical Elements for Energy Technologies," for elements, amount mined or refined, and countries where the elements are mined or refined. Most of this information can be found through the US Geological Survey website, www.usgs.gov. Their annual *Mineral Commodity Summaries* publication has information about uses, annual production in the U.S. and other countries, prices, and substitutes for most elements that are used by society.

Examples of some elements used for generation or transmission of electricity:

- Fossil fuel and biomass generation of electricity
  - Carbon
    - Burned (in wood and other biofuels, coal, petroleum, and natural gas) to produce heat to boil water to generate steam to turn turbines
  - Hydrogen
    - Burned (along with carbon, in petroleum and natural gas) to produce heat to boil water to generate steam to turn turbines
  - Oxygen
    - Used to burn the carbon
- Transmission of electricity
  - Copper
    - Wire used to transmit electricity
    - Wire used to carry the moving electrons generated by movement of a magnet through the coils of copper in an electrical generator
  - Aluminum
    - Used to transmit electricity, a substitute for copper, particularly in high-voltage transmission lines
  - Silver
    - Used to transmit electricity, particularly as contacts for silicon-based photovoltaic solar cells
- "Renewable" energy generation
  - Neodymium
    - Used for high strength magnets (along with iron and boron) to generate electrons moving through the copper wire
  - Iron
    - Used for high strength magnets (along with neodymium and boron) to generate electrons moving through the copper wire

    - Boron
        - Used for high strength magnets (along with neodymium and iron) to generate electrons moving through the copper wire
    - Lithium
        - Used for batteries to store electricity generated by noncontinuous sources such as wind or solar energy and to store electricity in cars
    - Cobalt
        - Used for batteries to store electricity generated by noncontinuous sources such as wind or solar energy and to store electricity in cars
    - Cadmium
        - Used in photovoltaic solar cells
    - Tellurium
        - Used in photovoltaic solar cells
    - Copper
        - Used in photovoltaic solar cells (CIGS, or copper-indium-gallium-selenide)
    - Indium
        - Used in photovoltaic solar cells
    - Germanium
        - Used in photovoltaic solar cells
    - Gallium
        - Used in photovoltaic solar cells
    - Selenium
        - Used in photovoltaic solar cells
    - Silicon
        - Used in photovoltaic solar cells
- Other methods of generating electricity
    - Uranium
        - Used in nuclear power plants to produce heat to boil water to make steam to turn turbines
- Gold
    - Used to conduct electrons in many computer applications; also used as thin (17.2 nanometers thick) coatings on windows to reflect heat (infrared radiation), thereby reducing heating and air-conditioning costs in buildings.

Many other elements are used in power plants (calcium, aluminum, silicon, oxygen, iron, and sulfur in cement for concrete floors and foundations; iron, carbon, nickel, and many other elements for steel in buildings and supports; carbon for resins and silicon and oxygen for fiberglass used in windmills; aluminum for supports for solar panels). High-temperature turbines are made of nickel-based super alloys that contain nickel, chromium, aluminum, titanium, cobalt, boron, carbon, zirconium, molybdenum, tungsten, tantalum, hafnium, and niobium.

Periodic table link: http://www.chemicool.com/

Printable periodic table: http://www.sciencegeek.net/tables/CA_CST.pdf

Printable maps: with country names http://english.freemap.jp/world_e/6.html

without country names http://english.freemap.jp/world_e/2.html

The US Geological Survey's *Mineral Commodity Summaries* annual publication lists the major countries from which the elements were mined in the previous few years. To show geographically where some of the larger deposits are within the countries, refer to U.S. Geological Survey Open-File Report 2005-1294, *Reviews of the Geology and Nonfuel Mineral Deposits of the World*.

EXTENSION

Introduction

Mining, or use of mined materials, is driven by economics. If a company loses money in an endeavor, that company won't pursue that endeavor for long. Although metals are concentrated in specific areas that make it possible to mine them, an average concentration in the crust, crustal abundance, can be calculated. So, a comparison of the price of a metal and its abundance can be made. Everything else being equal (such as geological processes that concentrate elements in ore deposits, metallurgical difficulty in extracting metals from ores, and geopolitical aspects of the uneven distribution of ore deposits throughout the world), less abundant (rarer) elements ought to cost more.

Of course, the price of a metal also depends on the demand, or the need for that element in products or as a medium for exchange of goods or services (money).

Studying the abundances, prices, and expected demands of metals can reveal some trends.

Materials

- The “Critical Elements for Energy Technologies” table (mostly derived from the U.S. Geological Survey’s annual report titled *Mineral Commodity Summaries*, available at http://minerals.usgs.gov/minerals/, a good source of information on annual production, uses, recycling, and substitutions)
- Related charts showing comparisons of prices
- Presentations by Zweibel and Smith about uses of metals for photovoltaics and rare earth elements, respectively. These are available as part of the *Minerals for a Green Society* symposium on 4 February 2010 sponsored by the Mining and Metallurgical Society of America at http://www.mmsa.net/.

Procedure

1. Using the charts and presentations, determine which elements will be in great demand in the near future.
2. Determine which elements may be in shortage.
3. Suggest what countries may be controlling the supply of certain elements and the products made from those elements.
   a. What factors might control wealth of countries?
   b. What factors might control wealth of companies involved in the production and use of the minerals?
   c. What factors control the prices of various mineral commodities?
4. Suggest reasons why the prices of some mineral commodities are either higher or lower than the general trend of decreasing price with increasing abundance in the Earth’s crust.

Prepared by Elisabeth M. Price (aaejprice@att.net) and Jonathan G. Price (jprice@unr.edu) for the Nevada Mining Association, edited by Charlotte Stock, Nevada Bureau of Mines and Geology, University of Nevada, Reno; 8 March 2010, updated 12 February 2015, 14 May 2018; 2 April 2020; 18 June 2021; 3 November 2023.

Data for the following tables and charts are from the U.S. Geological Survey, Energy Information Administration (Department of Energy), and CRC Handbook of Chemistry and Physics, and various websites for prices of rare-earth elements.

