Opportunities in Global Mineral Resources

Jon Price

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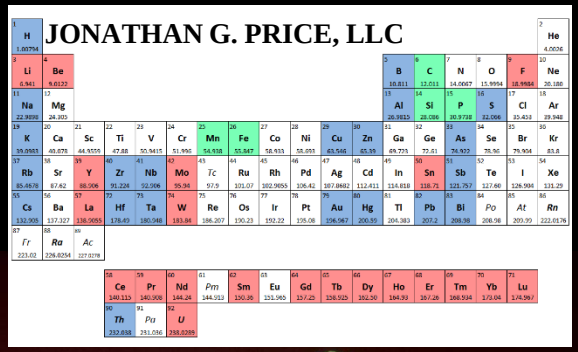
Nevada Bureau of Mines and Geology



University of Nevada, Reno
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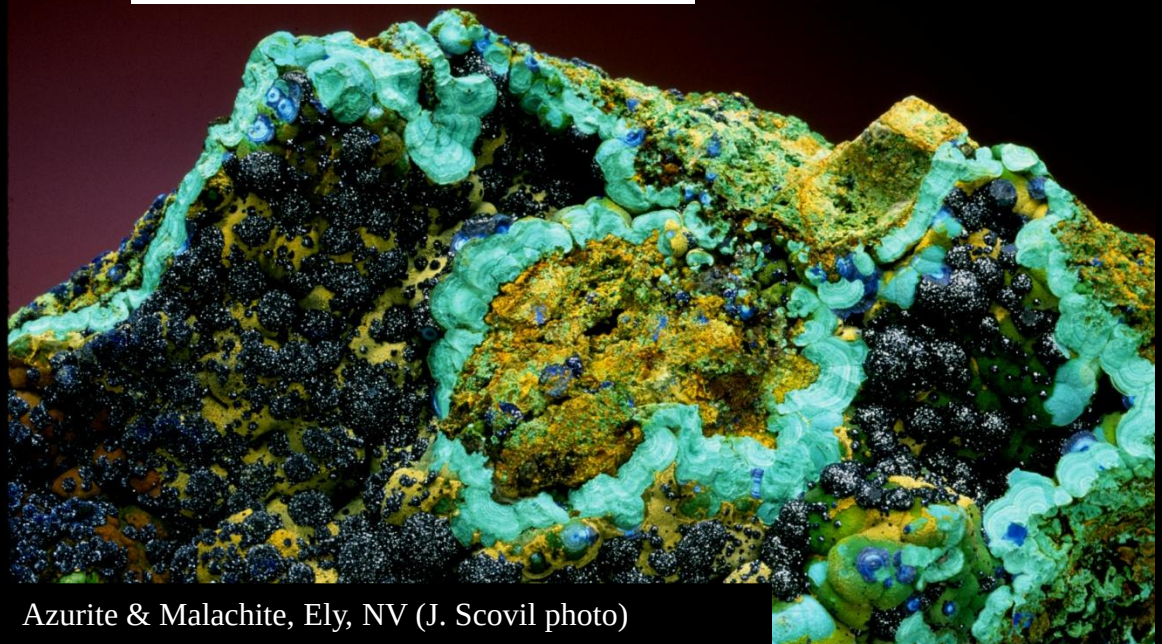


Azurite & Malachite, Ely, NV (J. Scovil photo)

Round Mountain, NV (2007)

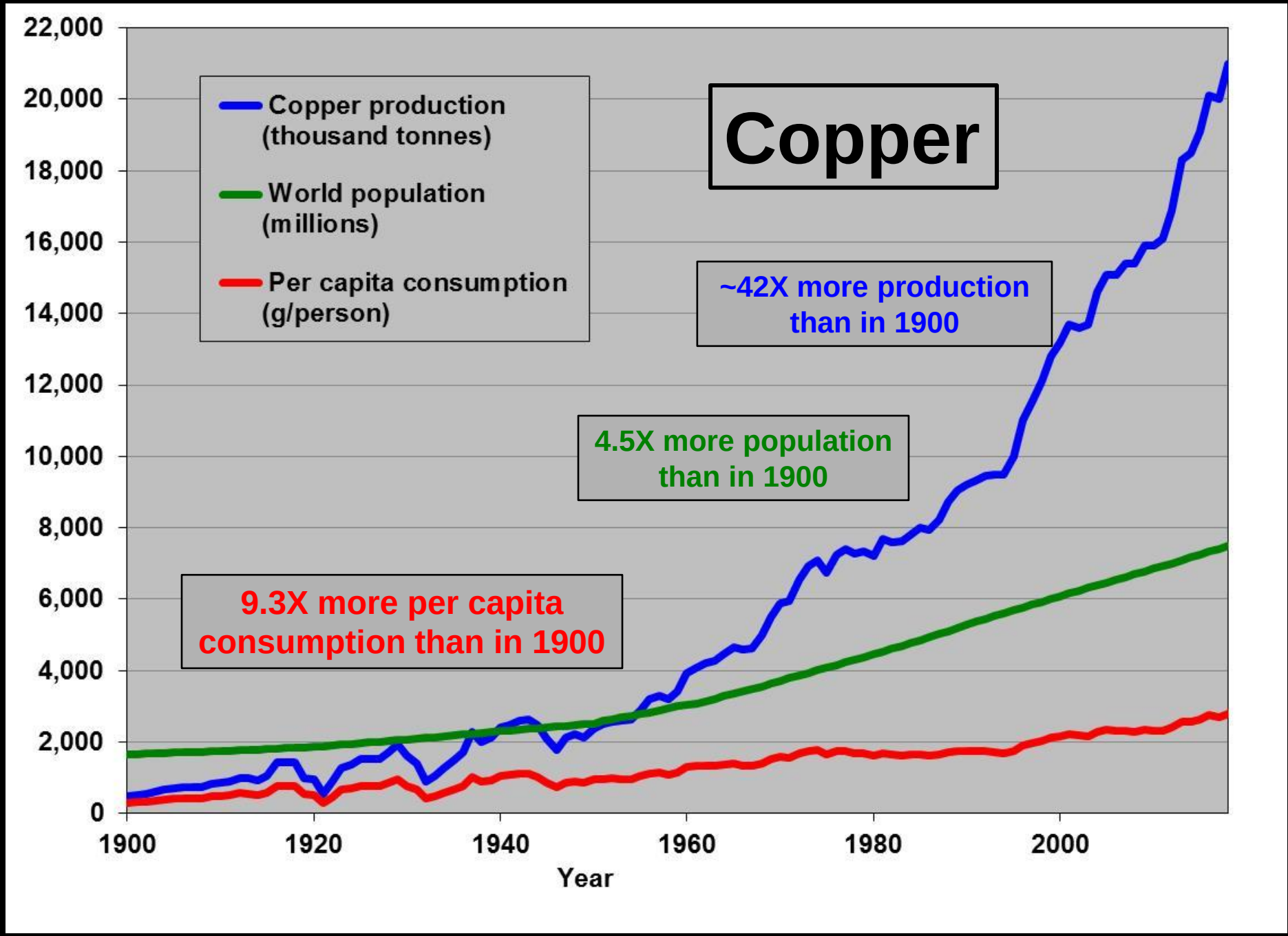
Opportunities in Global Mineral Resources

Demand is high.

Resources are global, but China is #1.

The trends will help guide exploration and development.

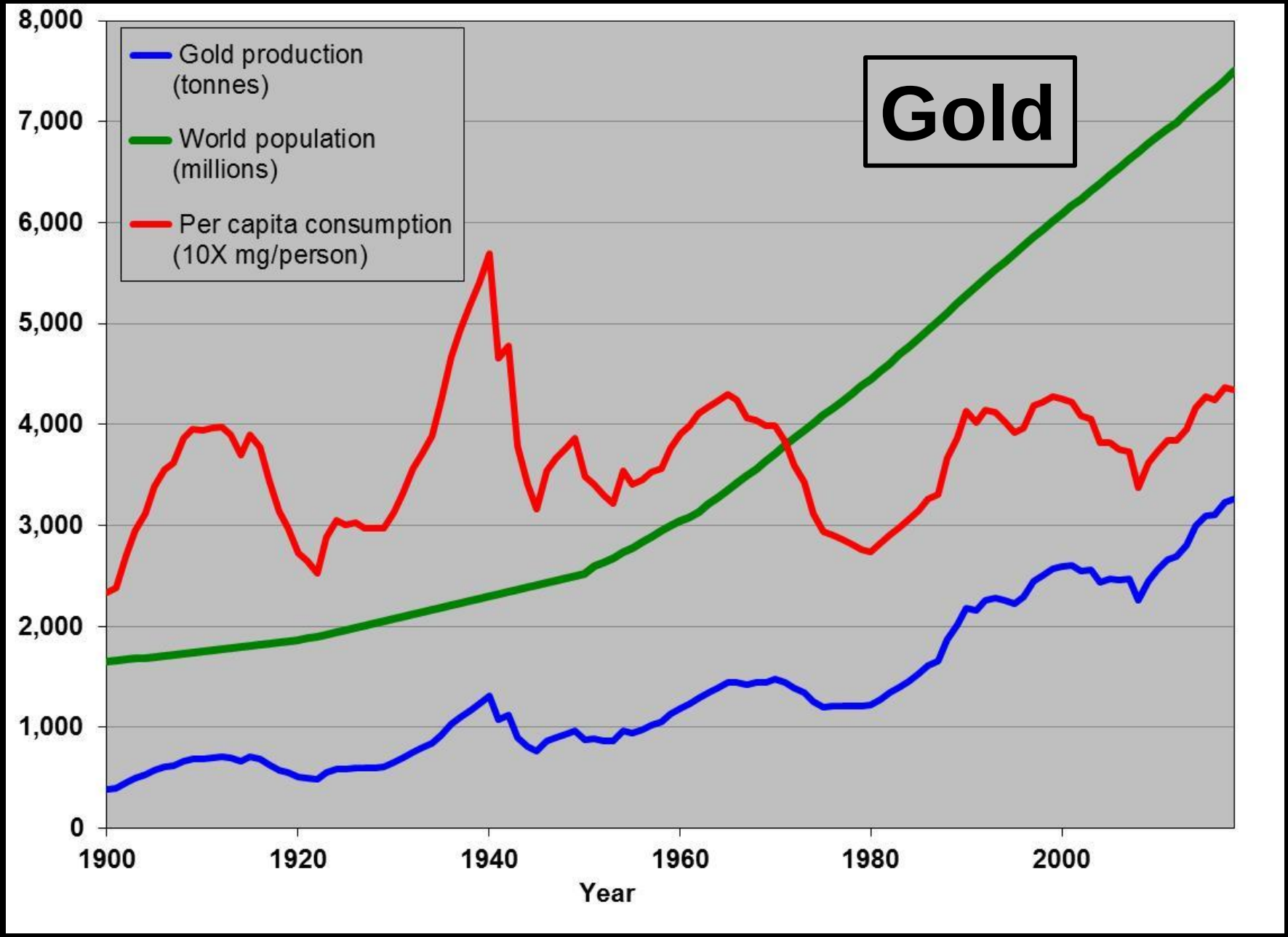
Round Mountain, NV (2007)



Data from USGS, USBM, & CIA, to 2018

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

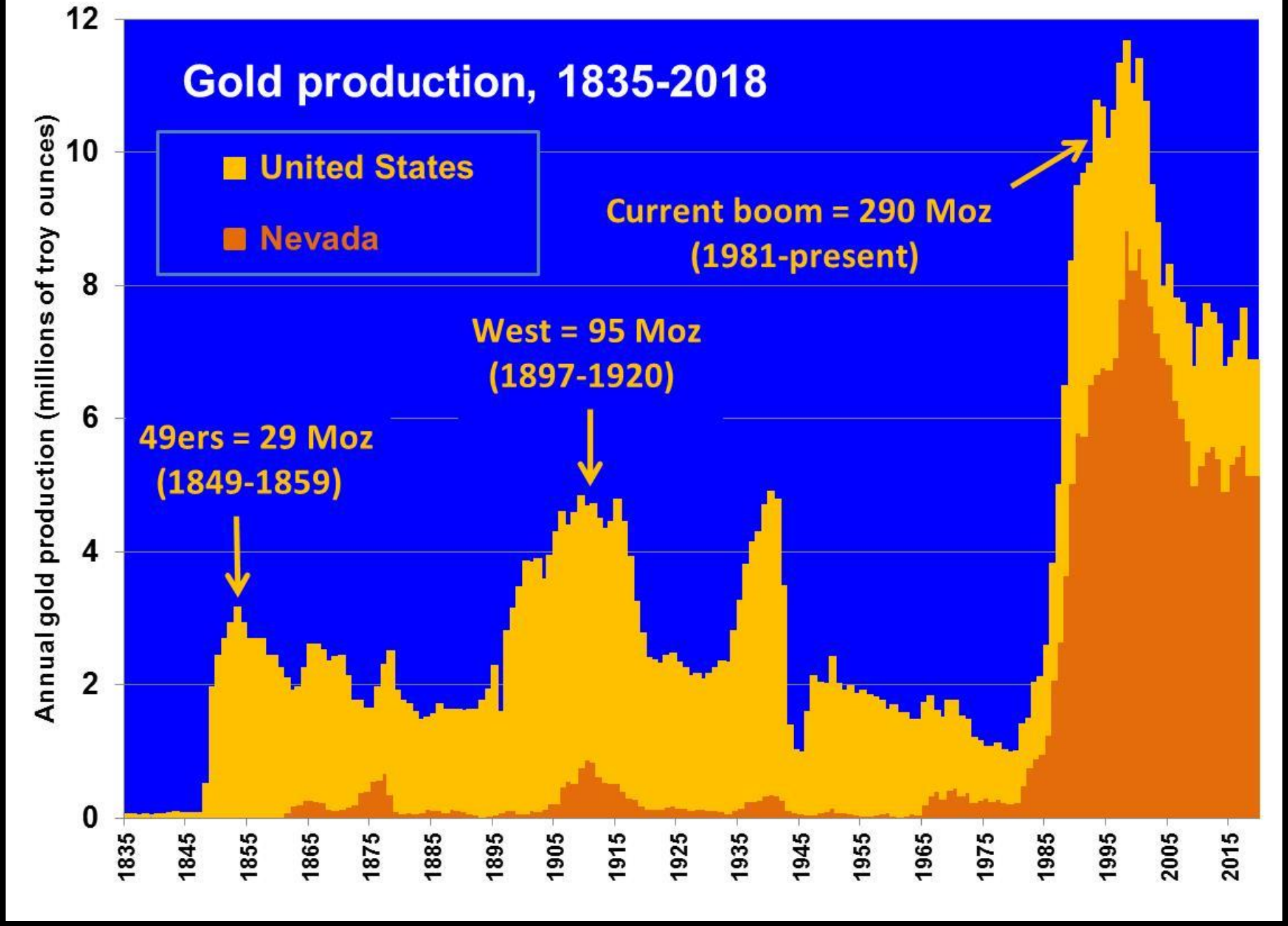
Global copper production in 2018 (21 million metric tons) exceeded over 100 years of production from the Bingham Canyon mine (~17 million metric tons).



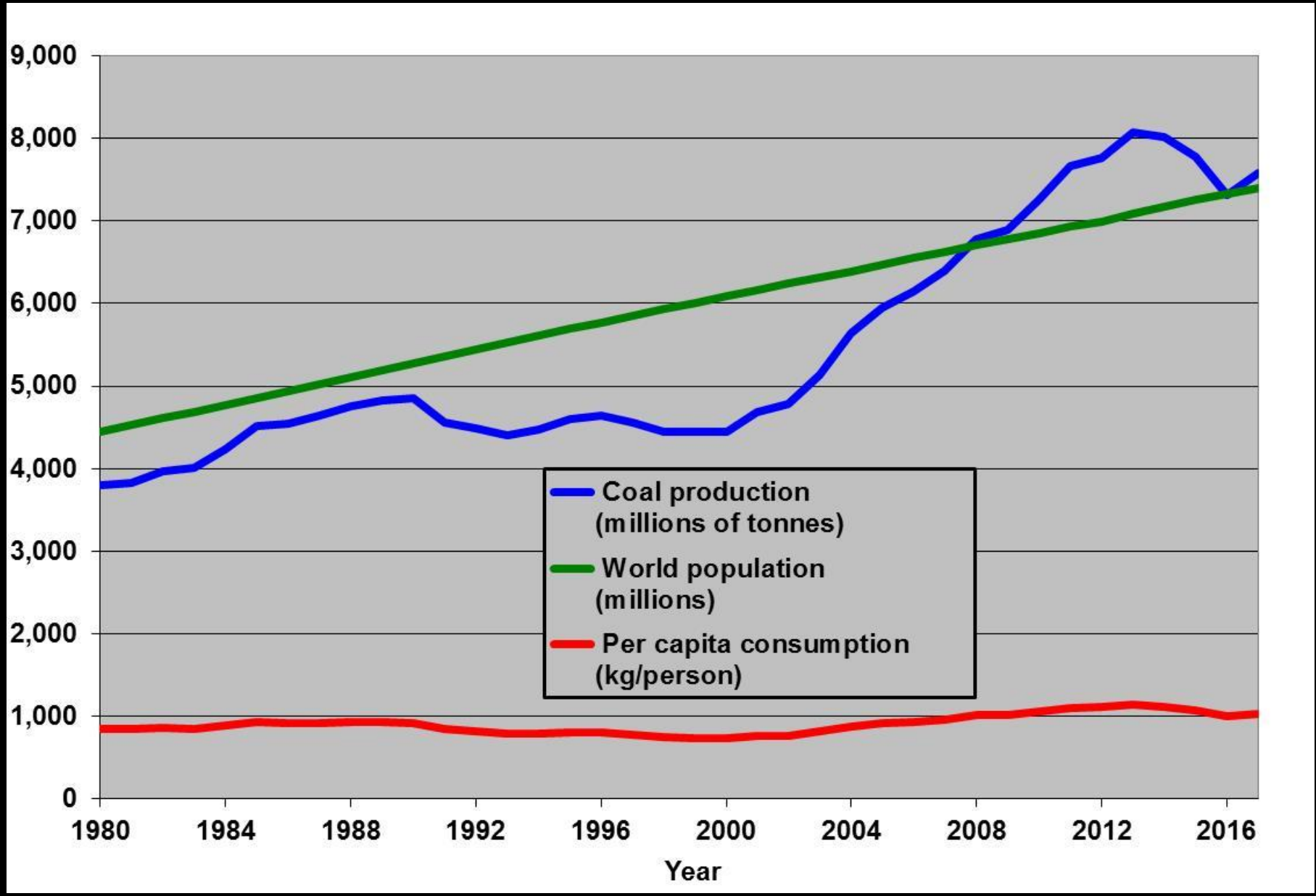
Demand is high for nearly every mineral resource.

Data from USGS, USBM, & CIA, to 2018

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.



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



Coal has recently become an exception.
Global demand has fluctuated; per capita consumption is steady.

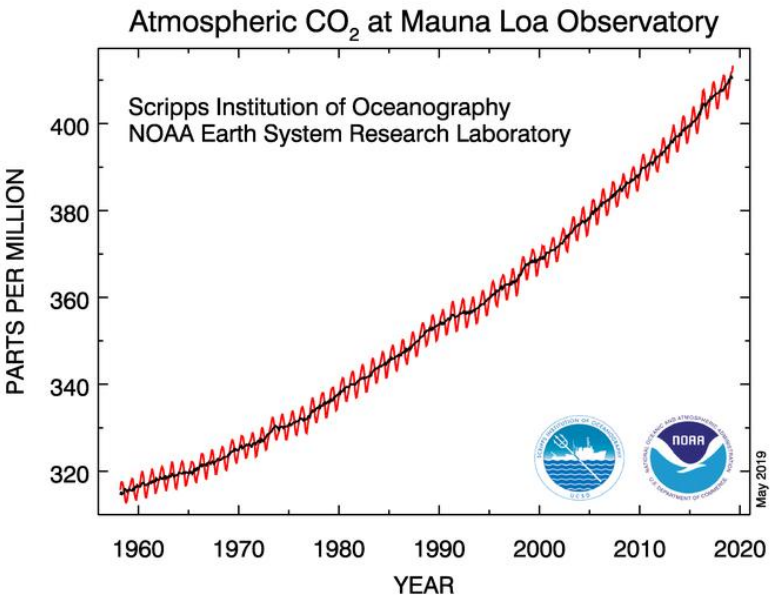
Coal seams near Healy, Alaska

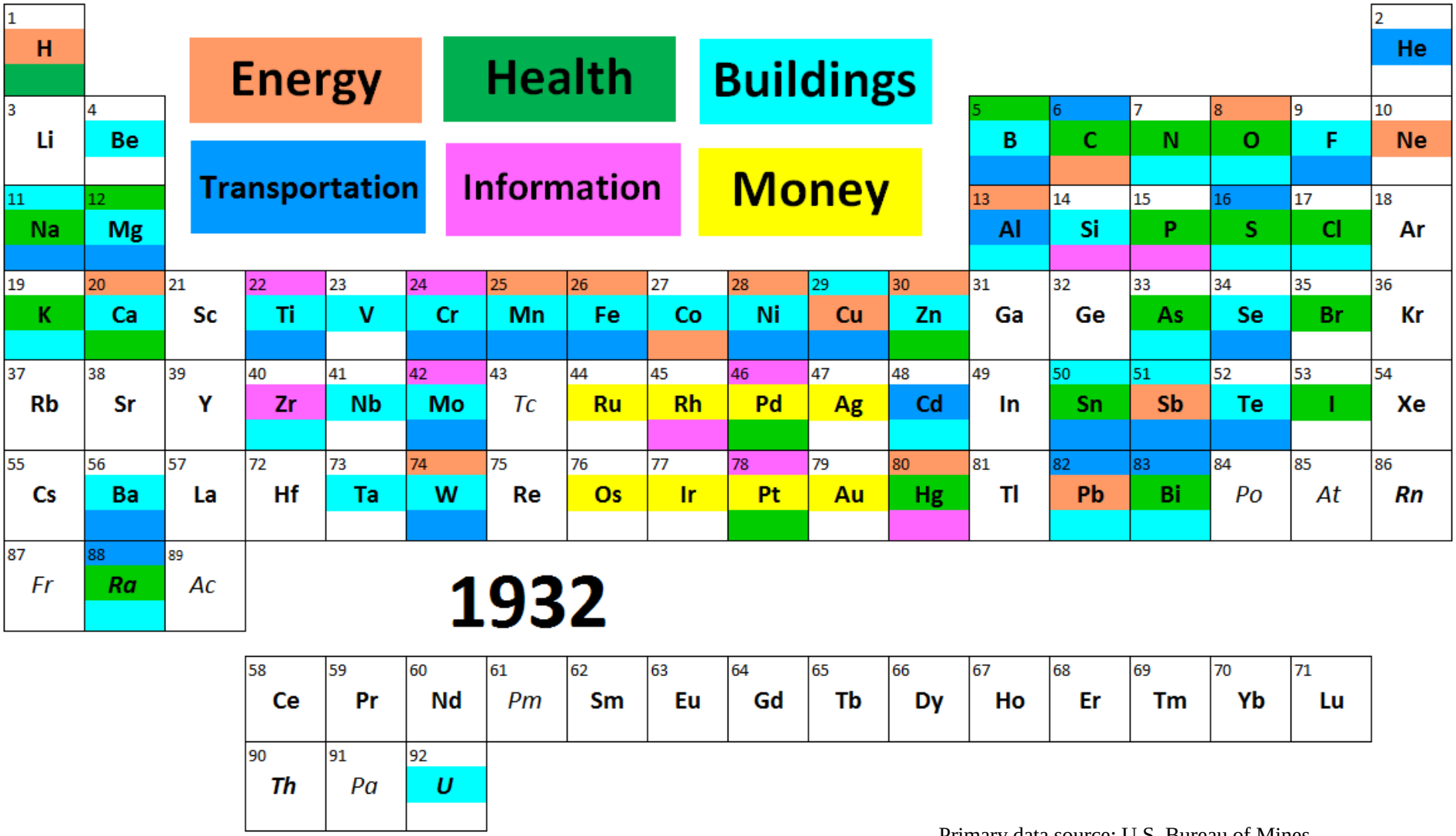
Annual global coal production (~7.6 billion metric tons in 2017) equals approximately 5.2 km^3 of coal, or ~1,840 km^2 of land with an average coal thickness of 3 m.

The amount of CO_2 released from burning of coal in 2017 would have been enough, without natural reduction from plant growth, rain, and other processes, to raise the concentration of CO_2 in the atmosphere by ~2.8 ppmv, a bit more than the recent global trend of CO_2 increasing ~2.2 ppmv per year.

Valmy coal-fired power plant, Humboldt County, Nevada

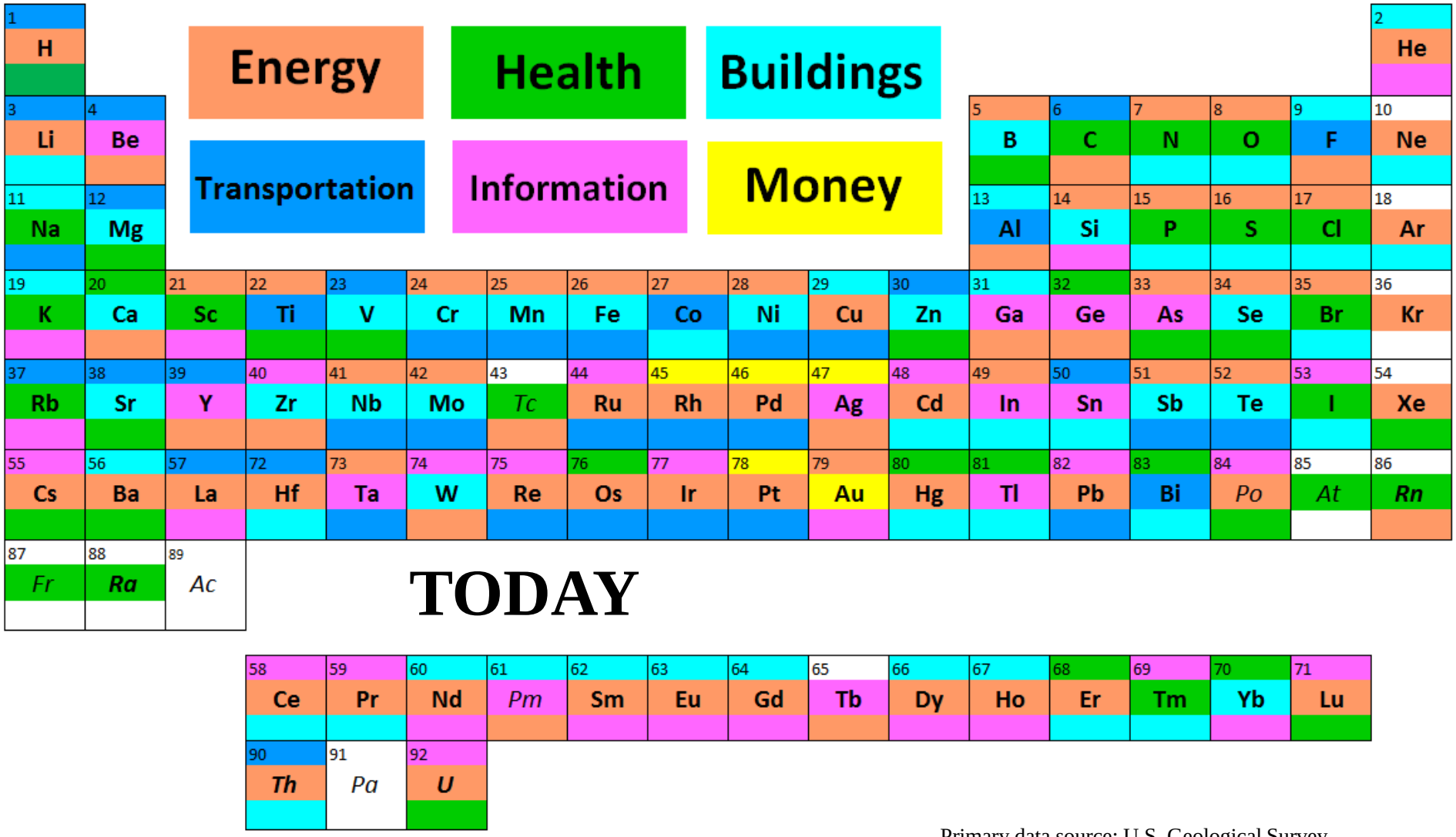
(7.585×10^{15} g coal burned in 2017) x (~0.8 g C/g coal) x (3.6642 g CO_2/ g C)/(5.15×10^{21} g air in the atmosphere) x (28.97 g air)/(mole air) x (1 mole CO_2)/(44.0095 g CO_2) x 10^6 ppmv CO_2/(mole CO_2/mole air)
= ~2.8 ppmv CO_2 potentially added to the atmosphere





Primary data source: U.S. Bureau of Mines

The number of mineral commodities in demand for products in society has increased markedly in the last 100 years.



The number of mineral commodities in demand for products in society has increased markedly in the last 100 years.

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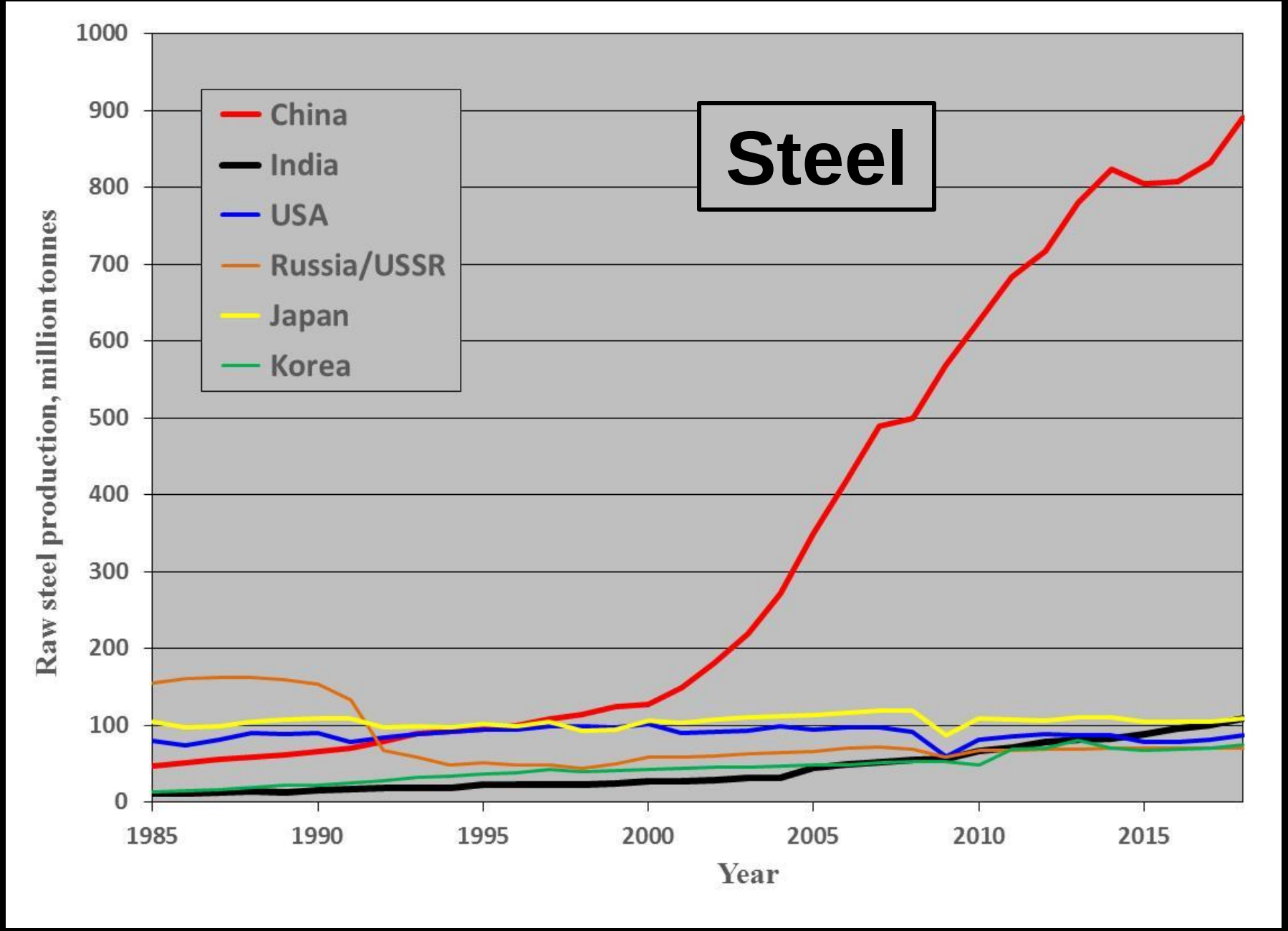
Resources are global, but China is #1.

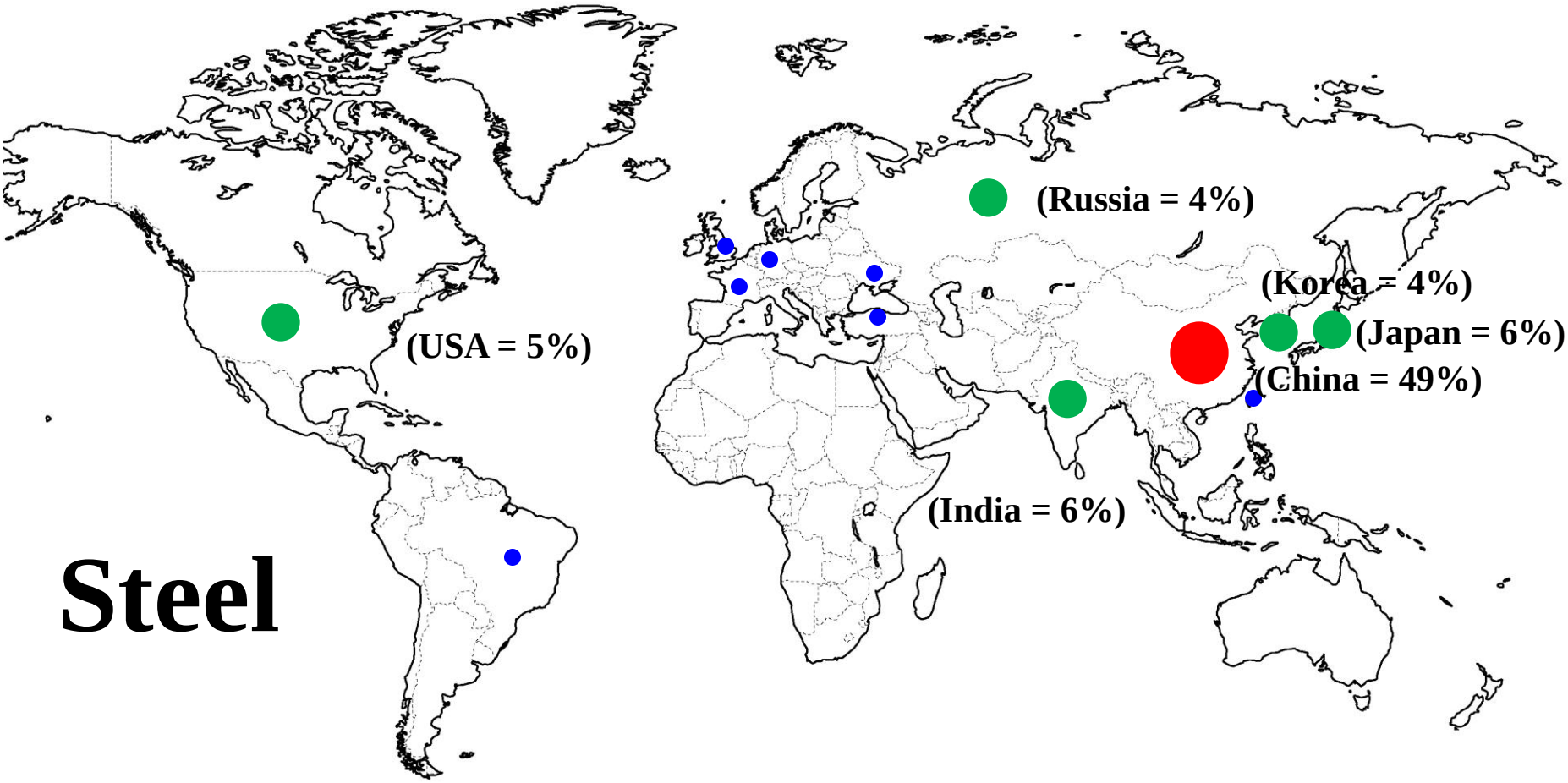
The trends will help guide exploration and development.

Round Mountain, NV (2007)



From 1997 to 2018, China's production increased by 8.2X; India's increased by 4.6X.

Steel



World's leading producer

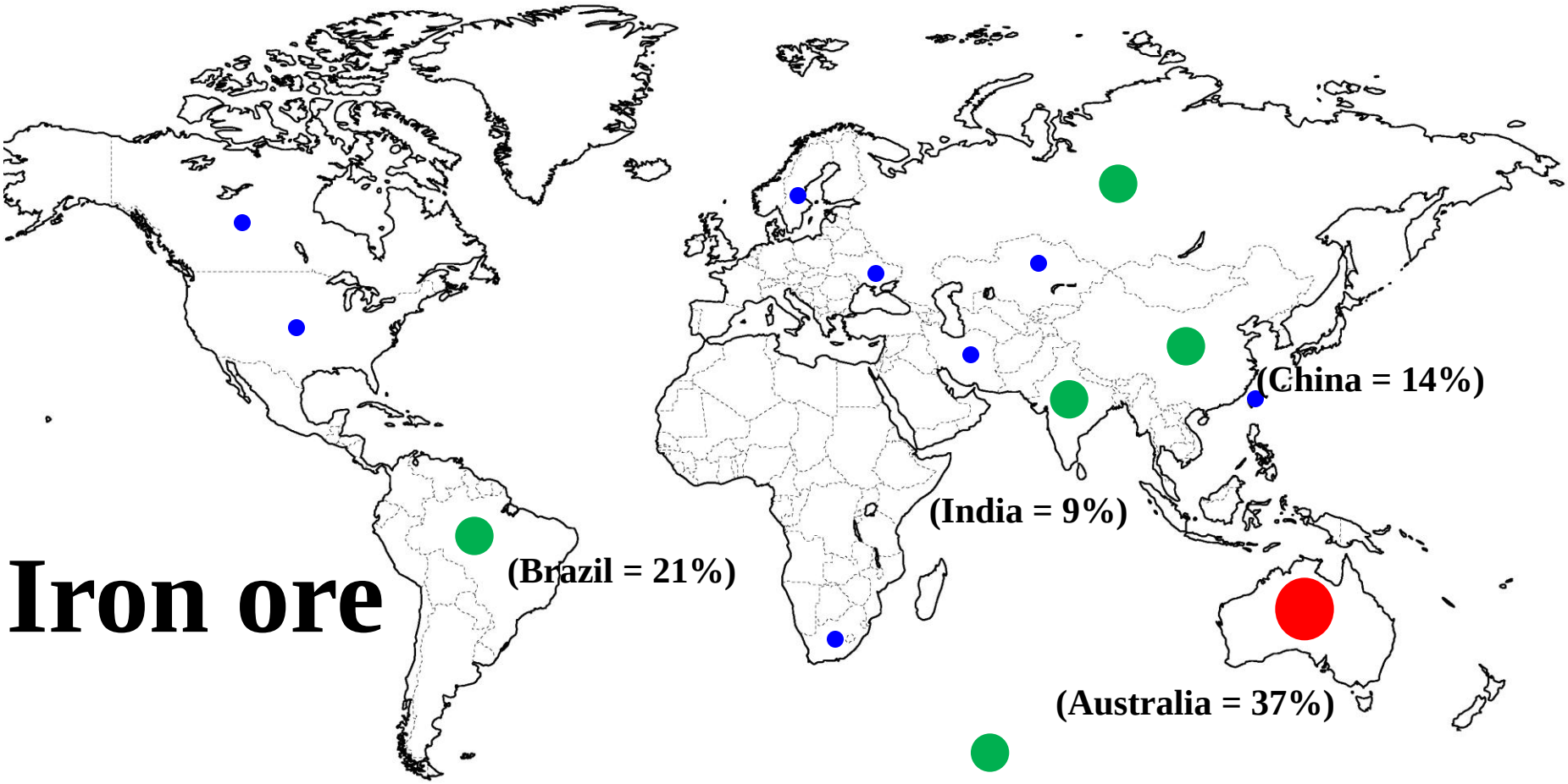
Countries with 4% or more of global production

Other countries with production or major reserves

Data source: USGS

Resources are global, but China is Number One.