Critical Elements for Energy Technologies

Element	**Aluminum**	**Al (refined)**	**Arsenic**	**Barium**	**Beryllium**	**Boron**	**Cadmium**	**Carbon coal**	**Carbon ind.diamonds**	**Carbon nat. gas**	**Carbon oil**	**Chromium**
Symbol	**Al**		**As**	**Ba**	**Be**	**B**	**Cd**	**C**	**C**	**C**	**C**	**Cr**
Atomic number	13		33	56	4	5	48	12	12	12	12	24
Abundance (g/t) in Earth's crust	**82,300**		**1.8**	**425**	**2.8**	**10**	**0.15**	**200**	**200**	**200**	**200**	**102**
Mined as primary ore	Yes		Yes	Yes	Yes	Yes	**No**	Yes	Yes	Yes	Yes	Yes
Mined as byproduct of:			Cu, Au, Pb				**Zn**			**oil**		
U.S. net import reliance	49%	13%	100%	>75%	11%	0%	<50%	0%	1%	0%	0%	69%
Global mine production (metric tons) in 2020	**1.28E+08**	**6.52E+07**	**24,236**	**4.65E+06**	**240**	**5.58E+06**	**23,000**	**7.44E+09**	**11**	**2.10E+09**	**3.90E+09**	**40,000,000**
Top producing country	**Australia**	**China**	**China**	**China**	**USA**	Turkey	**China**	**China**	**Congo (Kinshasa)**	**USA**	**USA**	**South Africa**
% world production in 2020	**30%**	**57%**	**75%**	**32%**	**63%**	**>43%**	**36%**	**50%**	**31%**	**21%**	**20%**	**40%**
Other major producers	Guinea	**Russia**	Morocco	India	**China**	**USA**	Korea	India	**Russia**	**Russia**	Saudia Arabia	Kazakhstan
%, 2nd	22%	**6%**	17%	25%	**29%**	**~36%**	13%	10%	**29%**	**16%**	12%	17%
	China	India	**Russia**	Morocco	Brazil	Chile	Japan	Indonesia	**Australia**	Iran	**Russia**	Turkey
%, 3rd	**16%**	6%	**5%**	10%	1%	~7%	8%	7%	**23%**	6%	**11%**	16%
	Indonesia	Canada	Belgium	Kazakhstan	Mozambique	China	Canada	**USA**	Botswana	Qatar	Canada	India
%, 4th	6%	5%	3%	8%	0.4%	~4%	8%	**7%**	10%	5%	6%	10%
	India	UAE	Bolivia	**USA**	Nigeria	Bolivia	Kazakhstan	**Australia**	South Africa	Canada	**China**	Finland
%, 5th	6%	4%	0.3%	**5%**	0.4%	~4%	7%	**6%**	3%	4%	**5%**	6%
	Jamaica	**Australia**	Japan	Laos	Rwanda	Germany	Mexico	**Russia**	Zimbabwe	**China**	Iraq	
%, 6th	2%	**2%**	0.1%	4.2%	0.4%	~2%	6%	**5%**	3%	**4%**	**4%**	
Price ($/kg, 2020)	**0.078**	**1.96**	**1.70**	**0.31**	**630**	**0.38**	**2.30**	**0.034**	**37,000**	**0.14**	**0.34**	**7.90**
Energy uses	power transmission, frames for solar panels and wind turbines, lightweight metal for transportation (cars, airplanes)		GaAs semicon-ductors in solar cells	barite as dense mineral added to drilling mud to prevent blowouts in oil and gas drilling	Cu-alloy electrical contacts	$Fe_{14}Nd_2B$ magnets, but most B sold as borax	CdTe solar cells; NiCd batteries	power production; steel	drilling for oil, gas, and mineral resources - to cut rocks with bits embedded with diamonds	producing electricity; transportation fuel	transport. fuel; electricity	stainless steel

Critical Elements for Energy Technologies (continued)

Element	**Cobalt**	**Copper**	**Dysprosium**	**Gallium**	**Germanium**	**Gold**	**Helium**	**Indium**	**Iron**	**Fe (steel)**
Symbol	**Co**	**Cu**	**Dy**	**Ga**	**Ge**	**Au**	**He**	**In**	**Fe**	
Atomic number	27	29	66	31	32	79	2	49	26	
Abundance (g/t) in Earth's crust	**25**	**60**	**5.2**	**19**	**1.5**	**0.004**	**0.008**	**0.25**	**56,300**	
Mined as primary ore	Yes	Yes	Yes	**No**	**No**	Yes	**No**	**No**	Yes	
Mined as byproduct of:	Ni, Cu	Mo, Zn, Au, Ag	Zr sands; other REE	**Al>Zn**	**Zn, Pb-Zn-Cu**	Cu, Ag	**natural gas**	**Zn>Cu, Sn**		
U.S. net import reliance	76%	33%	0%	100%	>50%	52%	0%	100%	0%	18%
Global mine production (metric tons) in 2020	**140,000**	**2.00E+07**		**300**	**130**	**3,200**	**22,693**	**900**	**1.50E+09**	**1.80E+09**
Top producing country	**Congo (Kinshasa)**	**Chile**	**China**	**China**	**China**	**China**	**USA**	**China**	**Australia**	**China**
% world production in 2020	**68%**	**29%**	**58%**	**97%**	**>50%**	**12%**	**48%**	**56%**	**37%**	**56%**
Other major producers	**Russia**	Peru	**USA**	**Russia**	**Russia**	**Australia**	Qatar	Korea	Brazil	India
%, 2nd	**5%**	11%	**16%**	**1%**	**probably 2nd**	**10%**	35%	22%	17%	5%
	Australia	**China**	**Australia**	Japan	**USA**	**Russia**	Algeria	Japan	**China**	Japan
%, 3rd	**4%**	**9%**	**7%**	1%	**probably 3rd**	**9%**	11%	33%	**14%**	5%
	Philippines	**USA**	Madagascar	Korea		**USA**	**Russia**	Canada	India	**USA**
%, 4th	3%	**6%**	3%	1%		**6%**	**4%**	6%	9%	**4%**
	Canada	**Australia**	**Russia**			Canada	**Australia**	France	**Russia**	**Russia**
%, 5th	2%	**4%**	**1%**			5%	**3%**	10%	**4%**	**4%**
	Papua New Guinea	**Russia**	Thailand			Ghana	Poland	Belgium	South Africa	Korea
%, 6th	2%	**4%**	1%			4%	1%	4%	3%	4%
Price ($/kg, 2020)	**35.27**	**6.17**	**380**	**170**	**1,000**	**56,907**	**24**	**400**	**0.173**	**1.26**
Energy uses	gas turbines; lithium-ion batteries; $SmCo_5$ magnets	power transmission; electrical motors	One of the rare earths; magnets	GaAs, GaN in electronics; LEDs, $CuIn_xGa_{(1-x)}Se_2$ solar cells	solar cells	electrical conduction; heat-reflecting thin coatings	cryogenic applications; super-conduction of electricity. NOTE: data from China are not available.	indium-tin oxide (ITO); $CuIn_xGa_{(1-x)}Se_2$ solar cells	steel for multiple uses, including towers for wind turbines; rebar in concrete	steel for multiple uses, including towers for wind turbines

Critical Elements for Energy Technologies (continued)

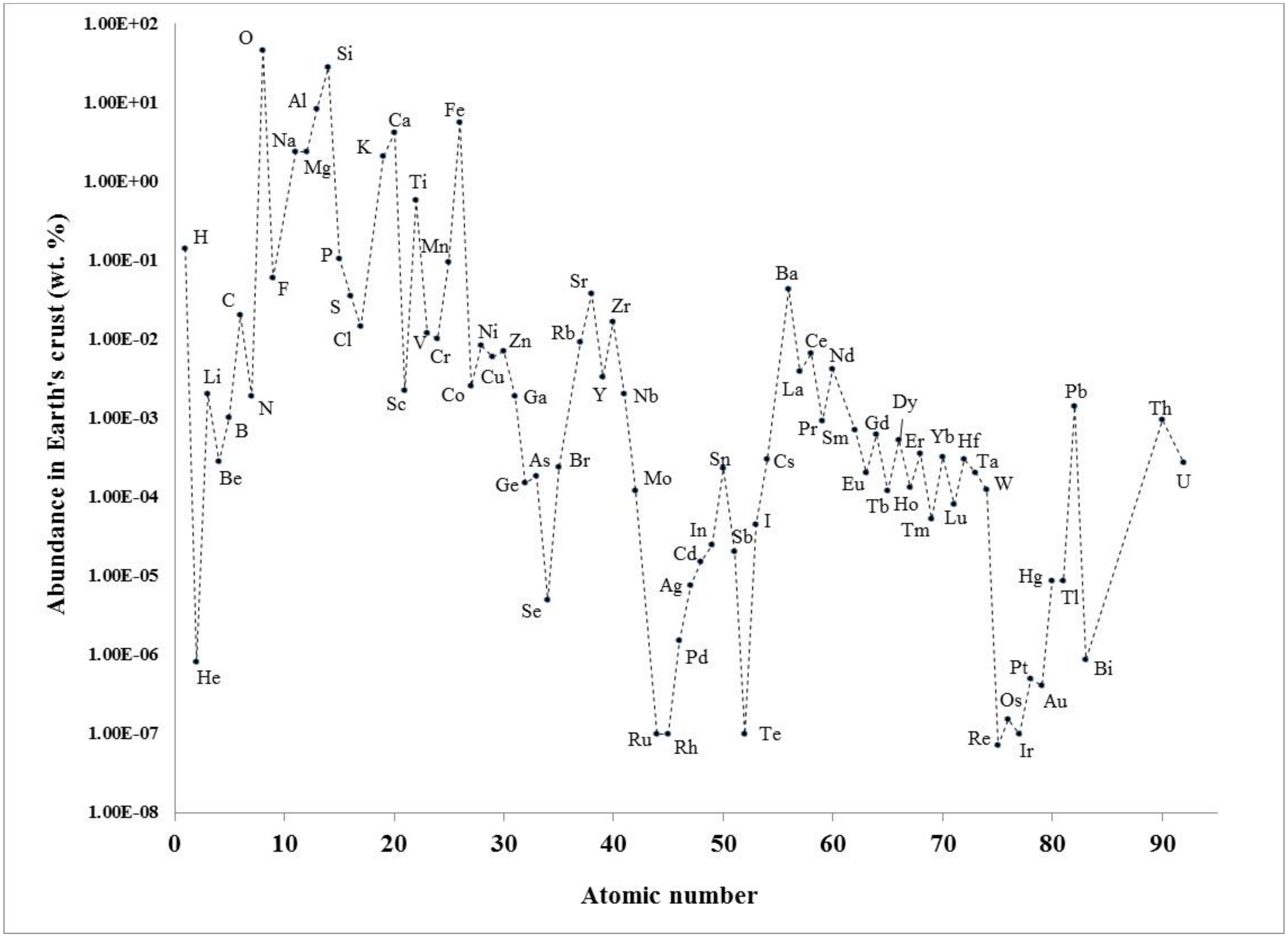
Element	Lanthanum	Lead	Lithium	Manganese	Mercury	Molybdenum	Neodymium	Nickel	Niobium	Palladium
Symbol	La	Pb	Li	Mn	Hg	Mo	Nd	Ni	Nb	Pd
Atomic number	57	82	3	25	80	42	60	28	41	46
Abundance (g/t) in Earth's crust	39	14	20	950	0.085	1.2	41.5	84	20	0.015
Mined as primary ore	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mined as byproduct of:	Zr sands; other REE	Zn			Au	Cu	Zr sands; other REE			Pt
U.S. net import reliance	0%	40%	>50%	100%	NA	0%	0%	59%	100%	40%
Global mine production (metric tons) in 2020		**4.40E+06**	**82,672**	**1.85E+07**	**3,700**	**300,000**		**2.50E+06**	**78,000**	**210**
Top producing country	**China**	**China**	**Australia**	**South Africa**	**China**	**China**	**China**	Indonesia	**Brazil**	**Russia**
% world production in 2020	**58%**	**43%**	**48%**	**28%**	**92%**	**40%**	**58%**	**30%**	**91%**	**43%**
Other major producers	**USA**	**Australia**	Chile	**Australia**	Tajikistan	Chile	**USA**	Philippines	Canada	**South Africa**
%, 2nd	**16%**	**11%**	22%	**18%**	3%	20%	**16%**	13%	8%	**33%**
	Australia	**USA**	**China**	Gabon	Mexico	**USA**	**Australia**	**Russia**		Canada
%, 3rd	**7%**	**7%**	**17%**	15%	2%	**16%**	**7%**	**11%**		10%
	Madagascar	Mexico	Argentina	Ghana	Agentina	Peru	Madagascar	New Caledonia		**USA**
%, 4th	3%	5%	7%	8%	1%	10%	3%	8%		**7%**
	Russia	Peru	Brazil	**China**	Peru	Armenia	**Russia**	**Australia**		Zimbabwe
%, 5th	**1%**	5%	2%	**7%**	1%	2%	**1%**	**7%**		6%
	Thailand	**Russia**	Zimbabwe	Brazil	Norway	Iran	Thailand	Canada		
%, 6th	1%	**5%**	1%	6%	1%	1%	1%	6%		
Price ($/kg, 2020)	**4.20**	**1.80**	**42.58**	**0.47**	**29.01**	**20.00**	**90.00**	**14.00**	**37**	**67,516**
Energy uses	One of the rare earths - Ni metal hydride batteries in hybrid cars	Pb-acid batteries	batteries	strengthen steel	electrical switches; lights	steel	$Fe_{14}Nd_2B$ magnets used for electrical generators (wind turbines)	stainless steel	steel	catalytic converters

Critical Elements for Energy Technologies (continued)