Iron ore



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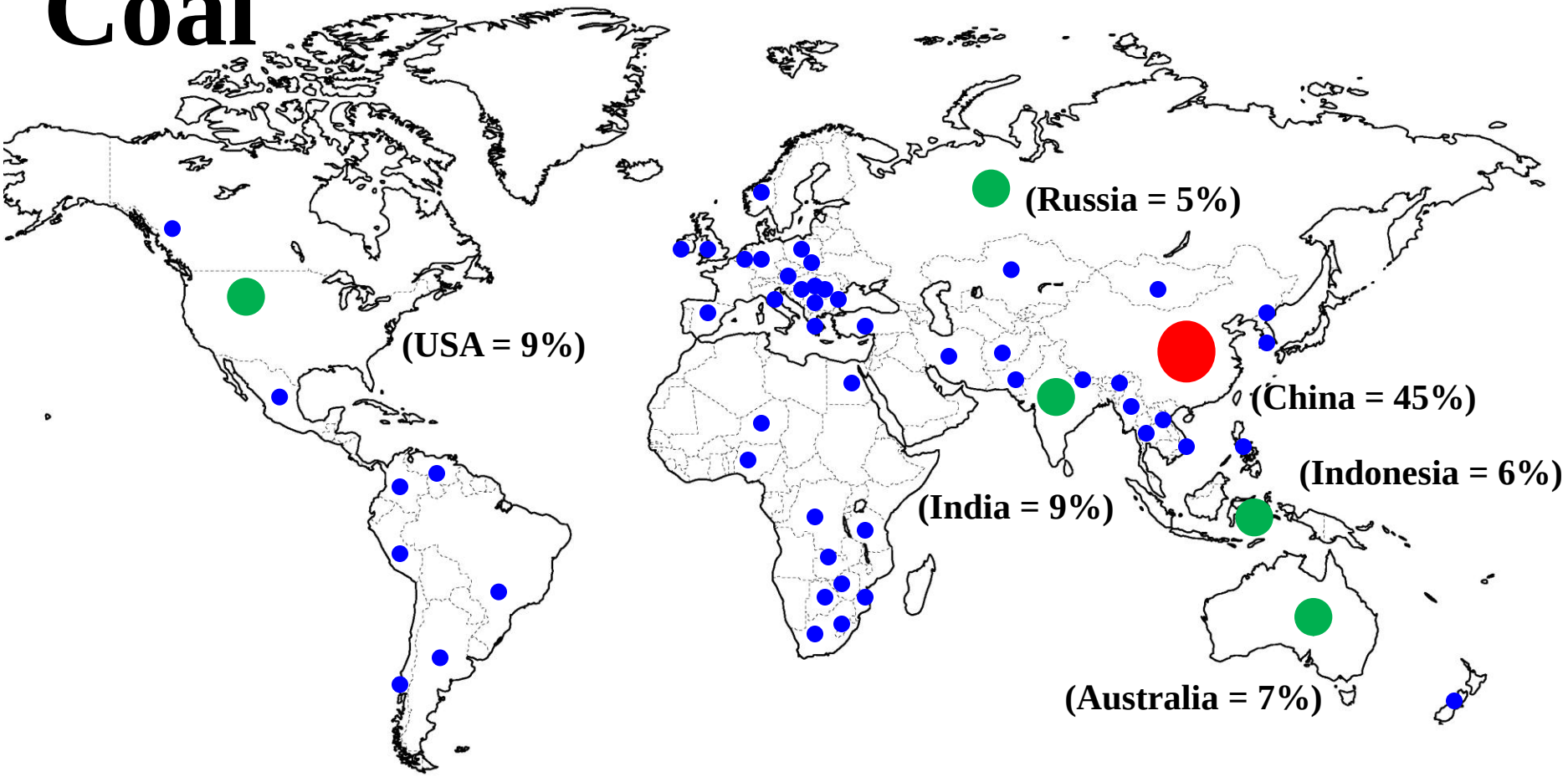
China imports iron from Australia & Brazil.

Coal



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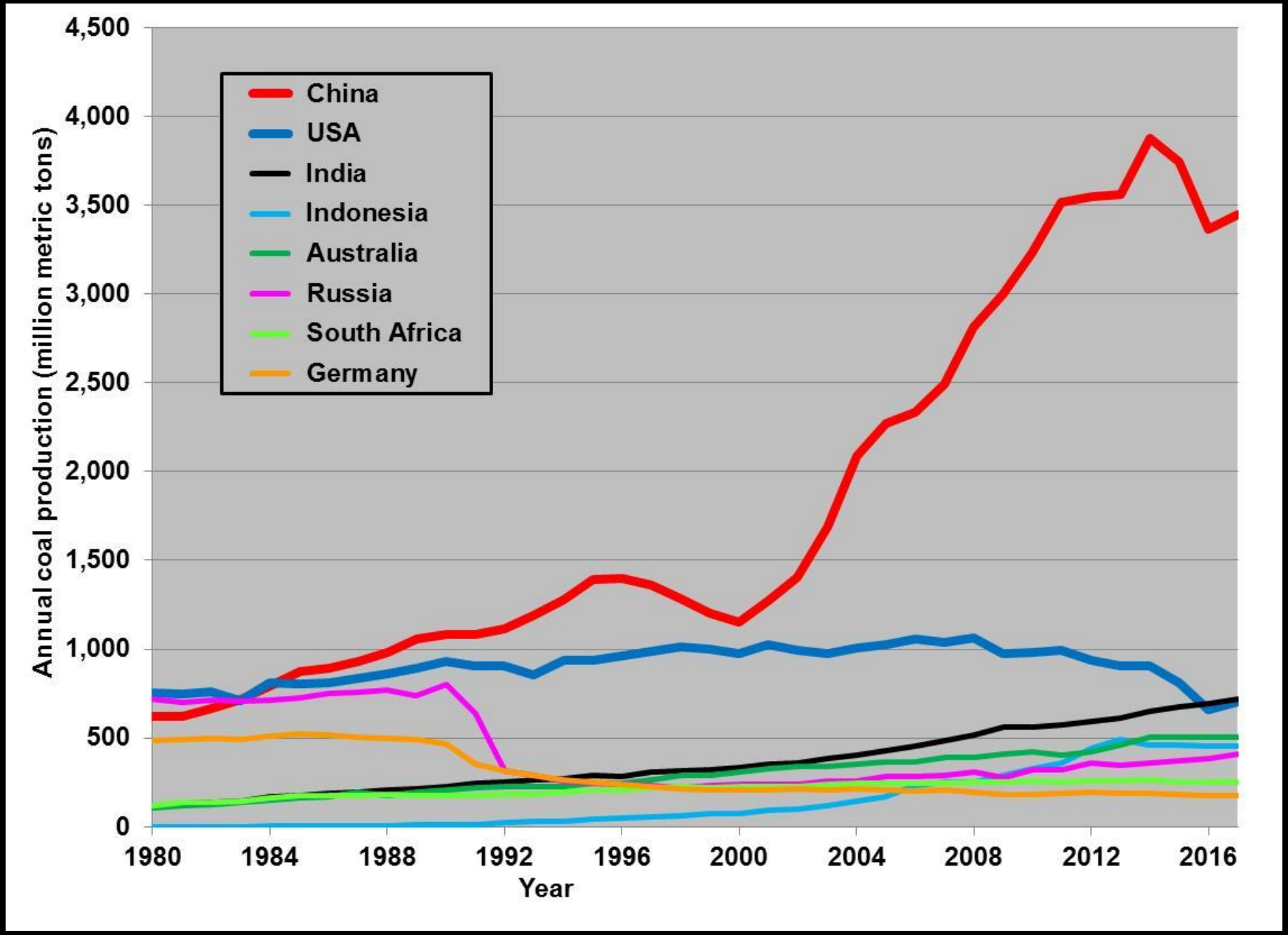
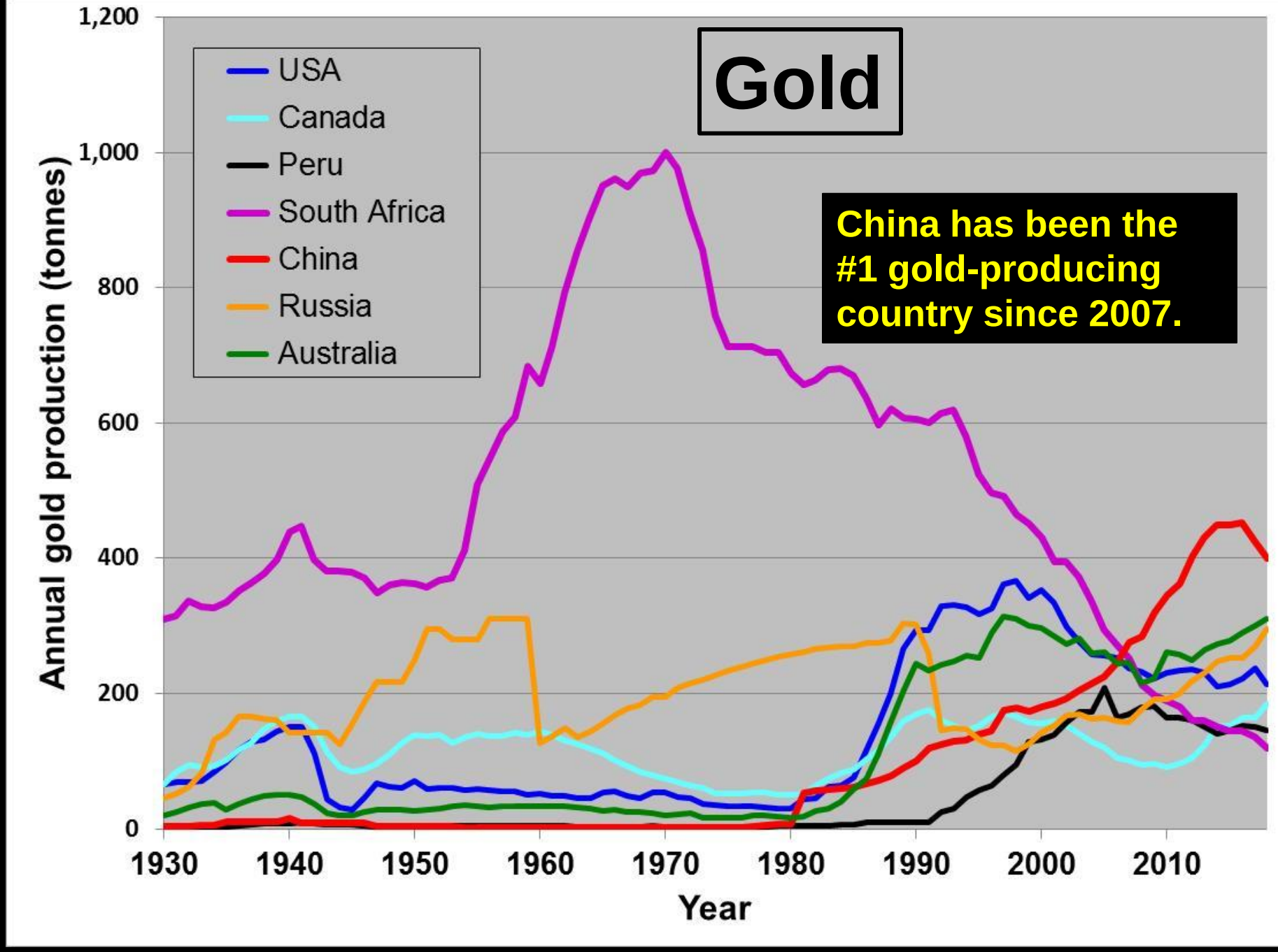
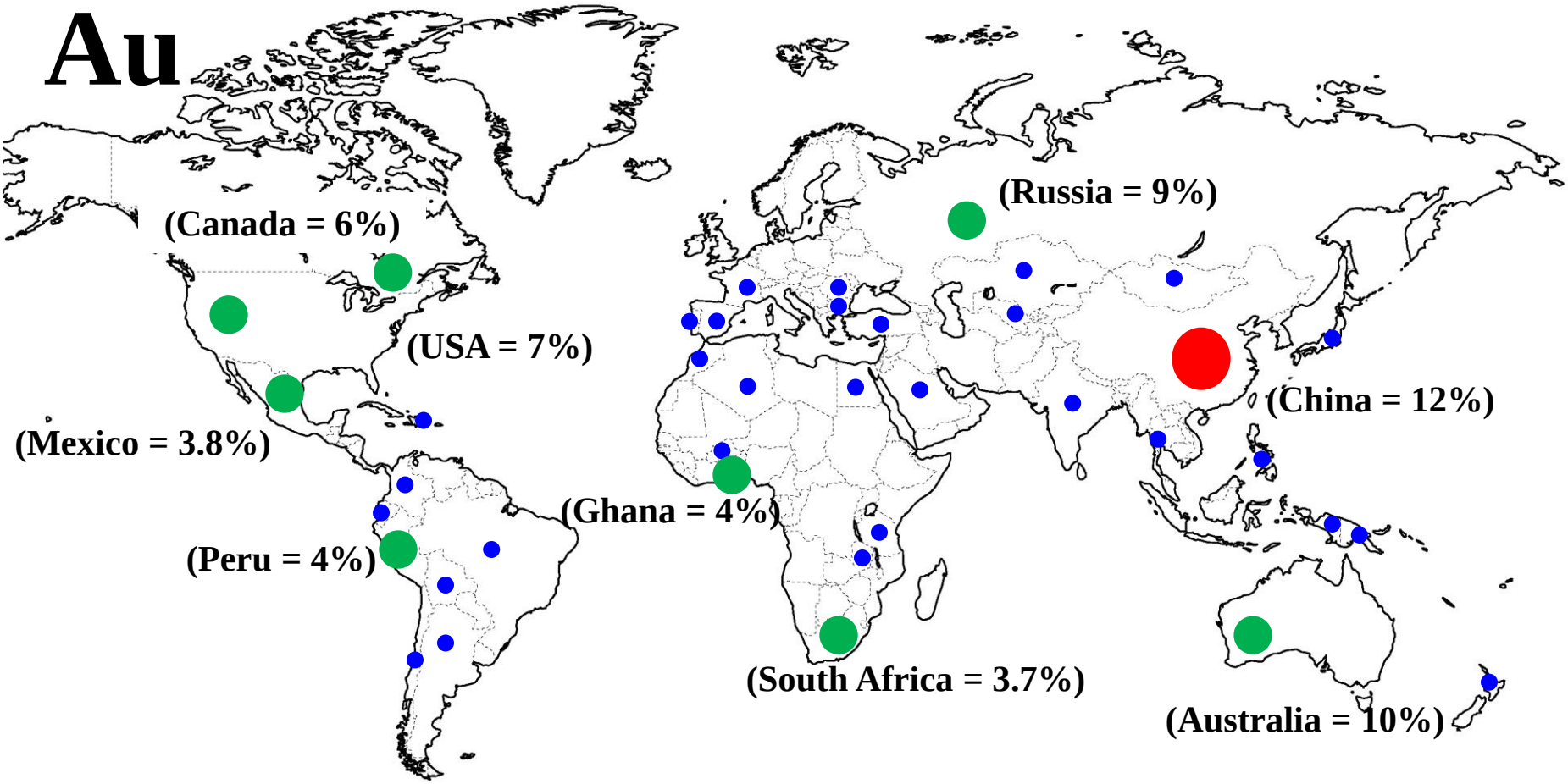


India has been increasing its coal use, while China & USA cut back.


Gold
USA
Canada
Peru
South Africa
China
Russia
Australia
China has been the #1 gold-producing country since 2007.
Annual gold production (tonnes)
1,200
1,000
800
600
400
200
0
1930
1940
1950
1960
1970
1980
1990
2000
2010
Year

Au



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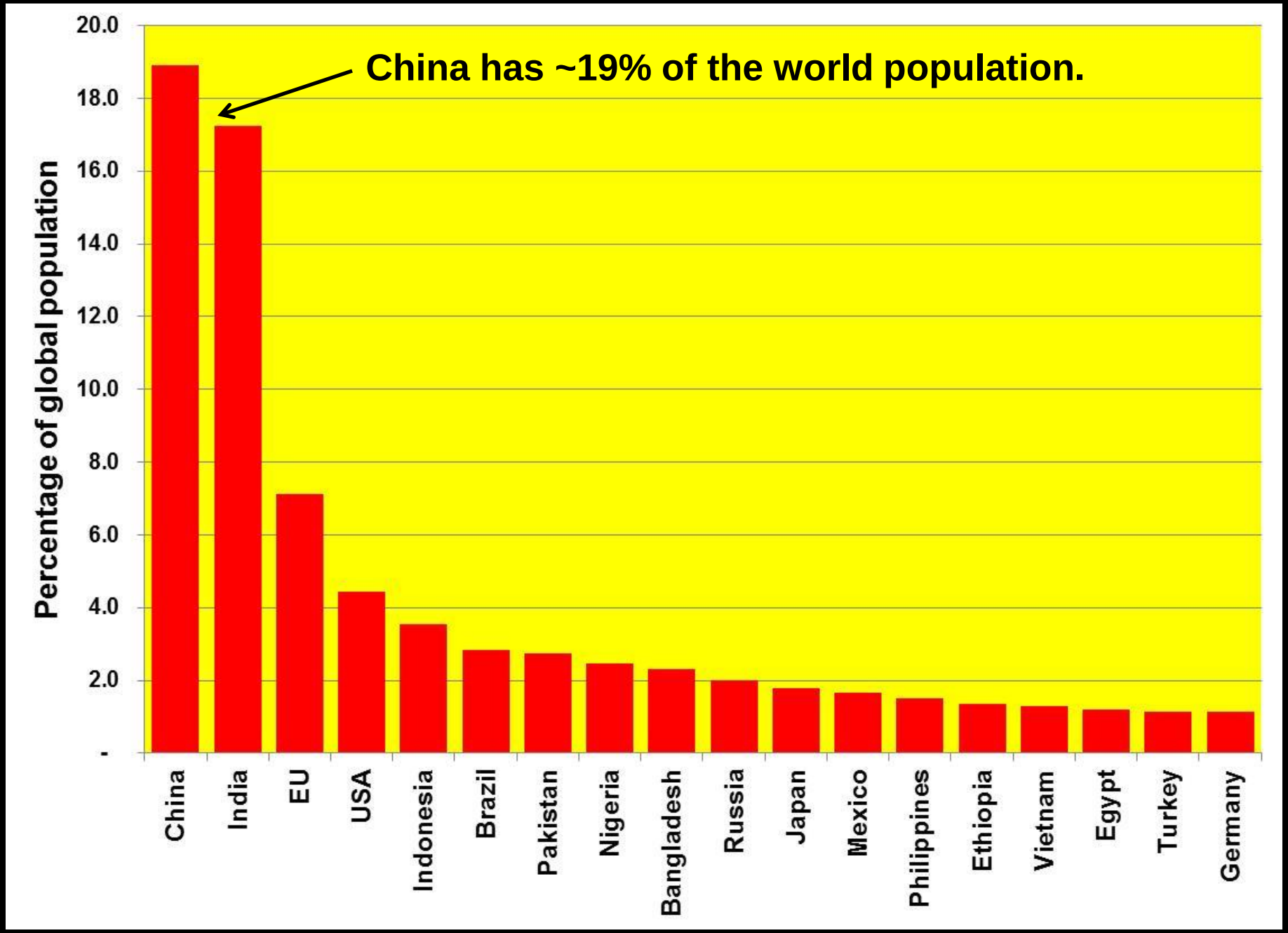
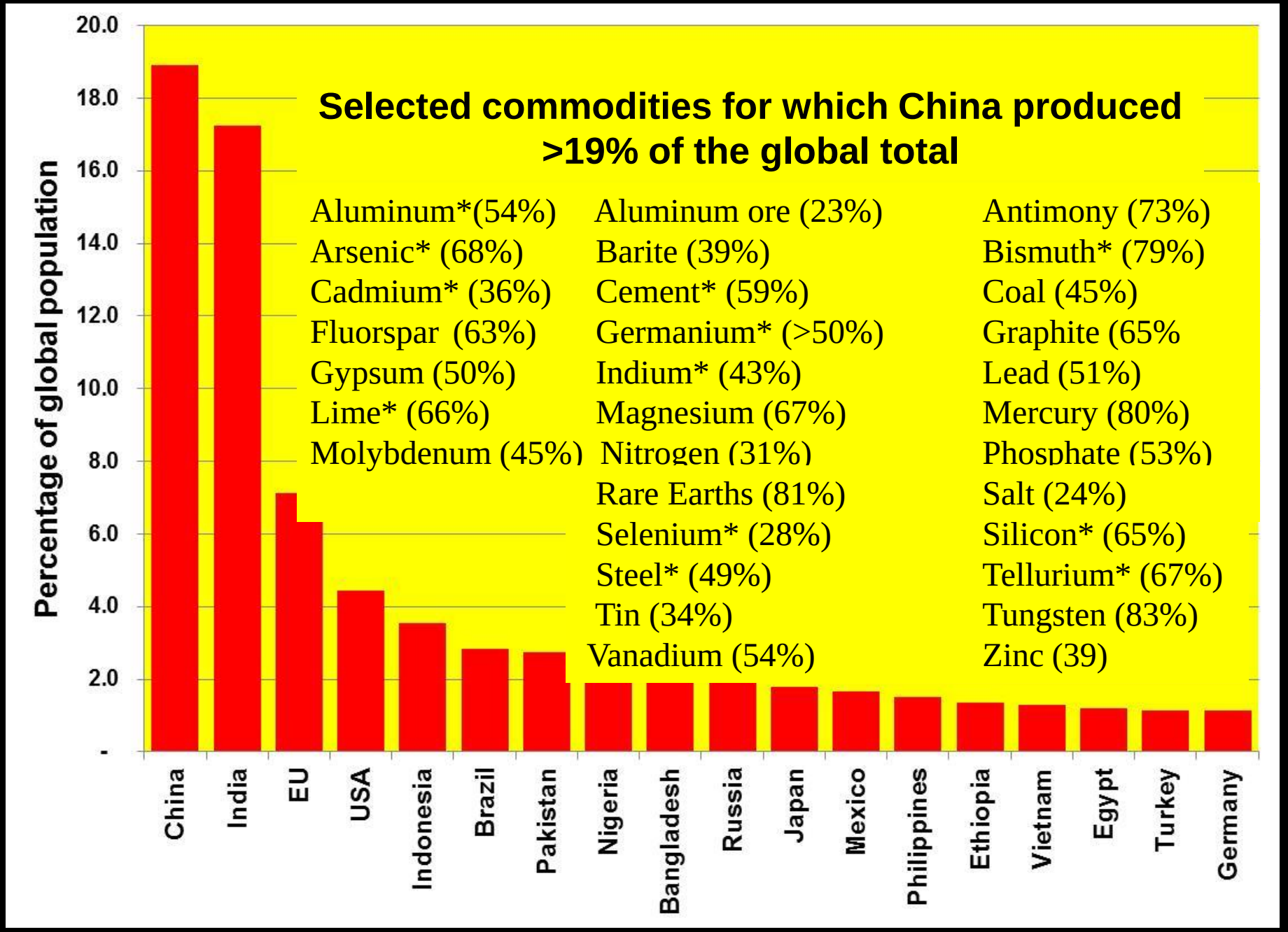


Data from CIA.

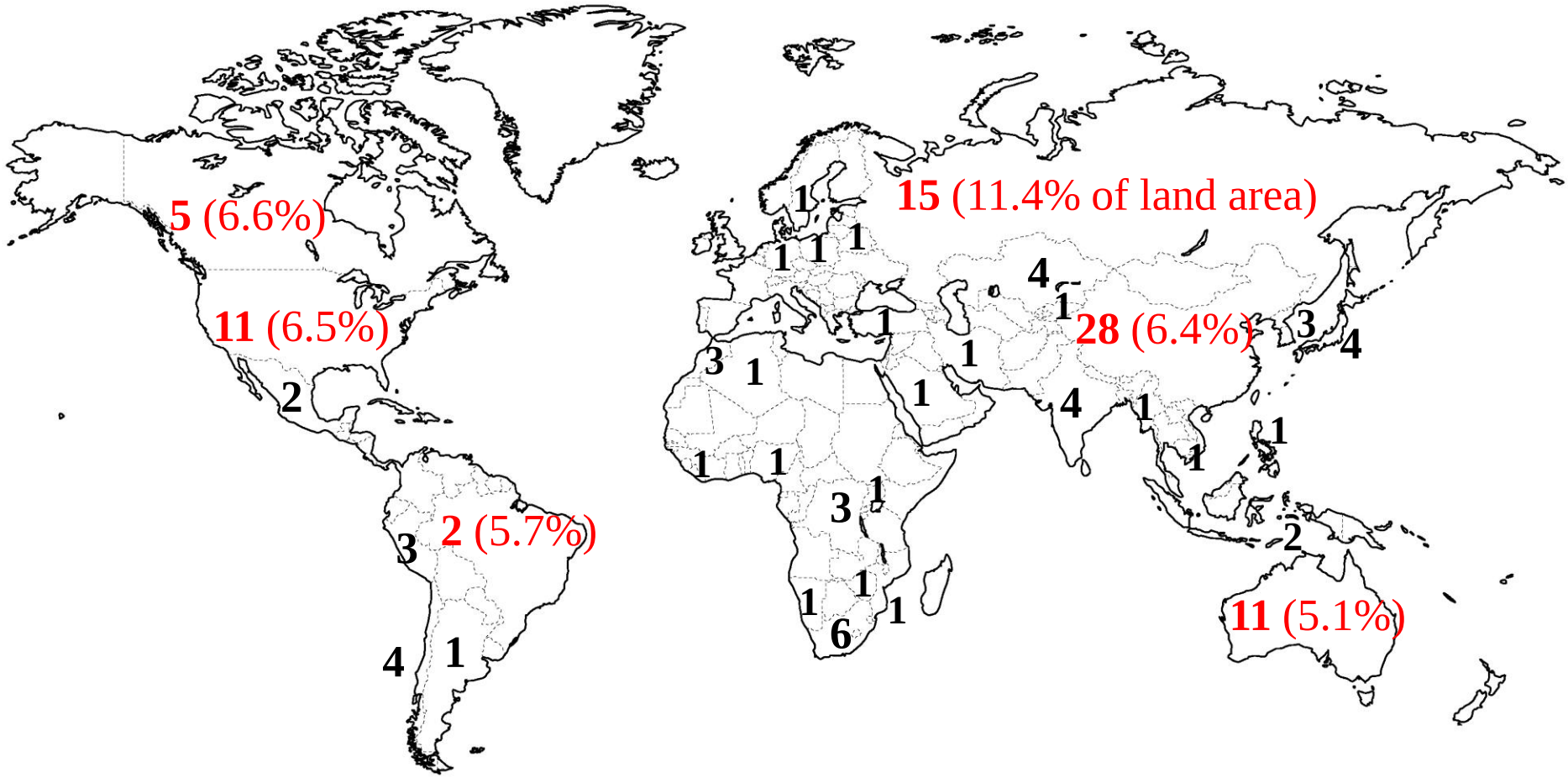


Data from USGS in 2017, except coal from IEA in 2016.

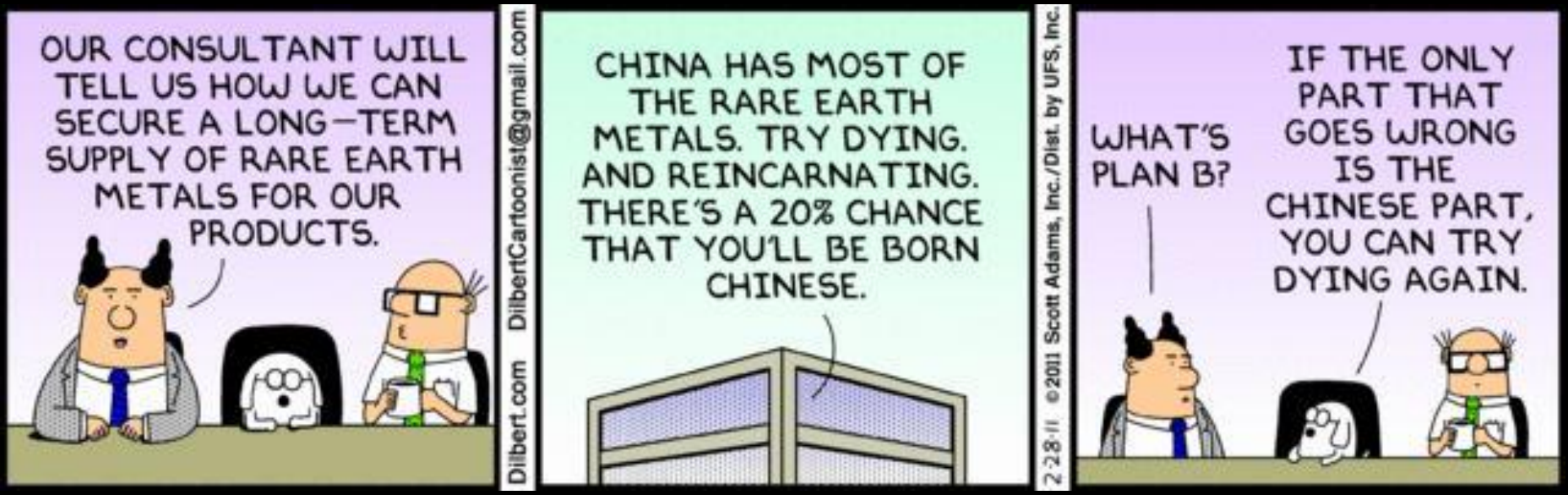
In production of 44 mineral commodities, China ranks well above all others.

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

Data for 2017, except coal, oil, and gas (2016)



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).


OUR CONSULTANT WILL TELL US HOW WE CAN SECURE A LONG-TERM SUPPLY OF RARE EARTH METALS FOR OUR PRODUCTS.
Dilbert.com DilbertCartoonist@gmail.com
CHINA HAS MOST OF THE RARE EARTH METALS. TRY DYING. AND REINCARNATING. THERE'S A 20% CHANCE THAT YOU'LL BE BORN CHINESE.
2-28-11 ©2011 Scott Adams, Inc./Dist. by UFS, Inc.
WHAT'S PLAN B?
IF THE ONLY PART THAT GOES WRONG IS THE CHINESE PART, YOU CAN TRY DYING AGAIN.

So what?

And who cares?

Opportunities in Global Mineral Resources

Demand is high.

Resources are global, but China is #1.

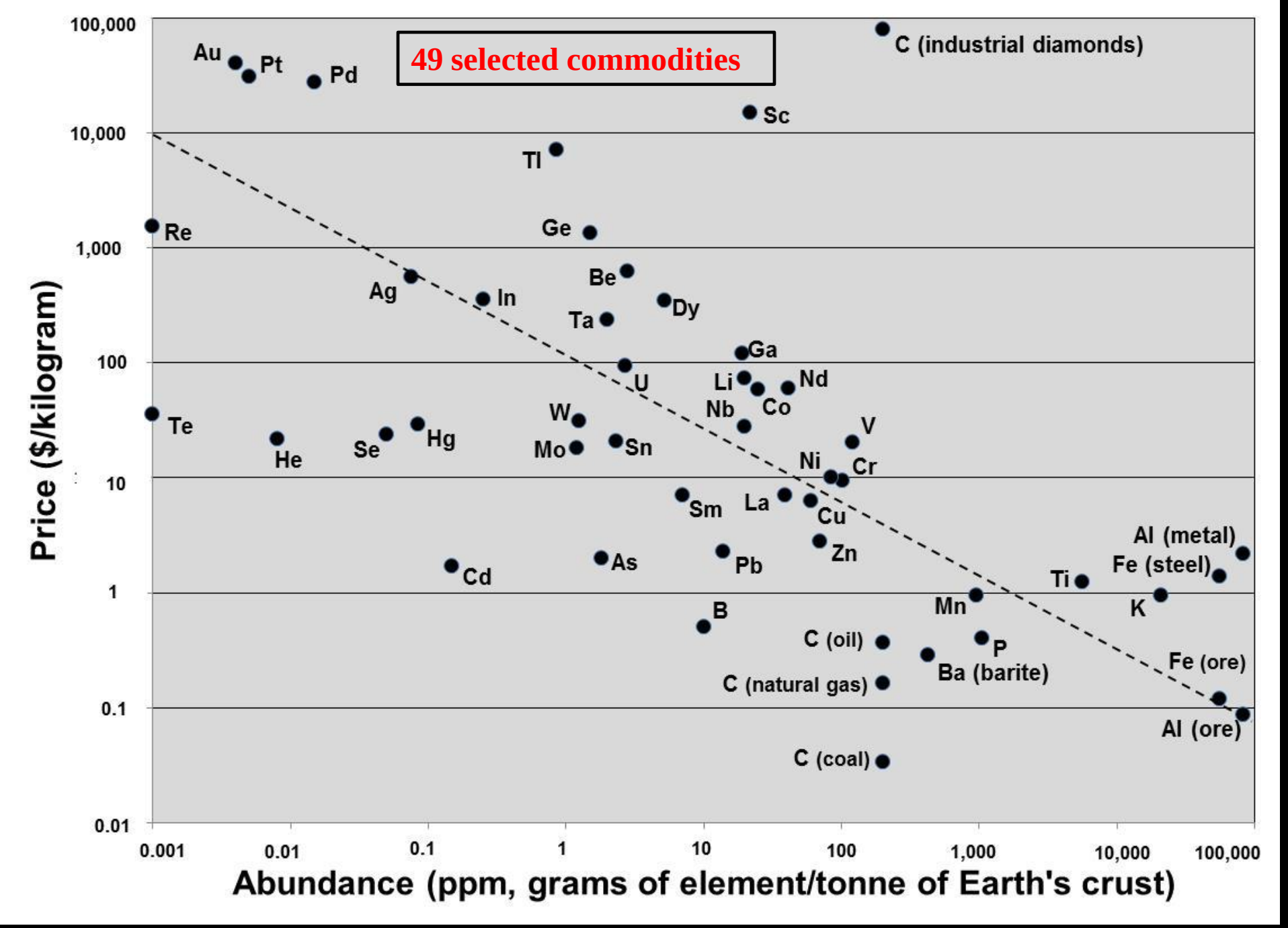
The trends will help guide exploration and development.

Round Mountain, NV (2007)

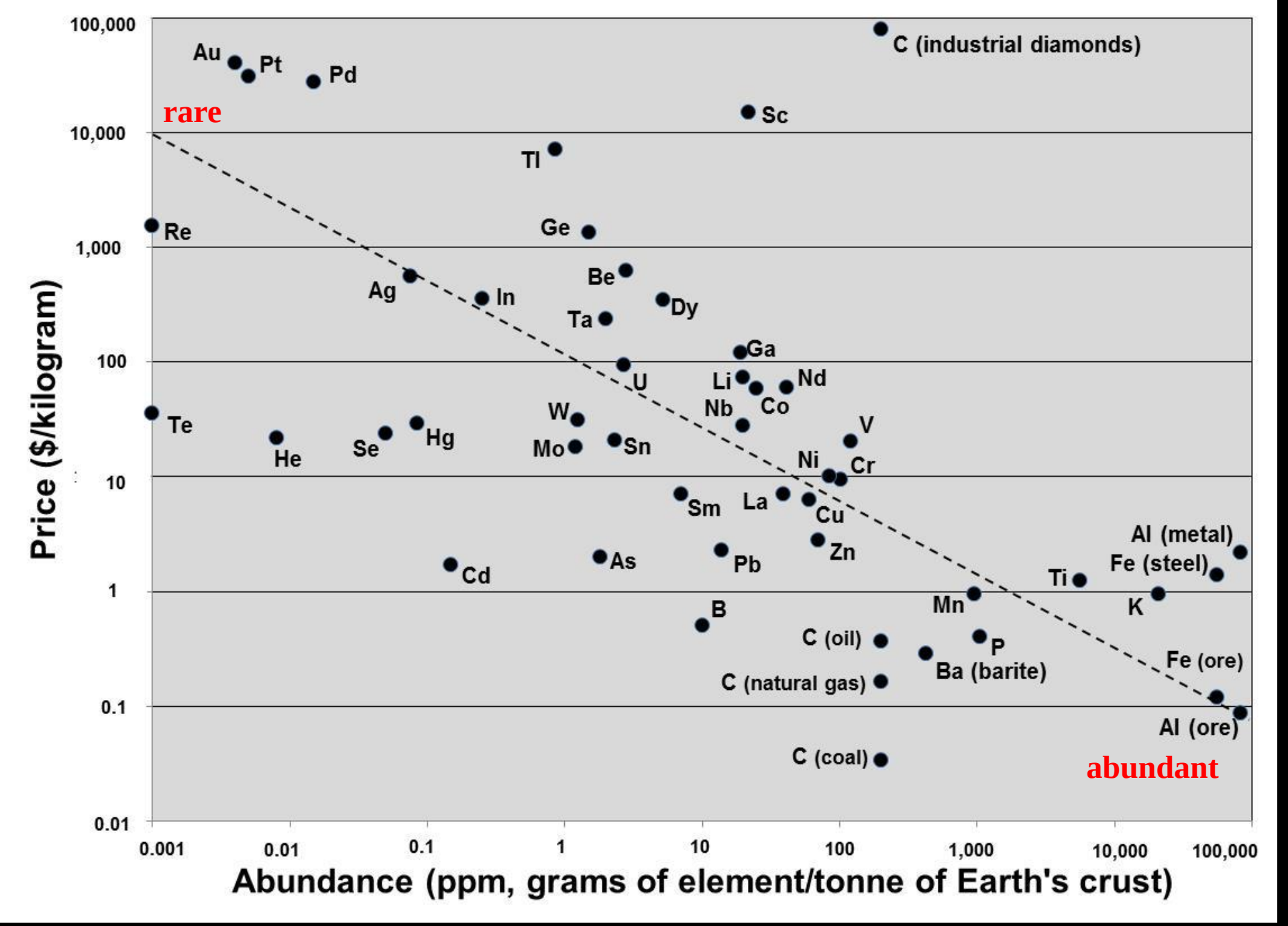
- **Which commodities does a country need to sustain or grow its economy?**

- **For which commodities is more research needed on models of formation and methods for extraction?**

- **For which commodities should a company explore?**



Data for 2017 (coal, oil, gas 2016)