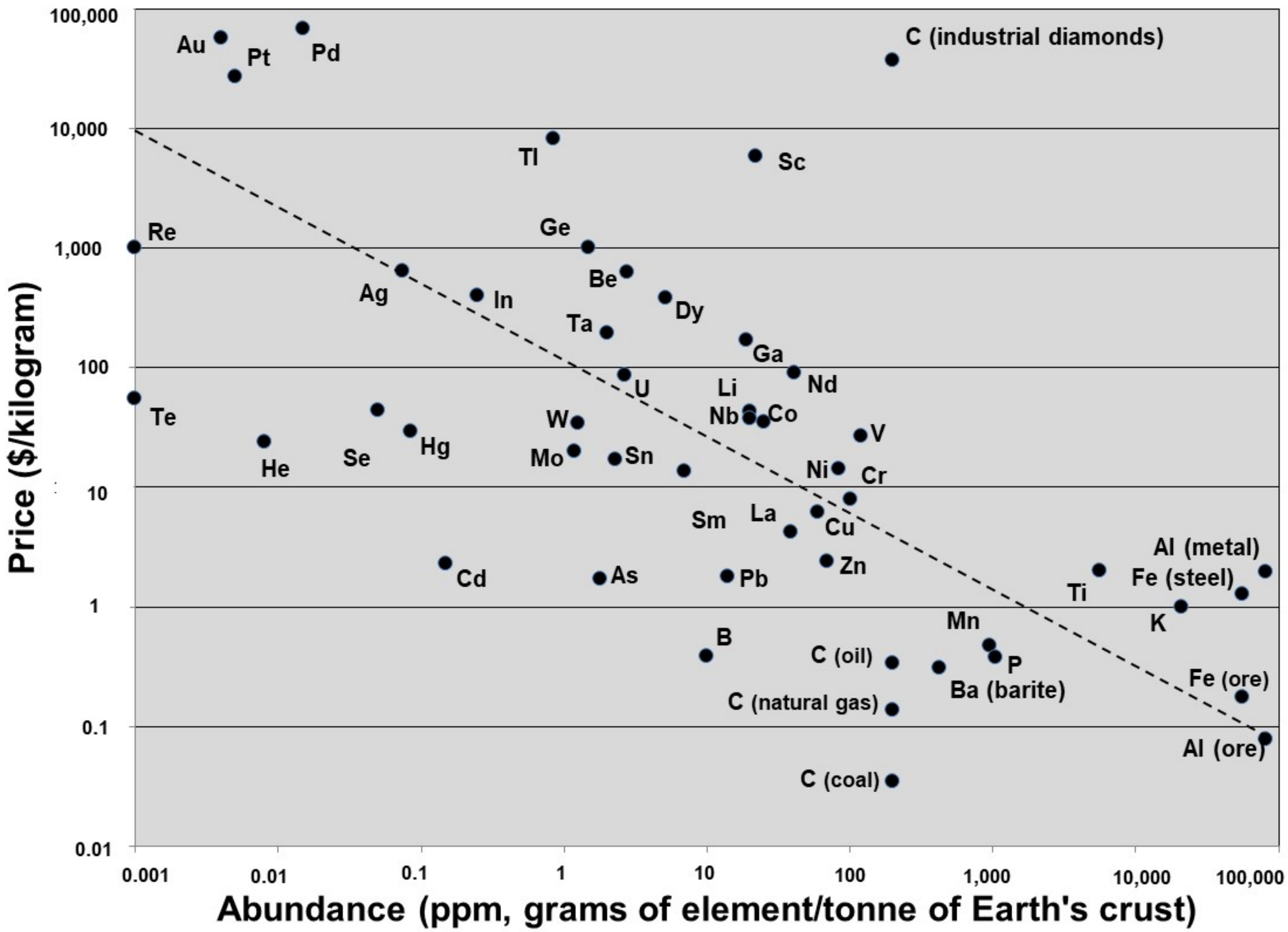
Element	Phosphorus	Platinum	Potassium	Rare Earth Elements	Rhenium	Samarium	Scandium	Selenium
Symbol	P	Pt	K	REE	Re	Sm	Sc	Se
Atomic number	15	78	19	57 to 71	75	62	21	34
Abundance (g/t) in Earth's crust	1050	0.005	20900	0.8 (Lu) to 66.5 (Ce)	0.001	7.05	22	0.05
Mined as primary ore	Yes	Yes	Yes	Yes	No	Yes	No	No
Mined as byproduct of:		Pd		Zr sands	Cu-Mo, Mo	Other REE	U, REE, Ti, phosphate, W, Ni-Co-Cu, PGE	Cu
U.S. net import reliance	10%	79%	90%	0%	76%	100%	100%	0%
Global mine production (metric tons) in 2020	**4.13E+07**	**170**	**3.57E+07**	**240,000 tonnes of Rare Earth Oxide**	**53**		**13**	**2,900**
Top producing country	**China**	**South Africa**	**Canada**	**China**	**Chile**	**China**	**China**	**China**
% world production in 2020	**40%**	**71%**	**33%**	**58%**	**57%**	**58%**		**38%**
Other major producers	Morocco	Russia	Russia	USA	Poland	USA	Philipines	Japan
%, 2nd	17%	5%	18%	16%	16%	16%		26%
	USA	Zimbabwe	Belarus	Australia	USA	Australia	Russia	Germany
%, 3rd	11%	8%	17%	7%	15%	7%		10%
	Russia	Canada	China	Madagascar	Korea	Madagascar		Belgium
%, 4th	6%	5%	12%	3%	5%	3%		7%
	Jordan	USA	Germany	Russia	China	Russia		Russia
%, 5th	4%	2%	7%	1%	5%	1%		5%
	Saudi Arabia		Israel	Thailand	Kazakhstan	Thailand		Finland
%, 6th	3%		5%	1%	2%	1%		3%
Price ($/kg, 2020)	**0.38**	**27,328**	**1.00**	**5.00**	**1,000**	**13.60**	**5,828**	**44.09**
Energy uses	fertilizer for growing biomass	catalytic converters; catalyst in fuel cells	fertilizer for growing biomass	catalyts; magnets	high-performance (high-temperature) turbines	$SmCo_5$ magnets	fuel cells, high-intensity lamps; isotopic tracer for fluid flow in oil wells	CIGS: thin-film photovoltaic copper-indium-gallium-diselenide solar cells

Critical Elements for Energy Technologies (continued)

Element	**Silver**	**Tantalum**	**Tellurium**	**Thallium**	**Tin**	**Titanium**	**Tungsten**	**Uranium**	**Vanadium**	**Zinc**
Symbol	**Ag**	**Ta**	**Te**	**Tl**	**Sn**	**Ti**	**W**	**U**	**V**	**Zn**
Atomic number	47	73	52	81	50	22	74	92	23	30
Abundance (g/t) in Earth's crust	**0.075**	**2**	**0.001**	**0.85**	**2.3**	**5650**	**1.25**	**2.7**	**120**	**70**
Mined as primary ore	Yes	**Yes**	**No**	**No**	Yes	Yes	Yes	Yes	Yes	Yes
Mined as byproduct of:	Au, Cu, Zn, Pb	**Nb**	**Cu>Pb,Zn, Ni,Au,Ag**	**Cu,Zn,Pb**				Au, phosphate	Ti-Fe, U, phosphate	Pb
U.S. net import reliance	80%	100%	>95%	100%	75%	88%	>50%	94%	96%	0%
Global mine production (metric tons) in 2020	**25,000**	**1,700**	**490**	**8**	**270,000**	**9.47E+06**	**84,000**	**54,752**	**88,000**	**1.20E+07**
Top producing country	**Mexico**	Congo (Kinshasa)	**China**	**China**	**China**	**China**	**China**	**Kazakhstan**	**China**	**China**
% world production in 2020	**22%**	39%	**61%**		**30%**	**15%**	**82%**	**42%**	**60%**	**35%**
Other major producers	Peru	Brazil	Japan	Kazakhstan	Indonesia	**South Africa**	Vietnam	Canada	**Russia**	**Australia**
%, 2nd	14%	22%	10%		24%	**7%**	**5%**	13%	**20%**	**12%**
	China	Rwanda	**Russia**	**Russia**	Burma	**Australia**	**Russia**	**Australia**	South Africa	Peru
%, 3rd	**13%**	16%	**8%**		12%	**6%**	**3%**	**12%**	9%	10%
	Russia	Nigeria	Sweden		Peru	Canada	Mongolia	Namibia	Brazil	India
%, 4th	**7%**	9%	10%		7%	4%	2%	10%	64%	6%
	Poland	**China**	Canada		Congo (Kinshasa)	Mozambique	Bolivia	Uzbekistan	**USA**	**USA**
%, 5th	5%	**4%**	5%		6%	4%	2%	6%	**0.2%**	**6%**
	Australia	Ethiopia	Bulgaria		Bolivia	Ukraine	Rwanda	Niger		Mexico
%, 6th	**5%**	4%	1%		6%	4%	1%	5%		5%
Price ($/kg, 2020)	**643**	**193**	**55**	**8,200**	**16.98**	**2.00**	**34.05**	**86.49**	**26.37**	**2.40**
Energy uses	Electrical transmission for Si solar cells	capacitors	CdTe solar cells	Tl-Ba-Ca-Cu oxide high-temperature supercon-ductors; possibly Tl-Pb-Te for converting heat into electricity; scintillometers	solder	light-weight allows	lightbulb filaments	fuel for nuclear reactors	strengthen steel; possible use in batteries	plating to prevent corrosion; solder