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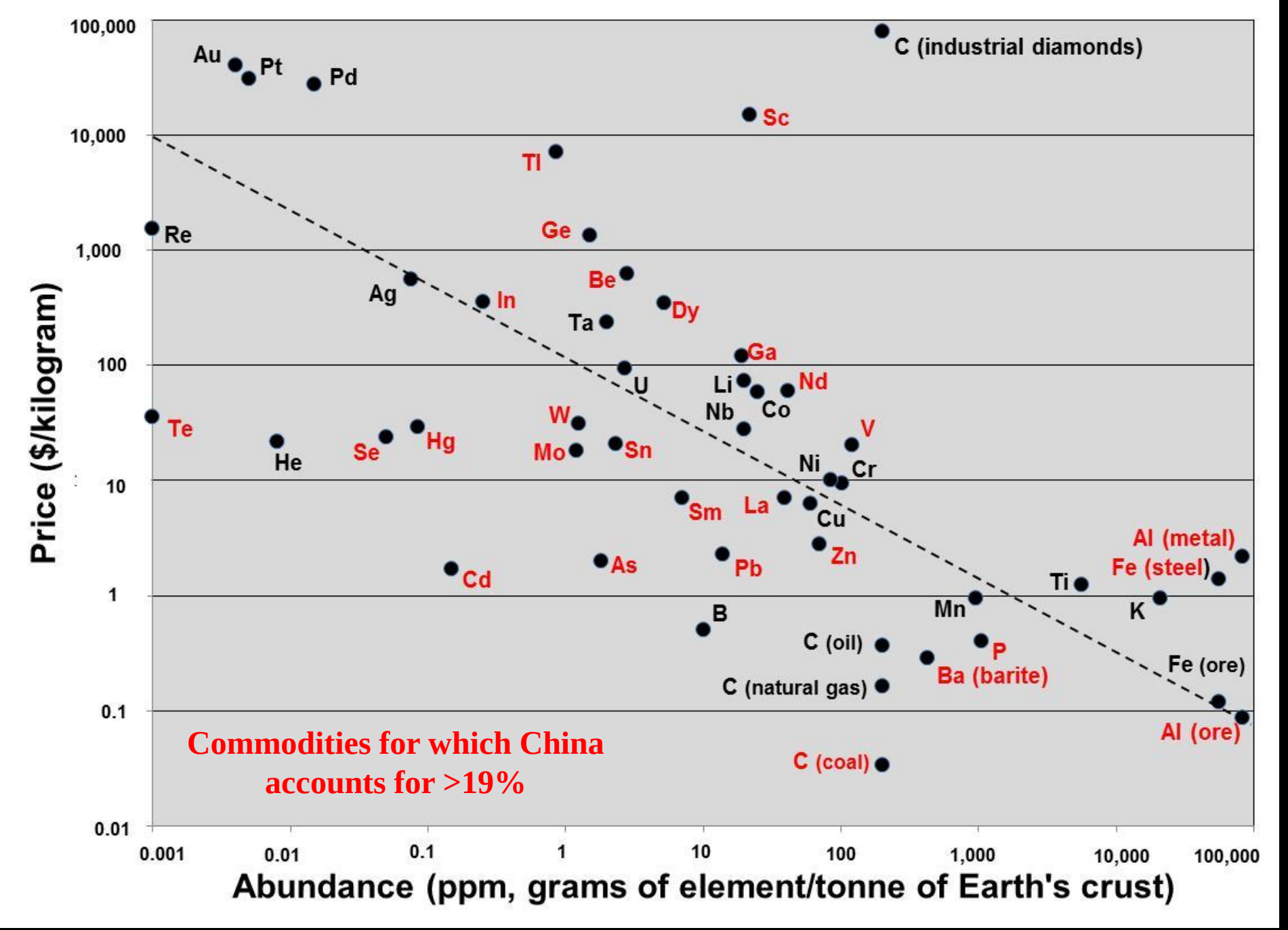
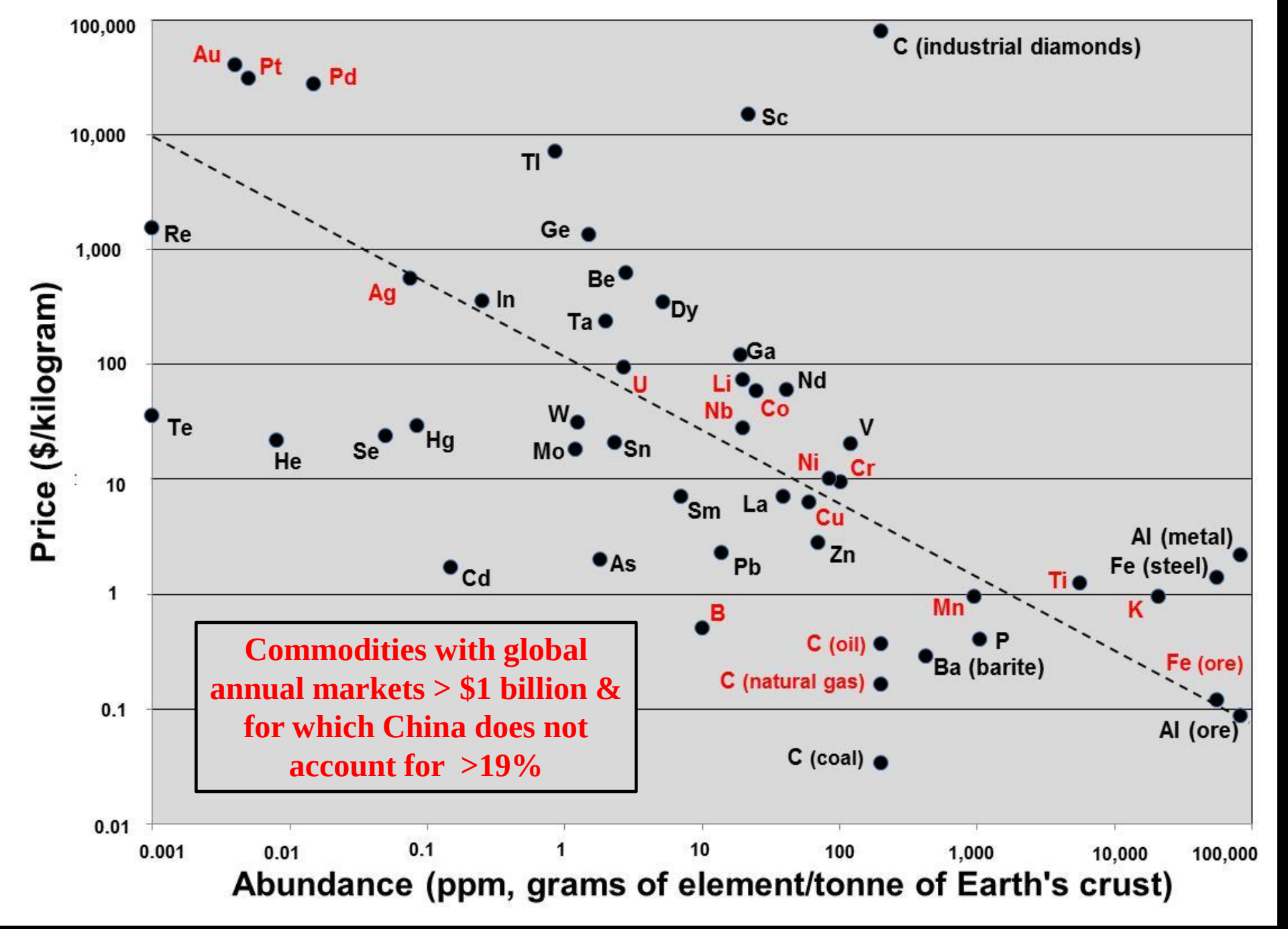

Price ($/kilogram)
100,000
10,000
1,000
100
10
1
0.1
0.01
0.001
0.01
0.1
1
10
100
1,000
10,000
100,000
Abundance (ppm, grams of element/tonne of Earth's crust)
Au
Pt
Pd
C (industrial diamonds)
Sc
Tl
Re
Ge
Be
Ag
In
Dy
Ta
Ga
U
Li
Nd
Co
Nb
Te
W
V
He
Se
Hg
Mo
Sn
Ni
Cr
Sm
La
Cu
Al (metal)
Fe (steel)
Zn
As
Pb
Cd
Ti
Mn
K
B
C (oil)
P
Ba (barite)
Fe (ore)
C (natural gas)
Al (ore)
C (coal)
Commodities for which China accounts for >19%


Price ($/kilogram)
100,000
10,000
1,000
100
10
1
0.1
0.01
Au
Pt
Pd
C (industrial diamonds)
Sc
Tl
Re
Ge
Be
Ag
In
Dy
Ta
Ga
U
Li
Nd
Co
Nb
Te
W
V
He
Se
Hg
Mo
Sn
Ni
Cr
Sm
La
Cu
Al (metal)
Zn
Fe (steel)
Cd
As
Pb
Ti
Mn
K
B
C (oil)
P
Ba (barite)
Fe (ore)
C (natural gas)
Al (ore)
C (coal)
Commodities with global annual markets > $1 billion & for which China does not account for >19%
0.001
0.01
0.1
1
10
100
1,000
10,000
100,000
Abundance (ppm, grams of element/tonne of Earth's crust)

Elements with (a) high prices relative to their abundances, (b) large markets, and (c) limited production from China are likely to be most attractive. These include

- **Gold**
- **Platinum-group elements**
- **Uranium**
- **Lithium**
- **Cobalt**
- **Niobium**
- **Titanium**
- **Potassium**
- **Iron**

"Forget gold. Strategic metals are where it's at."

Energy Critical Elements:

								2 **He** Helium 4.003
			5 **B** Boron 10.811	6 **C** Carbon 12.0107	7 **N** Nitrogen 14.00674	8 **O** Oxygen 15.9994	9 **F** Fluorine 18.9984032	10 **Ne** Neon 20.1797
			13 **Al** Aluminum 26.981538	14 **Si** Silicon 28.0855	15 **P** Phosphorus 30.973761	16 **S** Sulfur 32.066		
28 **Ni** Nickel 58.6934	29 **Cu** Copper 63.546	30 **Zn** Zinc 65.39	31 **Ga** Gallium 69.723	32 **Ge** Germanium 72.61	33 **As** Arsenic 74.92160	34 **Se** Selenium 78.96		
46 **Pd** Palladium 106.42	47 **Ag** Silver 107.8682	48 **Cd** Cadmium 112.411	49 **In** Indium 114.818	50 **Sn** Tin 118.710	51 **Sb** Antimony 121.760	52 **Te** Tellurium 127.60		
78 **Pt** Platinum 195.078	79 **Au** Gold 196.96655	80 **Hg** Mercury 200.59	81 **Tl** Thallium 204.3833	82 **Pb** Lead 207.2	83 **Bi** Bismuth 208.98038	84 **Po** Polonium (209)	85 **At** Astatine (210)	86 **Rn** Radon (222)
65 **Tb** Terbium 158.92534	66 **Dy** Dysprosium 162.50	67 **Ho** Holmium 164.93032	68 **Er** Erbium 167.26	69 **Tm** Thulium 168.93421	70 **Yb** Ytterbium 173.04	71 **Lu** Lutetium 174.967		

Securing Materials for Emerging Technologies

A REPORT BY THE APS PANEL ON PUBLIC AFFAIRS & THE MATERIALS RESEARCH SOCIETY

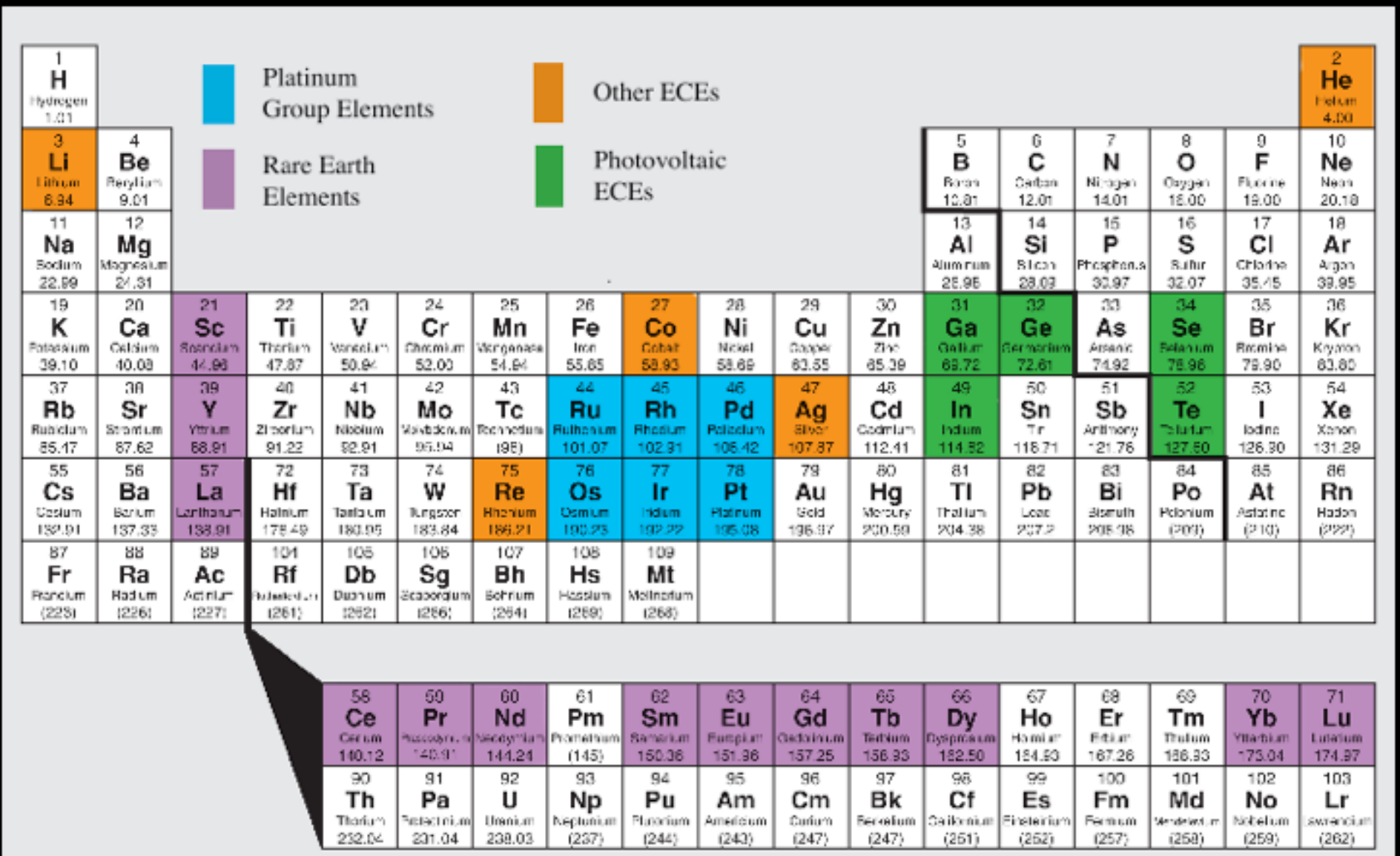
MRS

APS physics

Consider exploring for mineral resources that will likely be in higher demand in the future.

Energy-critical elements (ECEs) are a class of chemical elements that currently appear critical to one or more new energy-related technologies. A shortage of these elements would significantly inhibit large-scale deployment, which could otherwise be capable of transforming the way we produce, transmit, store, or conserve energy. We reserve the term ECE for chemical elements that have not been widely extracted, traded, or utilized in the past, and are therefore not the focus of well-established and relatively stable markets.

Some ECEs today



$CuIn_xGa_{(1-x)}Se_2$, CdTe, GaAs, Ag, and $Si_{1-x}Ge_x$ for solar panels

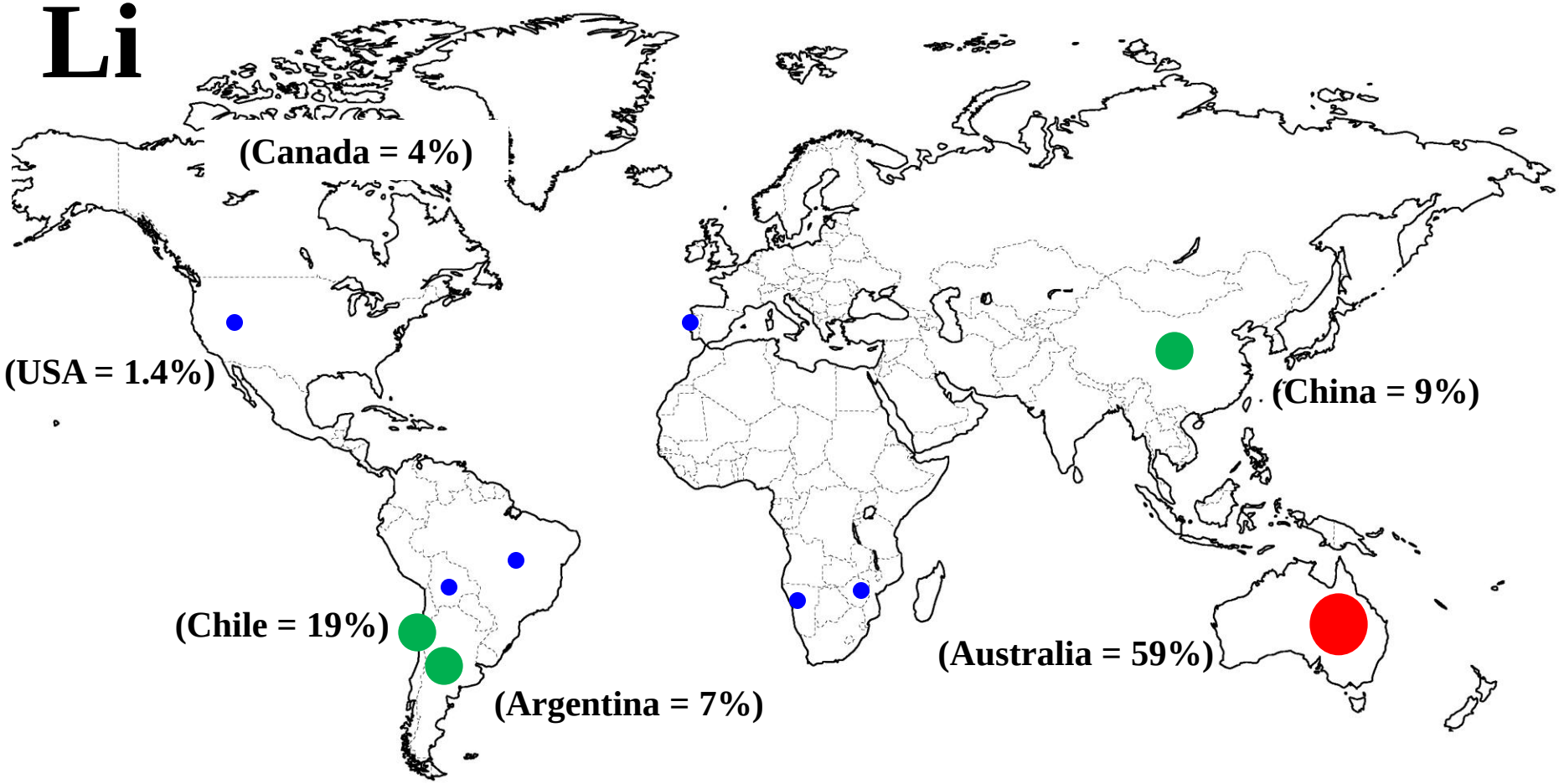
$Fe_{14}(Nd,Dy)_2B$, $SmCo_5$, and Sm_2Co_{17} for magnets, e.g., in wind turbines

Li, Co, La, Ni, and V for batteries

Pt, Pd for catalysts in fuel cells

Tb, Eu in fluorescent lights

Li



World's leading producer

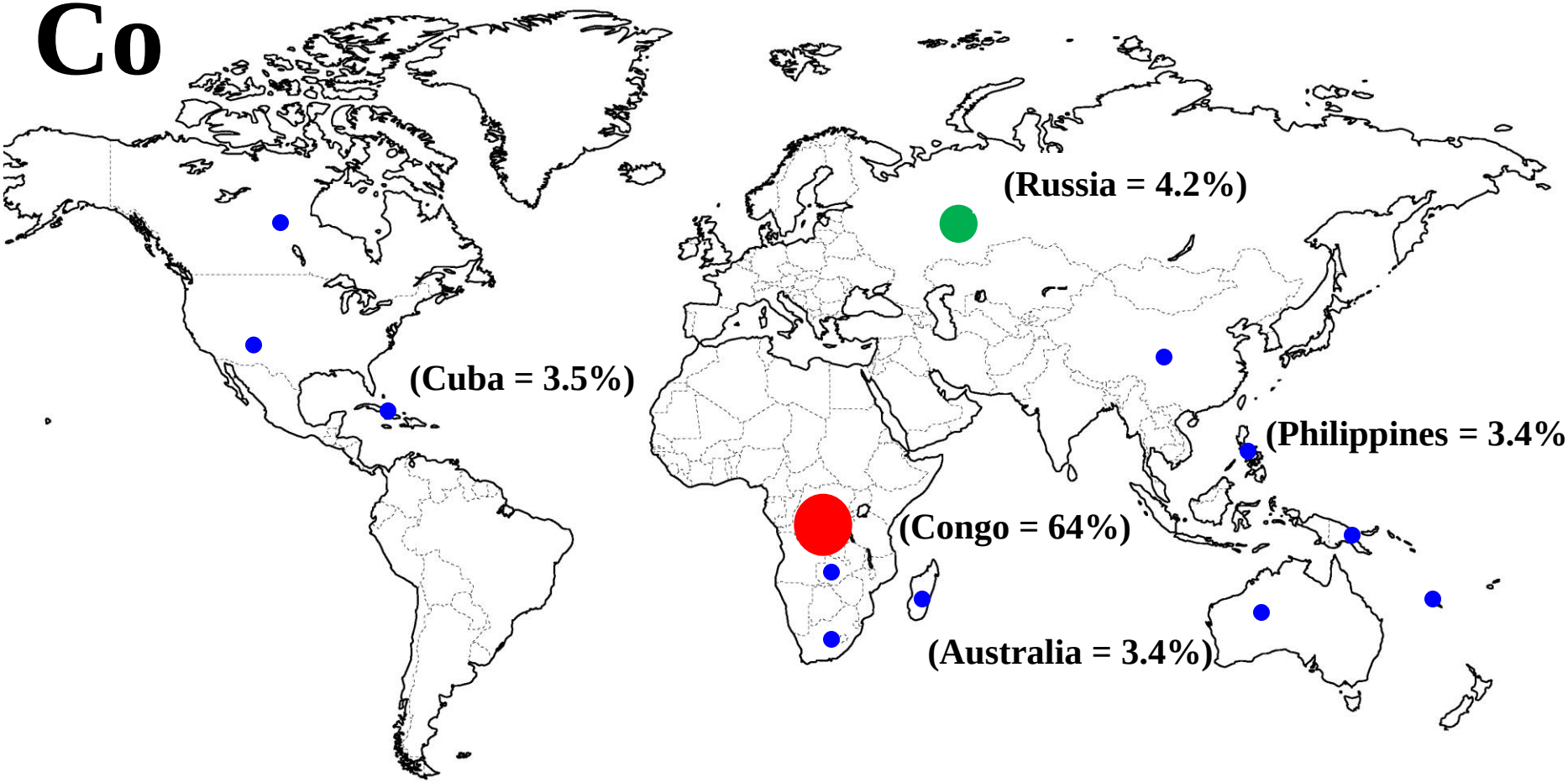
Countries with 4% or more of global production

Other countries with production or major reserves

Data source: USGS

Lithium is needed in batteries for electric cars, etc.

Co



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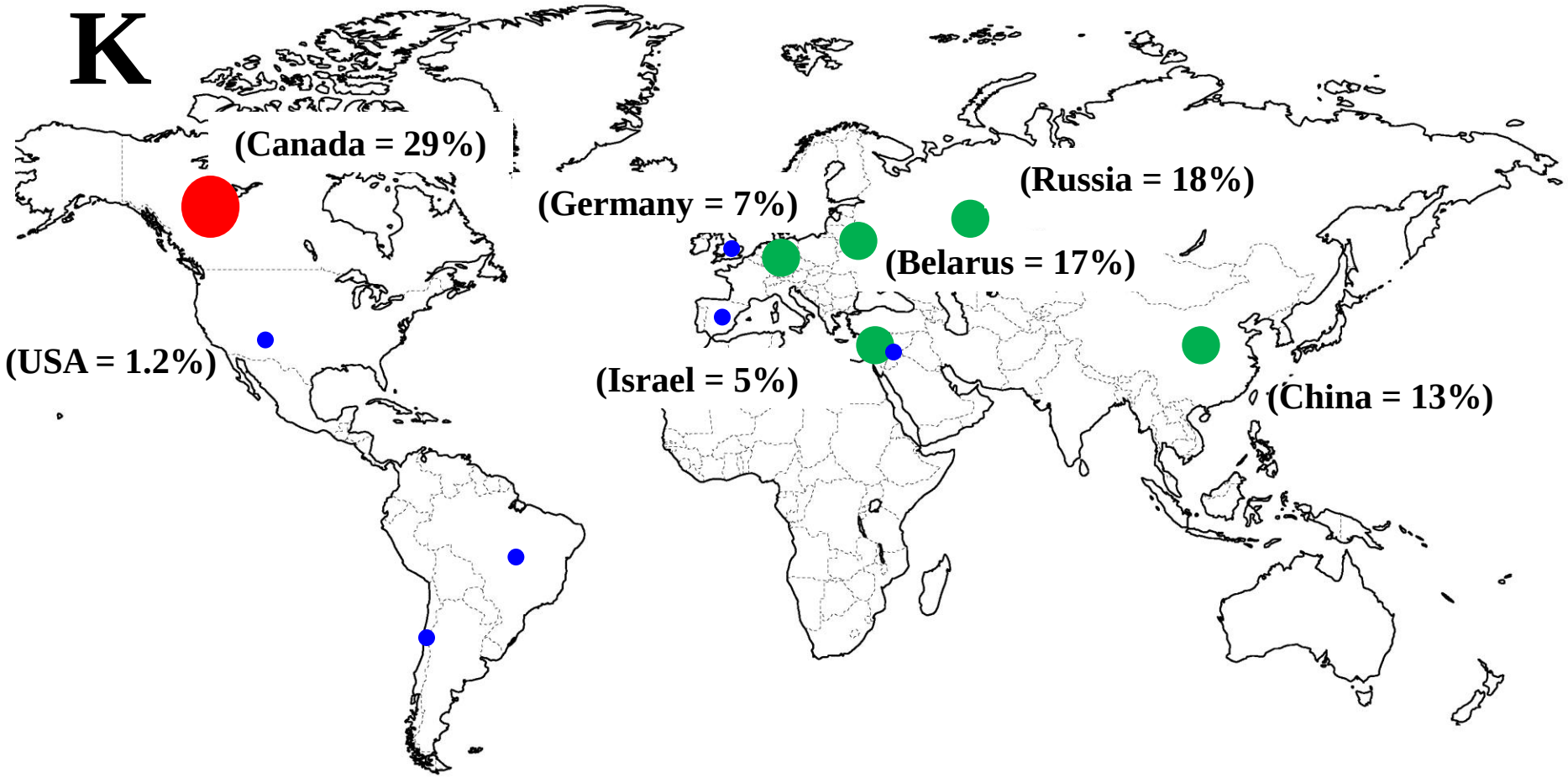
Cobalt is also needed in batteries for electric cars.

K



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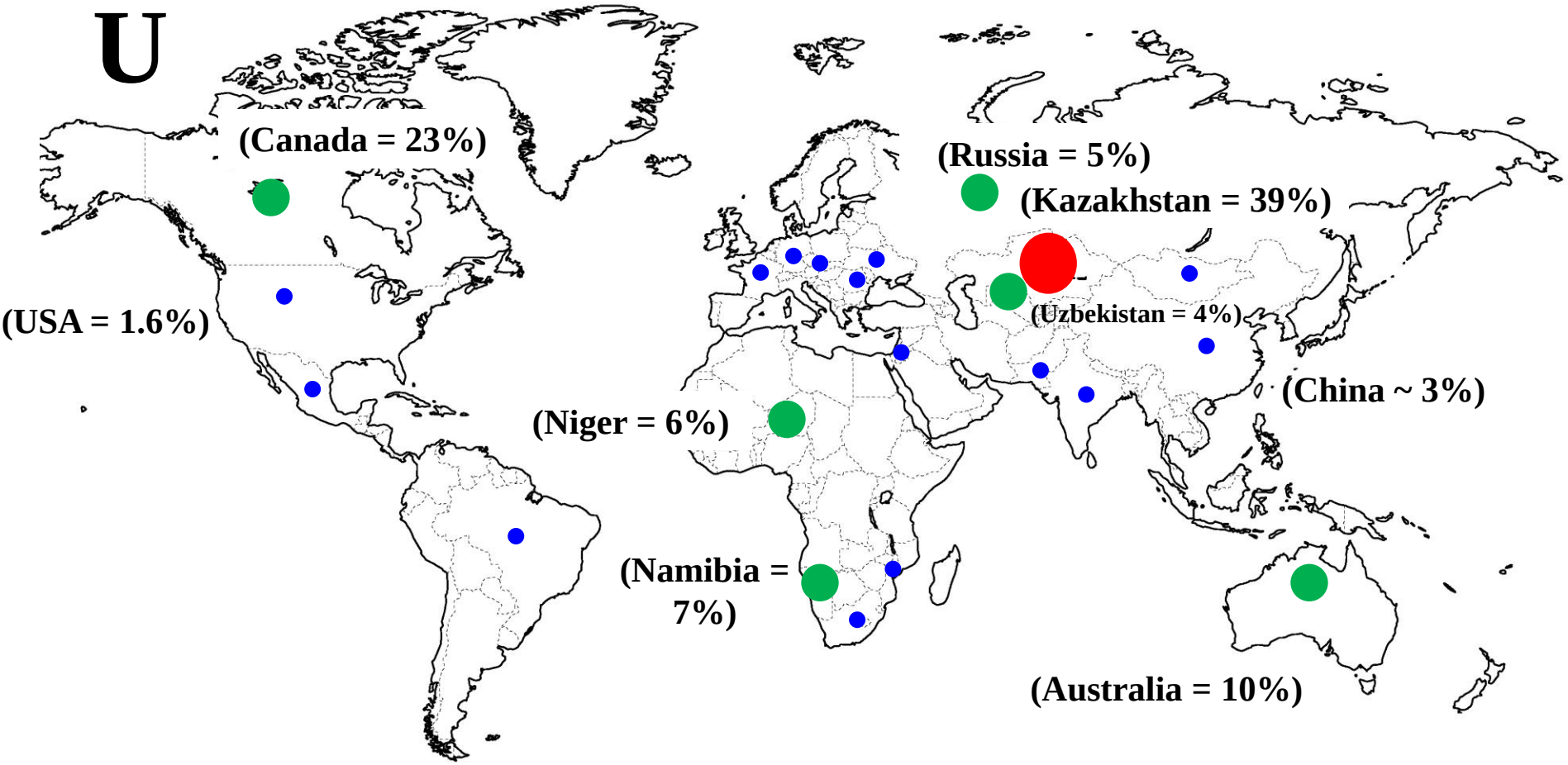
Potash (potassium) is used mostly in fertilizer.

U



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Other countries with production or major reserves

Data source: World Nuclear Association

Uranium is used mostly in generating electricity.

China's economy will likely drive up the demand for those commodities for which it can't mine enough domestically.

Commodity	% from China	% from Canada	% from US	Leading Producer
Platinum	~0	6	3	South Africa (69%)
Potash	13	29	1	Canada (29%)
Chromium	~0	~0	~0	South Africa (44%)
Copper	8	3	6	Chile (28%)
Nickel	5	7	1	Indonesia (24%)
Cobalt	2	3	0.4	Congo (64%)

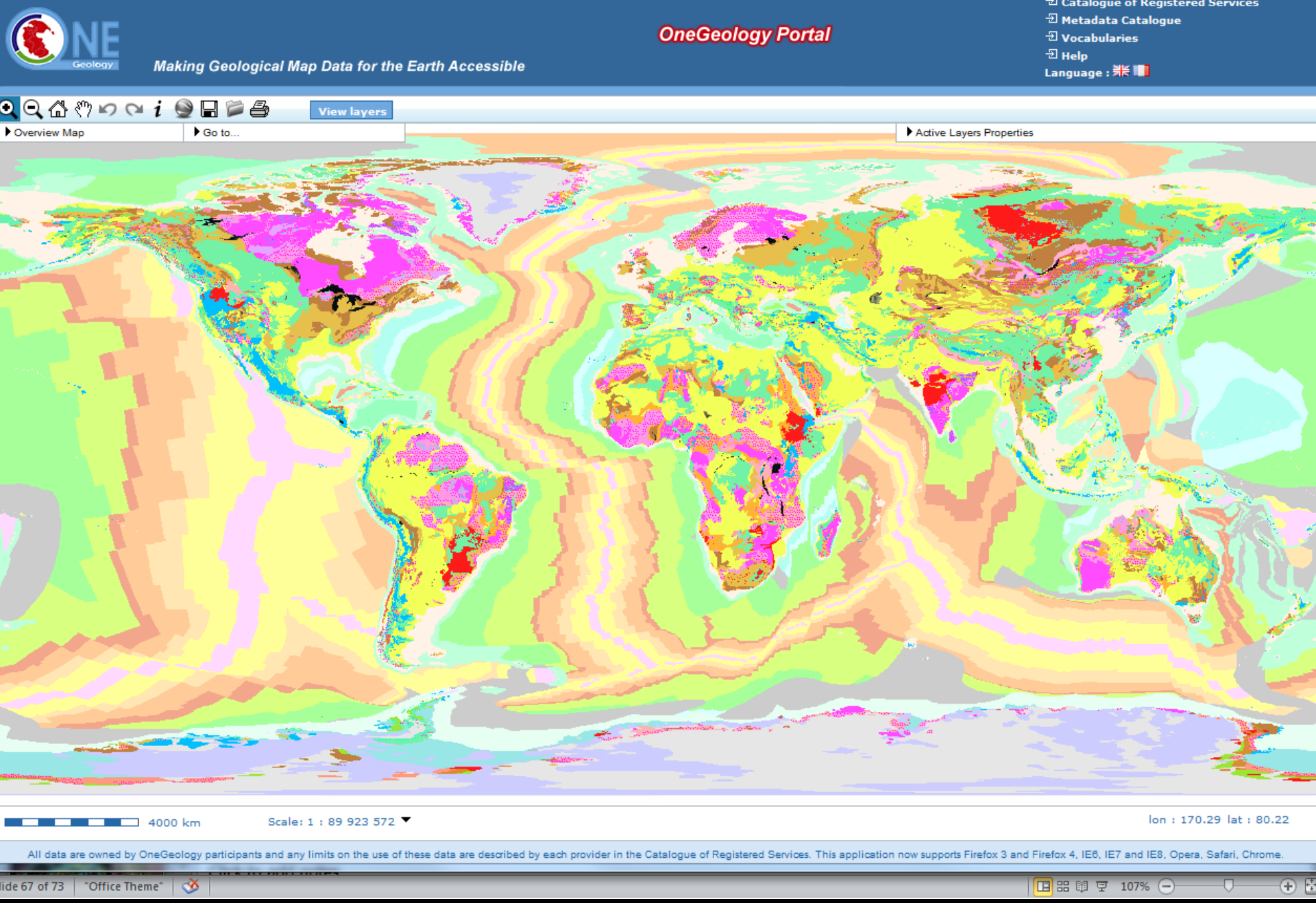
For example, the leading producers of nickel are Indonesia (24% of mine production), Philippines (15%), New Caledonia (9%), Russia (9%), Australia (7%), and Canada (7%),

Mount Keith Ni mine, Western Australia: 323 million metric tons @ 0.56% Ni

Spinifex texture in serpentinite, Honeymoon Well nickel deposit, Western Australia - indicator of bladed crystals of olivine, from quenching of an ultramafic lava flow

Production statistics from USGS

Watch for competition in the regions of resource-rich Precambrian cratons, which are major sources of iron, manganese, nickel, chromium, titanium, copper, cobalt, zinc, gold, palladium, platinum, and uranium. This includes parts of Africa, Australia, South America (particularly Brazil and Venezuela), Russia, and Canada.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Go to...
Active Layers Properties
4000 km
Scale: 1 : 89 923 572
lon : 170.29 lat : 80.22
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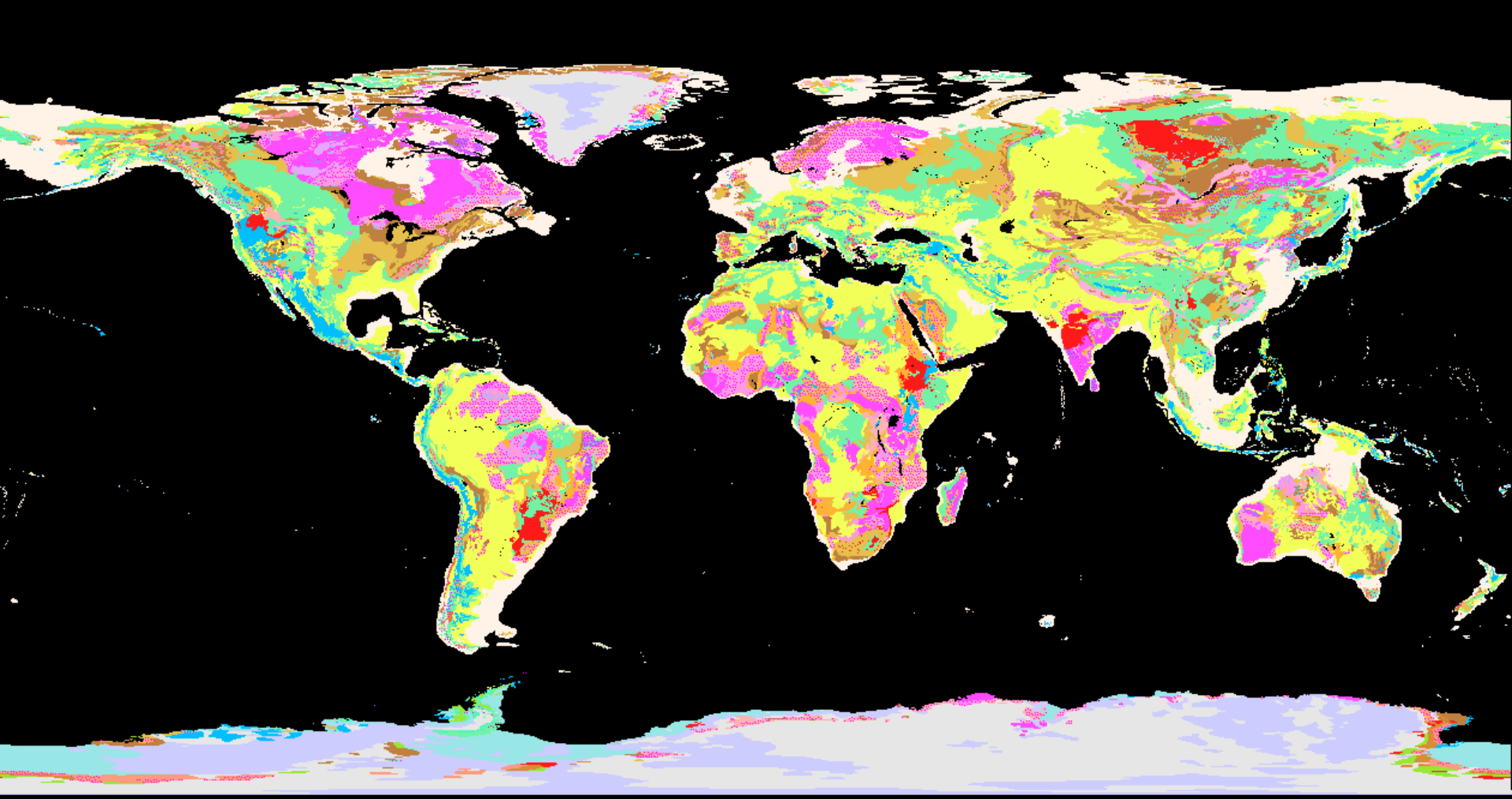
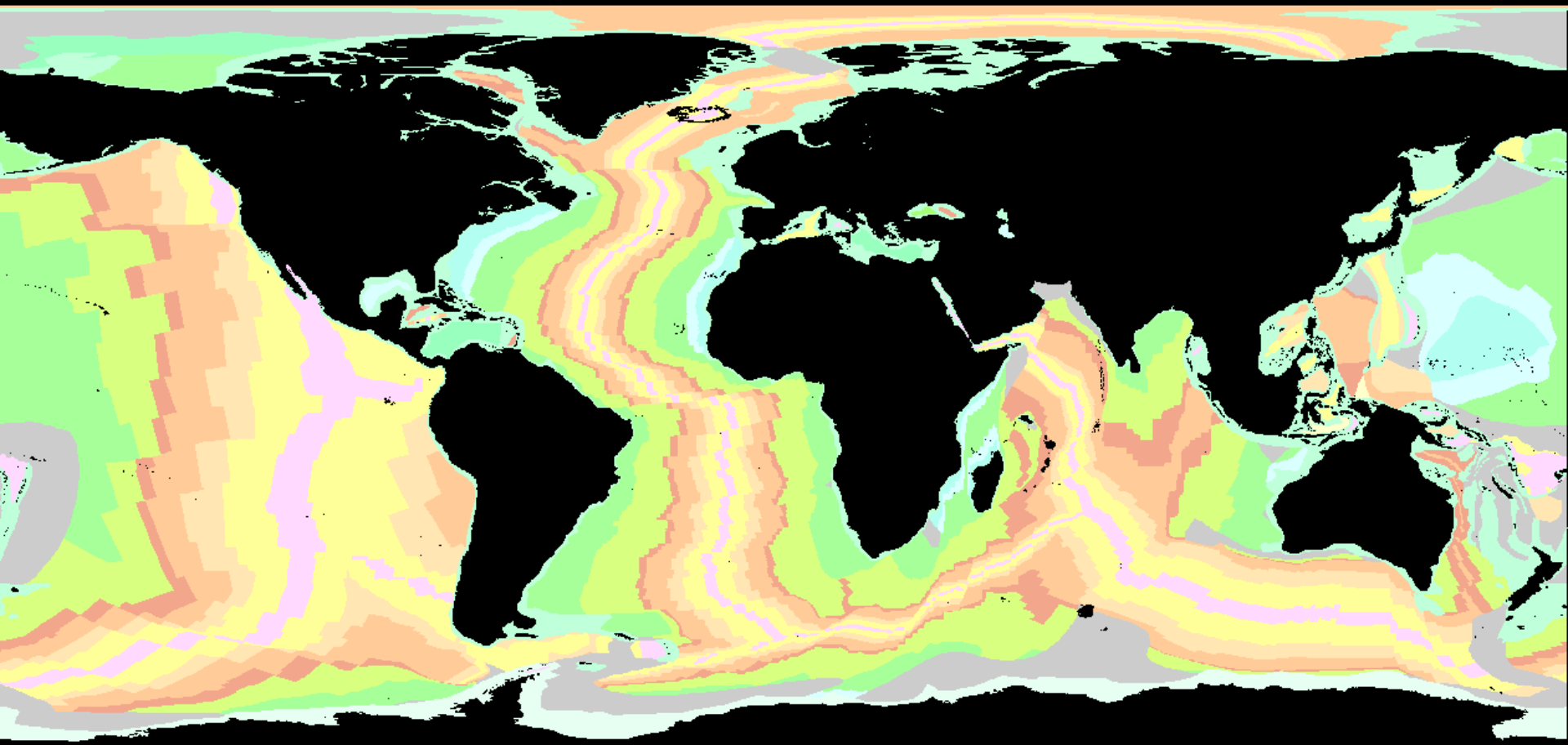