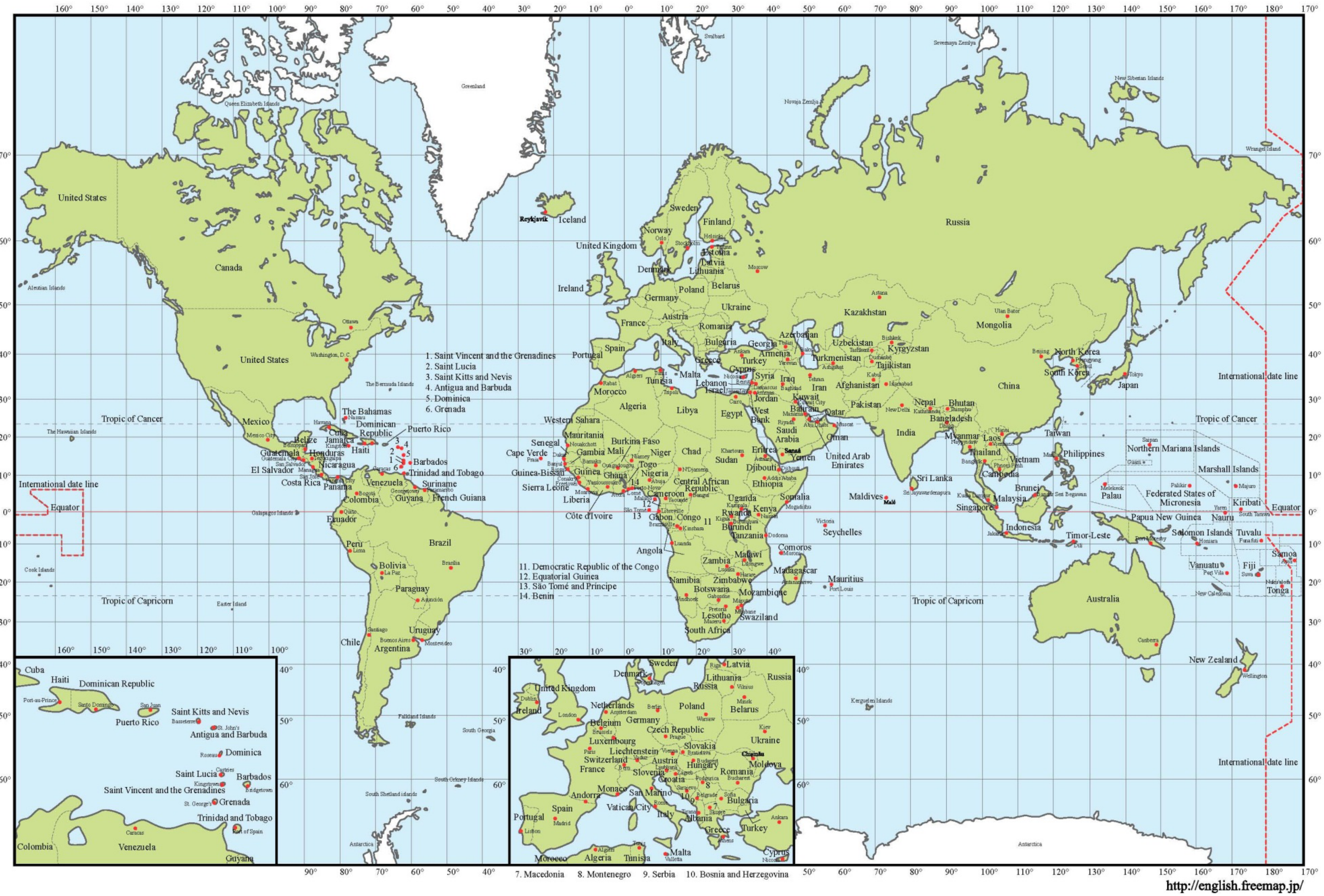


Abundance of elements in the Earth's crust as a function of atomic number. Source: CRC Handbook of Chemistry and Physics.

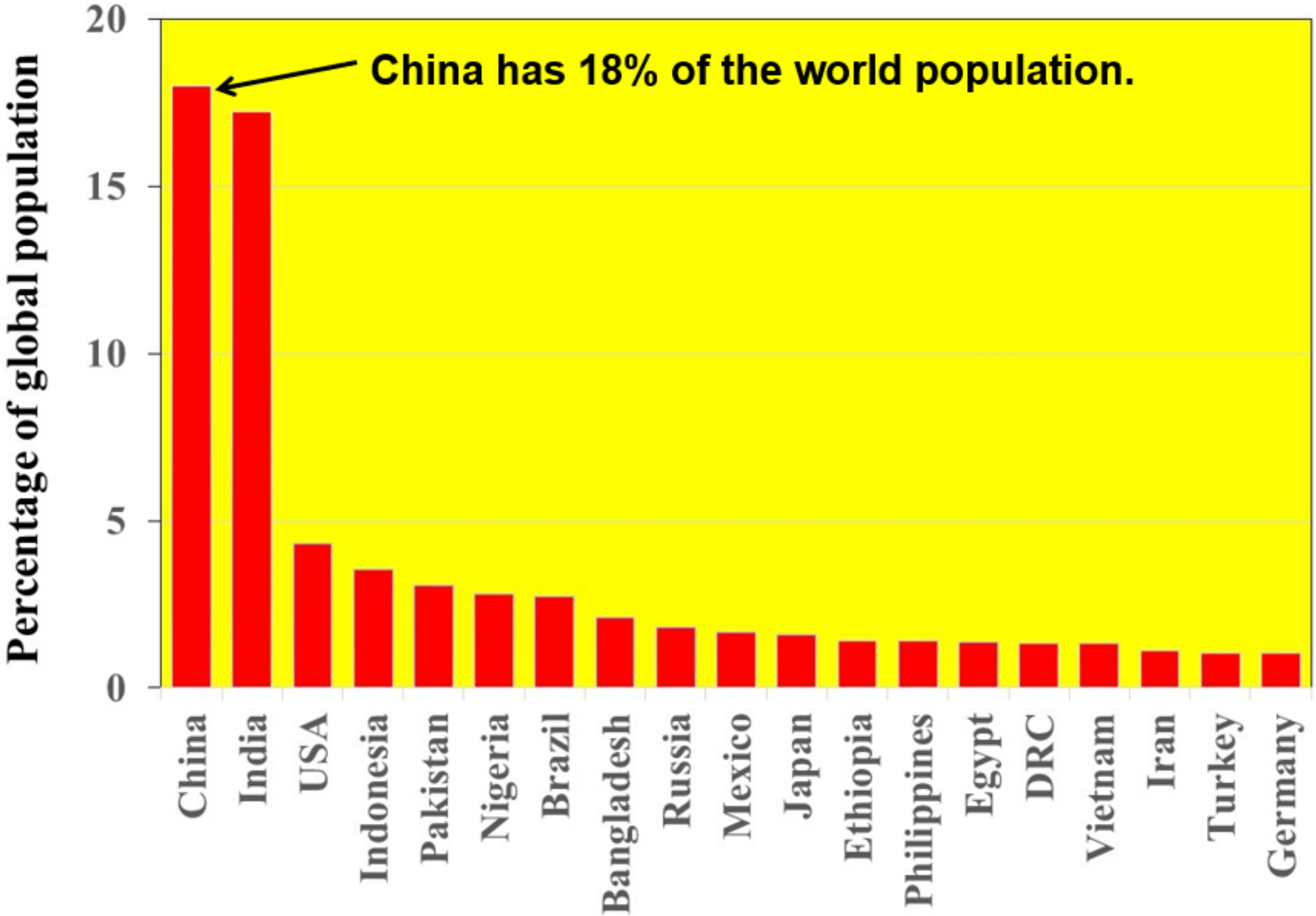


Price of mineral commodities (in 2020) as a function of abundance of the elements in the Earth's crust. Sources: U.S. Geological Survey, Energy Information Administration, World Coal Association, World Nuclear Association, and CRC Handbook of Chemistry and Physics.