Precambrian cratons

- **Archean** (2.5 to 4.0 Ga) –**Au, Ni, U**
- **Proterozoic** (542 Ma to 2.5 Ga) – **Fe, Mn, V, Pt, Pd, Cr, Ni, Au, Cu, Co, U, Ti, diamonds**

Source for geologic map: www.OneGeology.org

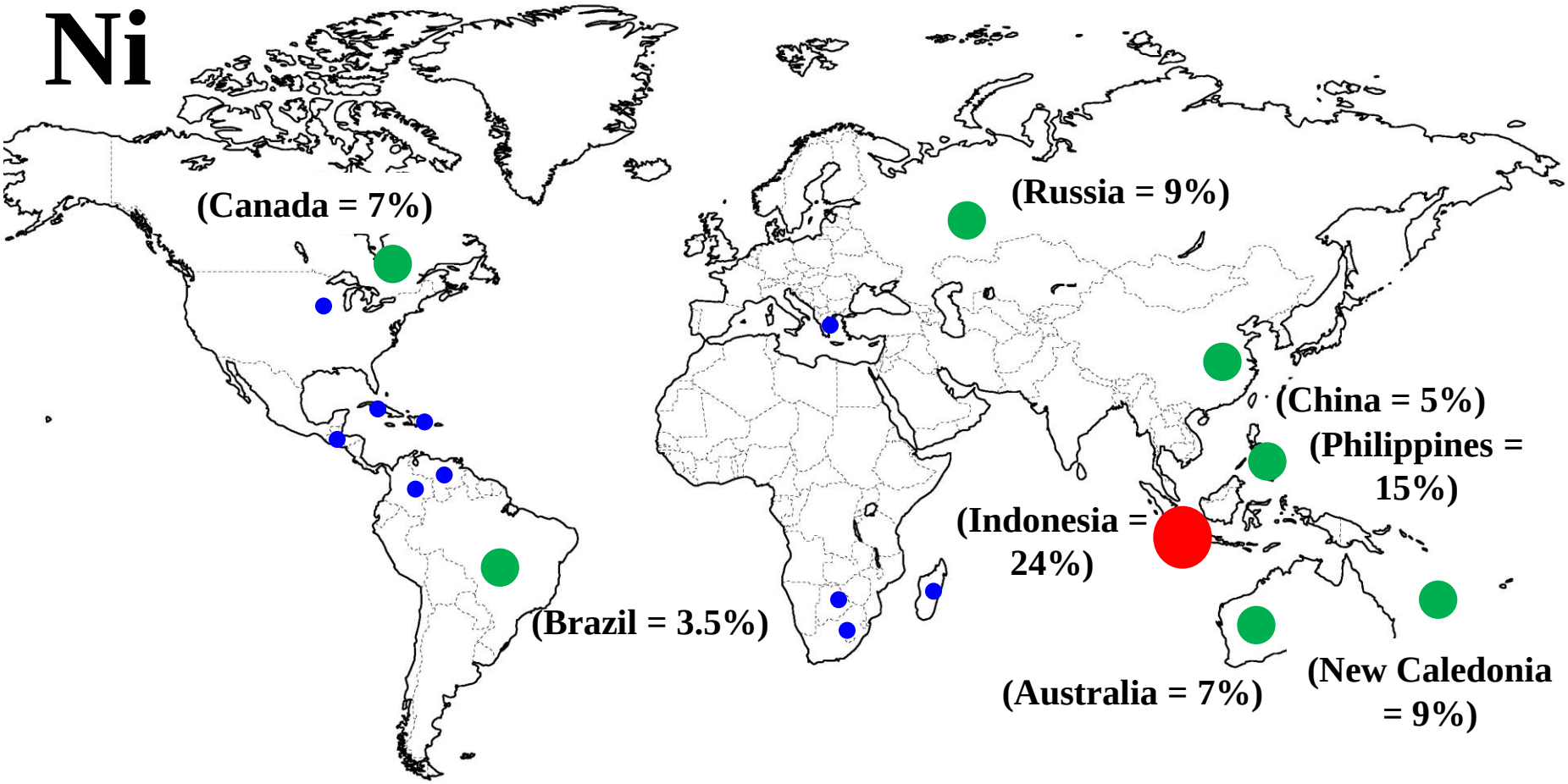


Jurassic to Recent oceanic crust – potential for

ore deposits of manganese nodules & crusts (Mn, Ni, Co, Cu), massive sulfide deposits & seafloor vents (Cu, Zn, Pb, Au, Ag), and phosphate nodule deposits (P)

Source for geologic map: www.OneGeology.org

Ni



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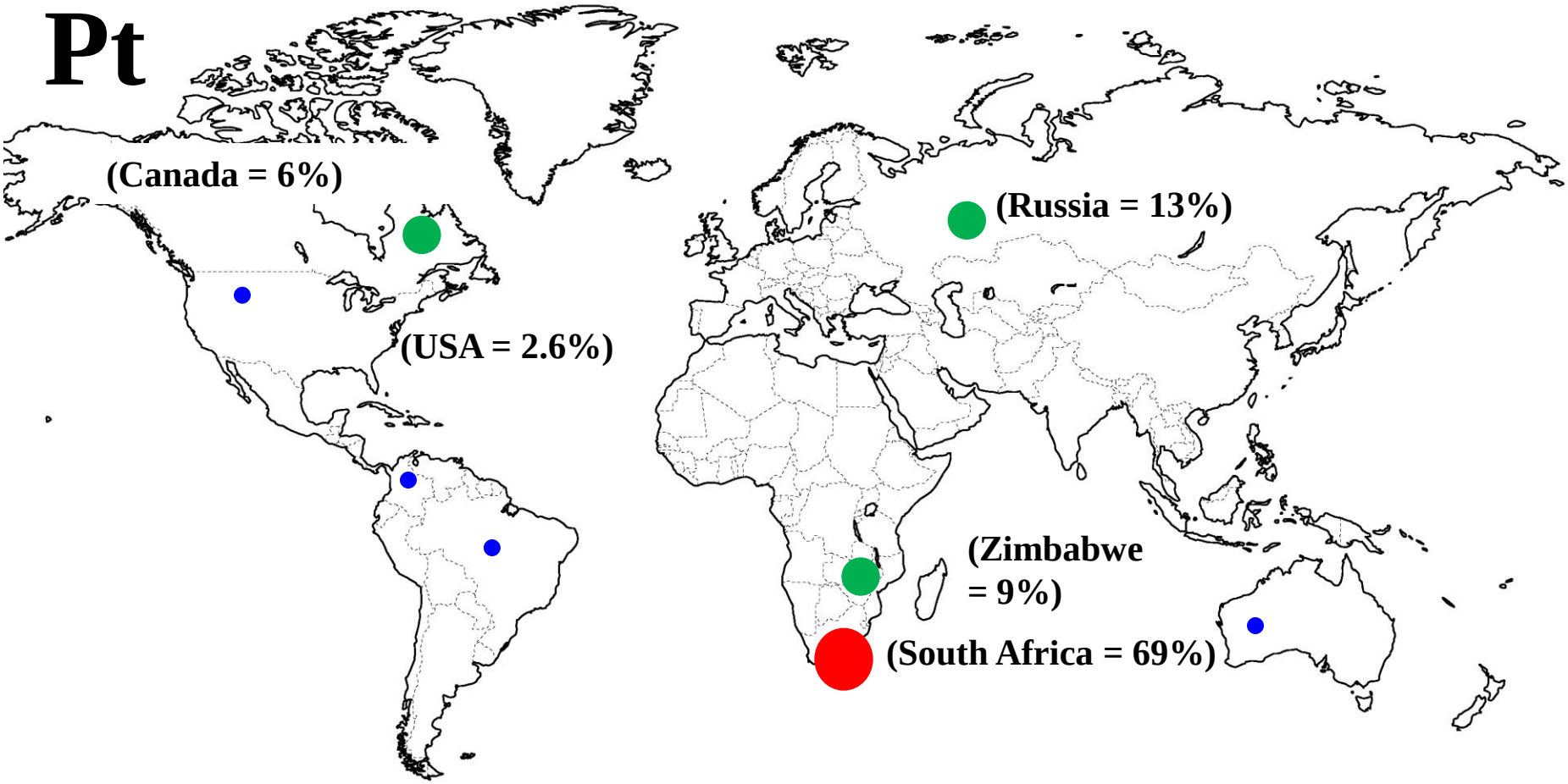
Nickel is used mostly in steel.

Pt



World's leading producer

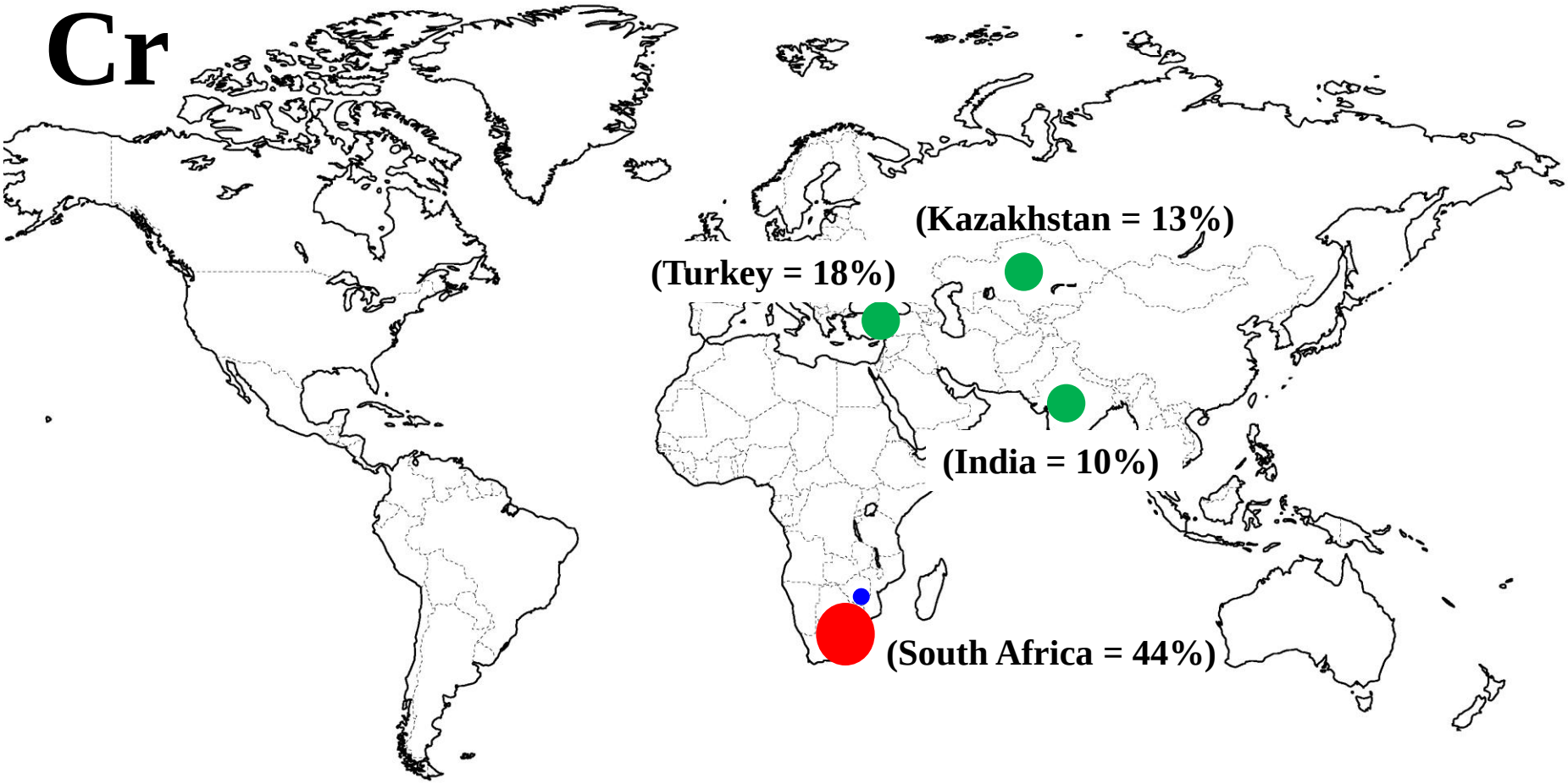
Countries with 4% or more of global production

Other countries with production or major reserves

Data source: USGS

Platinum is used mostly in catalytic converters.

Cr



World's leading producer

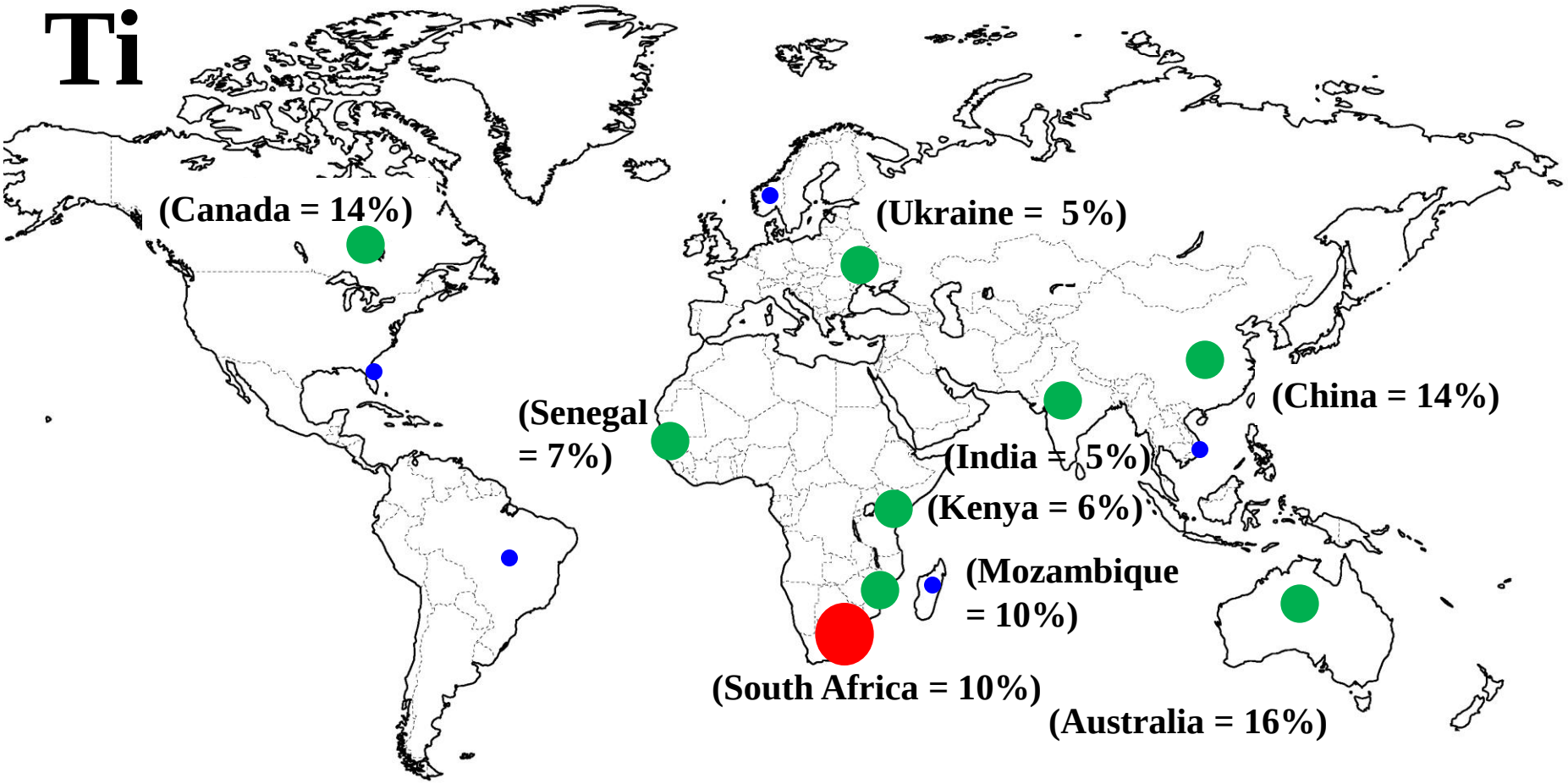
Countries with 4% or more of global production

Other countries with production or major reserves

Data source: USGS

Chromium is used mostly in steel & other alloys.