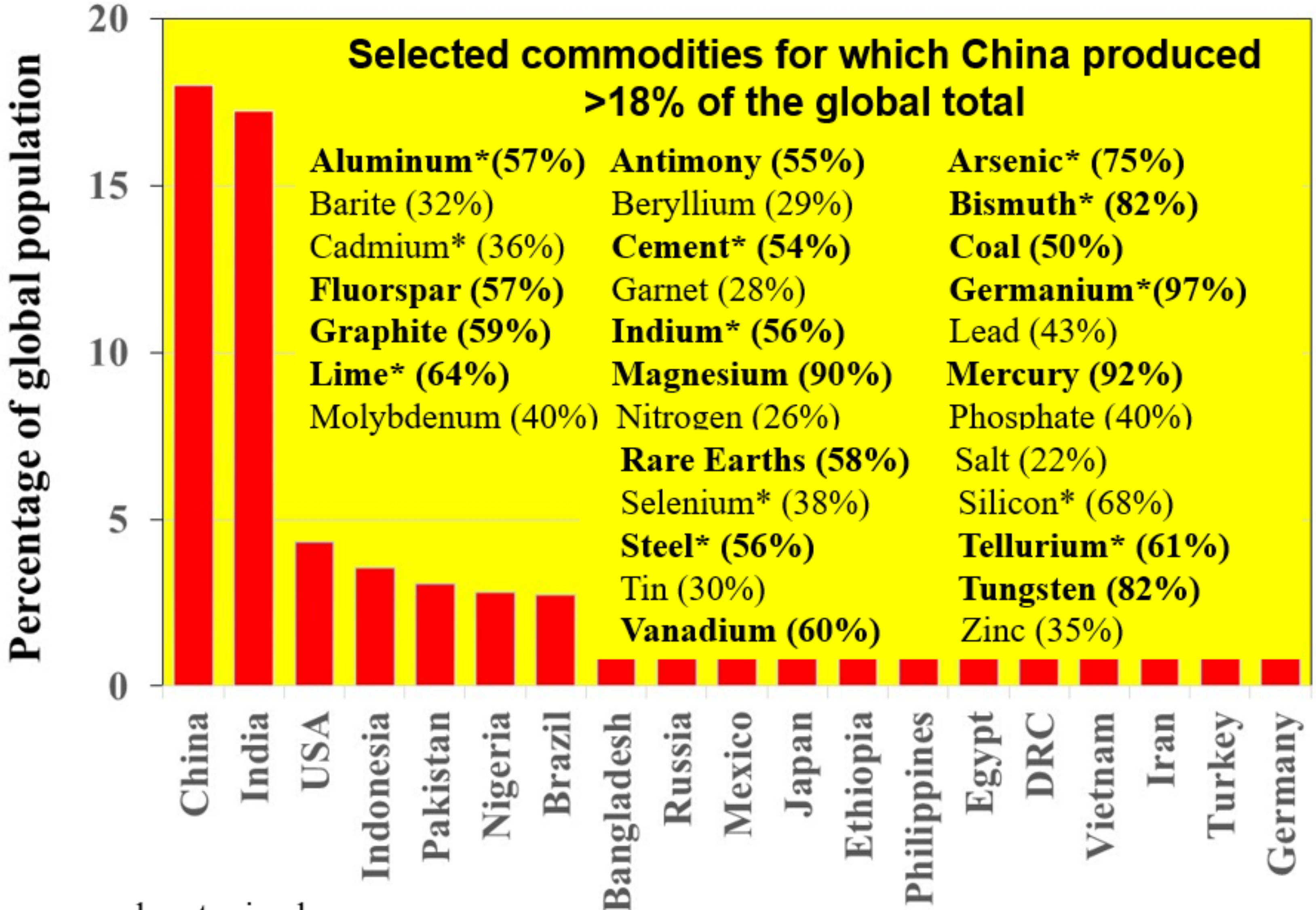
World map from http://english.freemap.jp/world_e/2.html



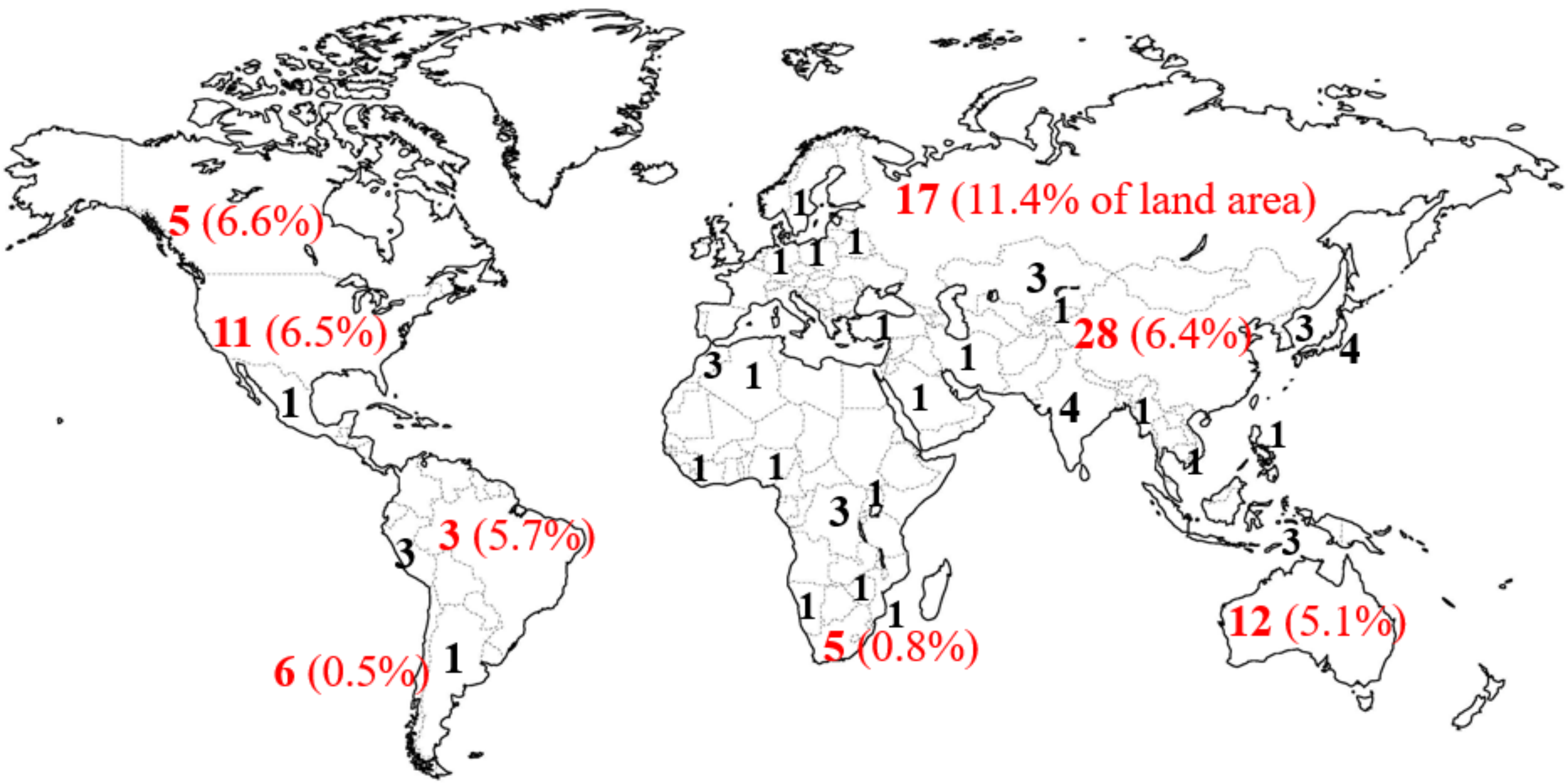
United States
Canada
Greenland
Iceland
Reykjavik
Russia
Mexico
The Bahamas
Cuba
Jamaica
Haiti
Dominican Republic
Puerto Rico
Belize
Guatemala
Honduras
El Salvador
Nicaragua
Costa Rica
Panama
Venezuela
Colombia
Guyana
Suriname
French Guiana
Ecuador
Peru
Brazil
Bolivia
Paraguay
Chile
Argentina
Uruguay
Barbados
Trinidad and Tobago
1. Saint Vincent and the Grenadines
2. Saint Lucia
3. Saint Kitts and Nevis
4. Antigua and Barbuda
5. Dominica
6. Grenada
11. Democratic Republic of the Congo
12. Equatorial Guinea
13. São Tomé and Príncipe
14. Benin
7. Macedonia
8. Montenegro
9. Serbia
10. Bosnia and Herzegovina
United Kingdom
Ireland
Norway
Sweden
Finland
Estonia
Latvia
Lithuania
Denmark
Belarus
Poland
Germany
Ukraine
France
Austria
Romania
Spain
Portugal
Italy
Bulgaria
Greece
Malta
Turkey
Georgia
Armenia
Azerbaijan
Cyprus
Syria
Lebanon
Israel
Jordan
Iraq
Iran
Kuwait
Bahrain
Qatar
Saudi Arabia
United Arab Emirates
Oman
Yemen
Kazakhstan
Uzbekistan
Turkmenistan
Kyrgyzstan
Tajikistan
Afghanistan
Pakistan
India
Nepal
Bhutan
Bangladesh
Sri Lanka
Maldives
Mongolia
China
North Korea
South Korea
Japan
Taiwan
Myanmar
Laos
Thailand
Vietnam
Cambodia
Philippines
Malaysia
Singapore
Brunei
Indonesia
Timor-Leste
Papua New Guinea
Palau
Australia
New Zealand
Morocco
Algeria
Tunisia
Libya
Egypt
Western Sahara
Mauritania
Mali
Niger
Chad
Sudan
Eritrea
Djibouti
Ethiopia
Somalia
Senegal
Gambia
Guinea-Bissau
Guinea
Sierra Leone
Liberia
Côte d'Ivoire
Burkina Faso
Ghana
Togo
Nigeria
Cameroon
Central African Republic
Gabon
Congo
Uganda
Kenya
Rwanda
Burundi
Tanzania
Angola
Zambia
Malawi
Mozambique
Zimbabwe
Namibia
Botswana
South Africa
Lesotho
Swaziland
Madagascar
Comoros
Seychelles
Mauritius
Cape Verde
Northern Mariana Islands
Marshall Islands
Federated States of Micronesia
Nauru
Kiribati
Solomon Islands
Tuvalu
Vanuatu
Fiji
Samoa
Tonga
Tropic of Cancer
Tropic of Capricorn
Equator
International date line
Netherlands
Belgium
Luxembourg
Czech Republic
Slovakia
Hungary
Liechtenstein
Switzerland
Slovenia
Croatia
Moldova
Andorra
Monaco
San Marino
Vatican City
Albania
http://english.freemap.jp/



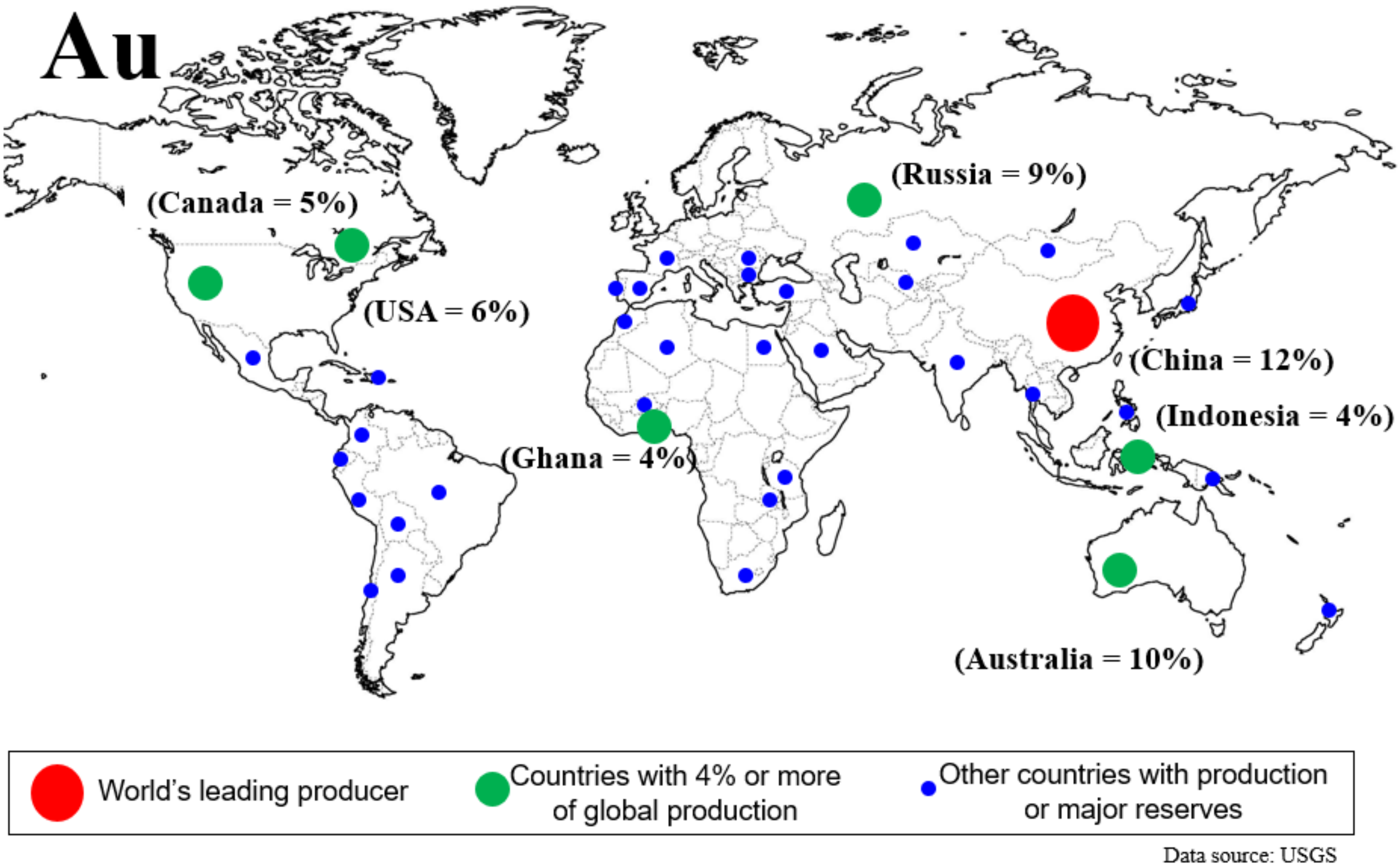
Percentage of global population
20
15
10
5
0
China has 18% of the world population.
China
India
USA
Indonesia
Pakistan
Nigeria
Brazil
Bangladesh
Russia
Mexico
Japan
Ethiopia
Philippines
Egypt
DRC
Vietnam
Iran
Turkey
Germany



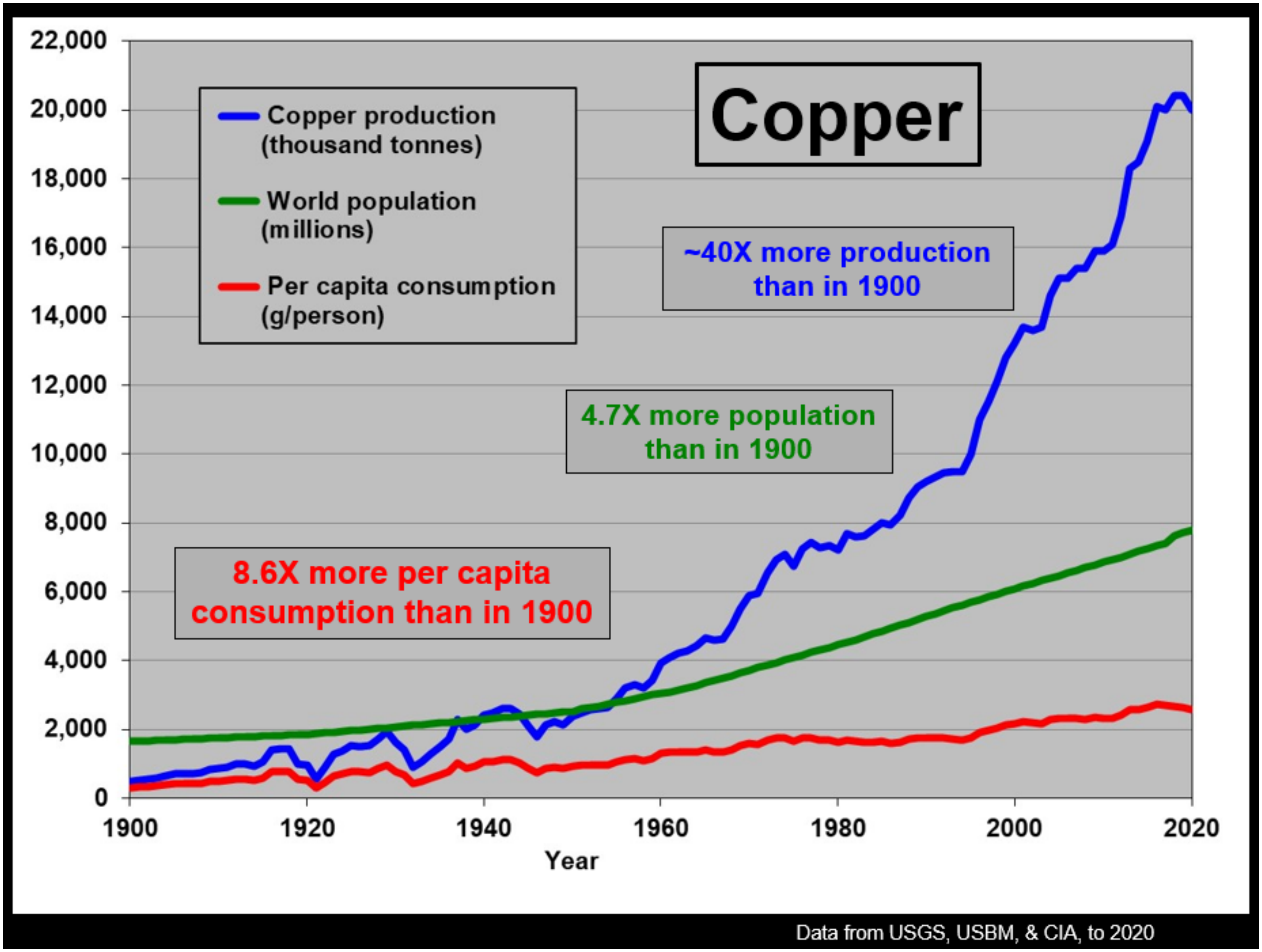
* processed, not mined



Number of selected mineral commodities (among 44) for which these countries are among the top three global producers (with percentage of land area in parentheses).



Resources are global, but China is Number One.


Copper
Copper production (thousand tonnes)
World population (millions)
Per capita consumption (g/person)
~40X more production than in 1900
4.7X more population than in 1900
8.6X more per capita consumption than in 1900
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1900
1920
1940
1960
1980
2000
2020
Year
Data from USGS, USBM, & CIA, to 2020

Critical Elements for Energy - Next Generation Science Standards* – High School

Disciplinary Core Ideas

HS-ESS3 Earth and Human Activity - ESS3.A: Natural Resources

- **Resource availability has guided the development of human society. (HS-ESS3-1)**
- **All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors.** (HS-ESS3-2)

Science and Engineering Principles

Using Mathematics and Computational Thinking

Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, **exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data.** Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Create a computational model or simulation of a phenomenon, designed device, process, or system. (HS- ESS3-3)
- Use a computational representation of phenomena or design solutions to describe and/or support claims and/or explanations. (HS-ESS3-6)

Crosscutting Concepts

Cause and Effect

Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-ESS3-1)

Systems and System Models

When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. (HS-ESS3-6)

Stability and Change

- Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. (HS- ESS3-3),(HS-ESS3-5)
- Feedback (negative or positive) can stabilize or destabilize a system. (HS- ESS3-4)

Connections to Engineering, Technology, and Applications of Science

Influence of Engineering, Technology, and Science on Society and the Natural World

- Modern civilization depends on major technological systems. (HS-ESS3-1),(HS- ESS3-3)
- Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. (HS- ESS3-2), (HS-ESS3-4)

- -

NOTE: The data in the tables on pages 7 through 11 can be used by the students to create graphs like those on pages 12 and 13. These data are best represented as logarithmic plots.

*The Nevada Academic Content Standards for Science (NVACSS) are based on the Next Generation Science Standards and include ESS3.A – Natural Resources.

Critical Elements for Energy - Next Generation Science Standards* – Middle School

Disciplinary Core Ideas

MS-ESS3 Earth and Human Activity - ESS3.A: Natural Resources

Humans depend on Earth's land, ocean, atmosphere, and biosphere for many different resources. Minerals, fresh water, and biosphere resources are limited, and many are not renewable or replaceable over human lifetimes. These resources are distributed unevenly around the planet as a result of past geological processes. (MS-ESS3-1)

Science and Engineering Principles

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 6-8 builds on K-5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific ideas, principles, and theories.

- Construct a scientific explanation based on valid and reliable evidence obtained from sources (including the student's own experiments) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (MS-ESS3-1)
- Apply scientific principles to design an object, tool, process or system. (MS-ESS3-3)

Crosscutting Concepts

Cause and Effect

- Relationships can be classified as causal or correlational, and correlation does not necessarily imply causation. (MS-ESS3-3)
- Cause and effect relationships may be used to predict phenomena in natural or designed systems. (MS-ESS3-1), (MS-ESS3-4)

Stability and Change

- Stability might be disturbed either by sudden events or gradual changes that accumulate over time. (MS-ESS3-5)

Connections to Engineering, Technology, and Applications of Science

Influence of Engineering, Technology, and Science on Society and the Natural World

All human activity draws on natural resources and has both short and long-term consequences, positive as well as negative, for the health of people and the natural environment.
(MS-ESS3-1), (MS-ESS3-4)

The uses of technologies and any limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. Thus technology use varies from region to region and over time. (MS-ESS3-2), (MS-ESS3-3)

- -

NOTE: China's dominance in global mineral-resource production can be explained only partly by its large population. The dominance of some countries is related to geological factors.

*The Nevada Academic Content Standards for Science (NVACSS) are based on the Next Generation Science Standards and include ESS3.A – Natural Resources.