Ti



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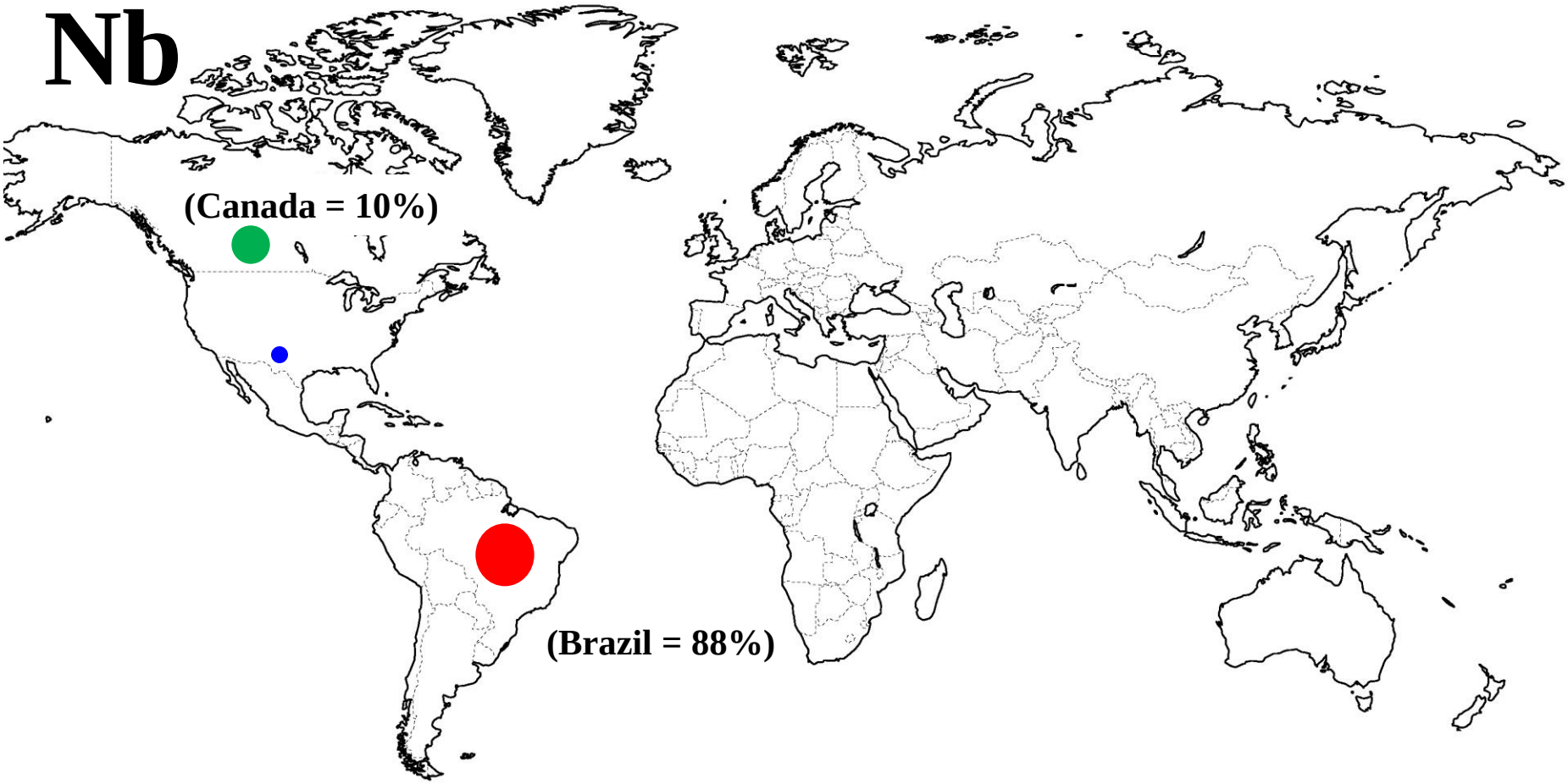
Titanium has a variety of uses, including aerospace.

Nb



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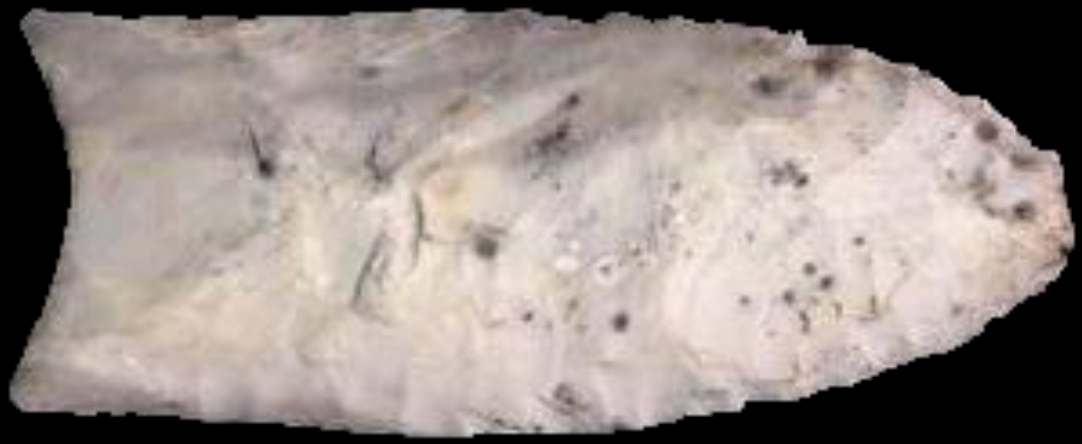
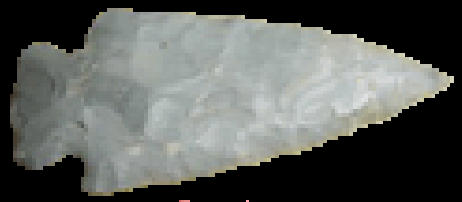
Niobium is used mostly in steel & other alloys.

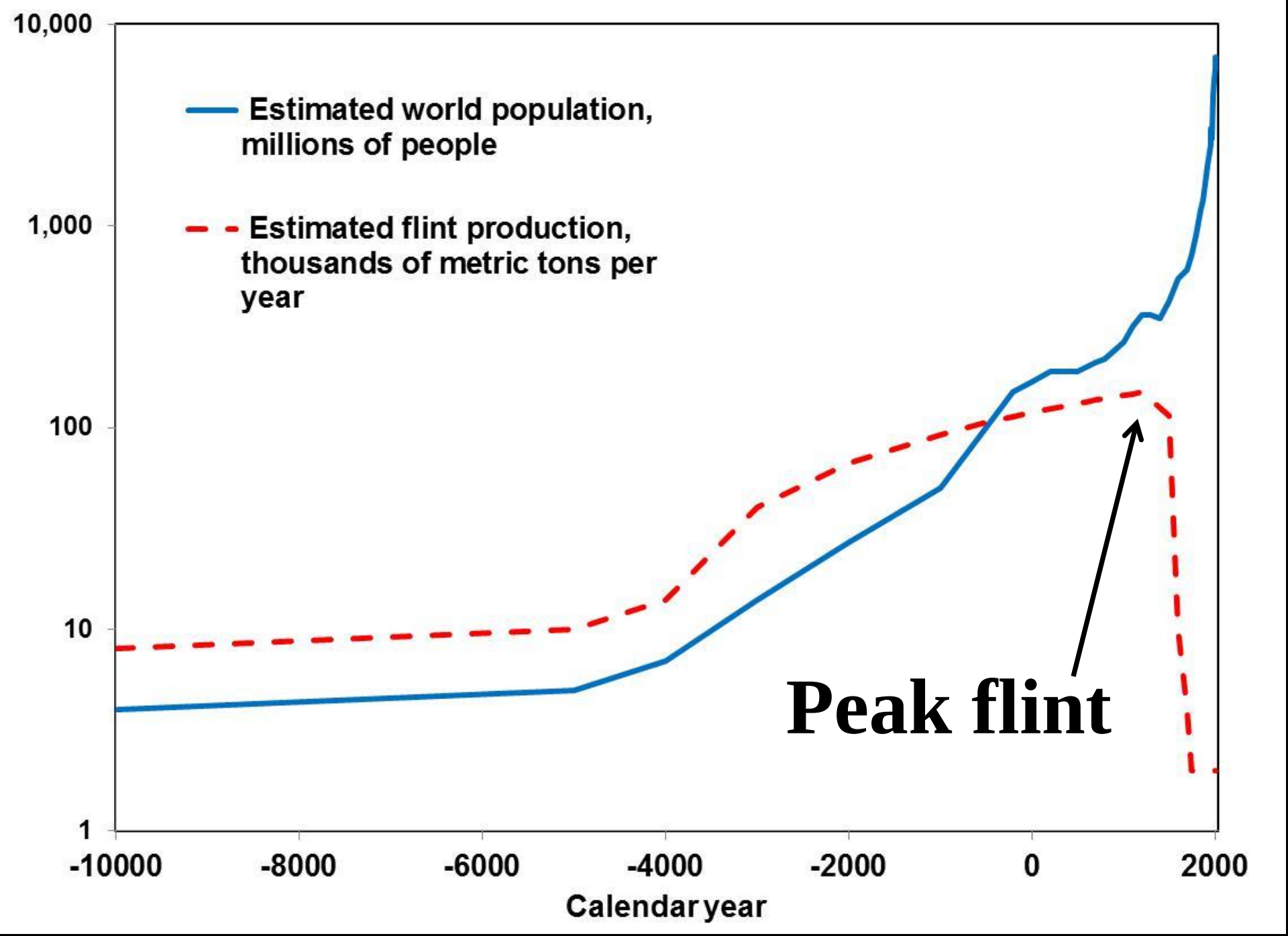


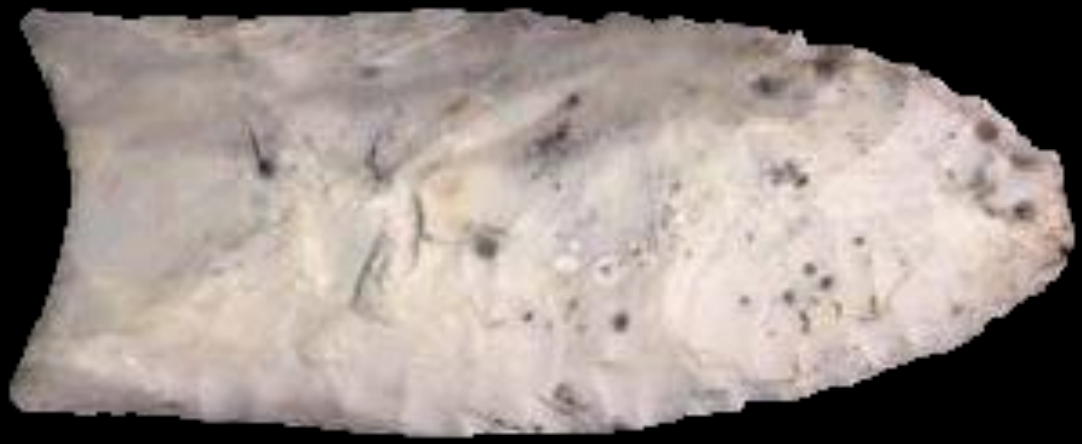
Arrowhead clipart from www.firstpeople.us



Critical and strategic minerals will change with time.

Avatar


10,000
1,000
100
10
1
Estimated world population, millions of people
Estimated flint production, thousands of metric tons per year
Peak flint
-10000
-8000
-6000
-4000
-2000
0
2000
Calendar year



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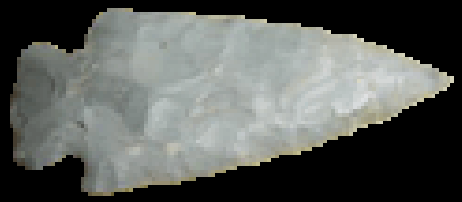
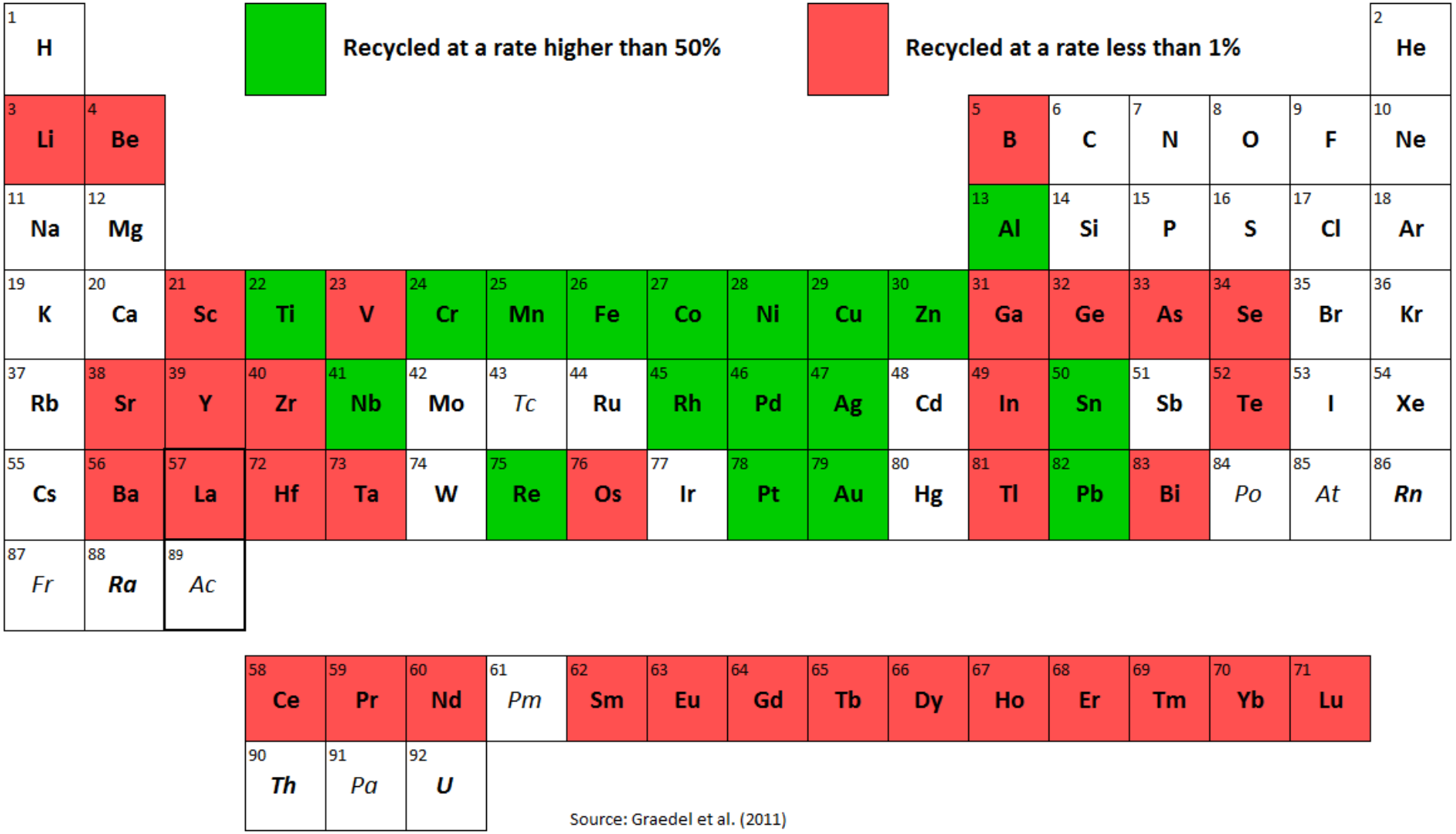


Critical and strategic minerals will change with time.

$CuIn_xGa_{(1-x)}Se_2$ or CIGS, for solar panels?
CdTe , GaAs, and Ge for solar panels?
Nd for magnets for wind and other electrical turbines?
Li, Co, and V for different types of batteries?

More recycling can be accomplished by increasing collection rates of various products, better product design with recycling in mind, and improvements in recycling technologies. - Reck and Graedel (2012).



Source: Graedel et al. (2011)

Social and cultural concerns are part of mining today.

- Sustainability and sustainable development – environment, economy, social and cultural structure
- International Standards Organization environmental management (ISO 14001)
- International Cyanide Management Institute
- Community Outreach and Economic Security
- World Bank
- Stockholder demands
- Governmental regulations

Scams happen.

Mark Twain (1872) described a classic scheme involving an unscrupulous assayer (Fig. 17): (a) “Assaying was a good business, and so some men engaged in it, occasionally, who were not strictly scientific and capable. One assayer got such rich results out of all specimens brought to him that in time he acquired almost a monopoly of the business. But like all men who achieve success, he became an object of envy and suspicion. The other assayers entered into a conspiracy against him, and let some prominent citizens into the secret in order to show that they meant fairly. Then they broke a little fragment off a carpenter's grindstone and got a stranger to take it to the popular scientist and get it assayed.”

“In the course of an hour the result came---whereby it appeared that a ton of that rock would yield $1,284.40 in silver and $366.36 in gold! Due publication of the whole matter was made in the paper, and the popular assayer left town 'between two days.”

The Bre-X hoax of the mid-1990s led to the development of Canadian National Instrument 43-101, Standards of Disclosure for Mineral Projects. The Calgary-based junior mining company supposedly discovered a major gold deposit at Busang, Indonesia. The assayed samples were salted, and investors lost $2 billion.

Opportunities in Global Mineral Resources

Demand is high.

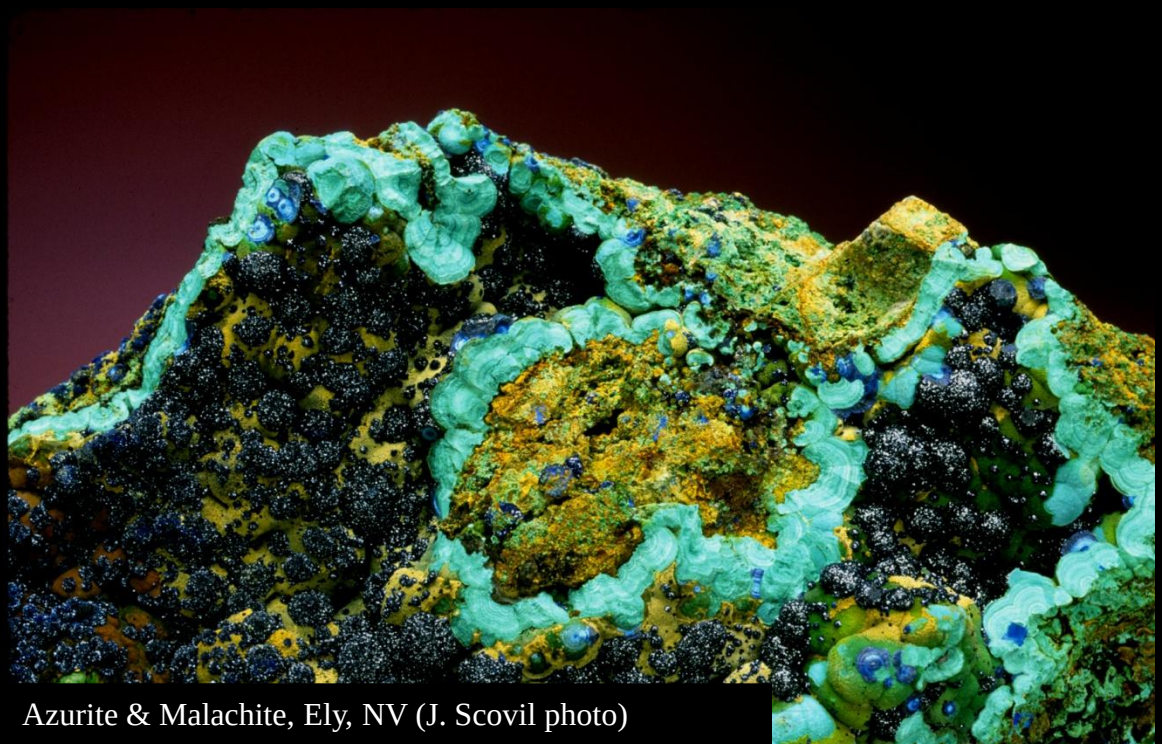
Resources are global, but China is #1.

The trends will help guide exploration and development.

Round Mountain, NV (2007)

Opportunities in Global Mineral Resources

Thank you!

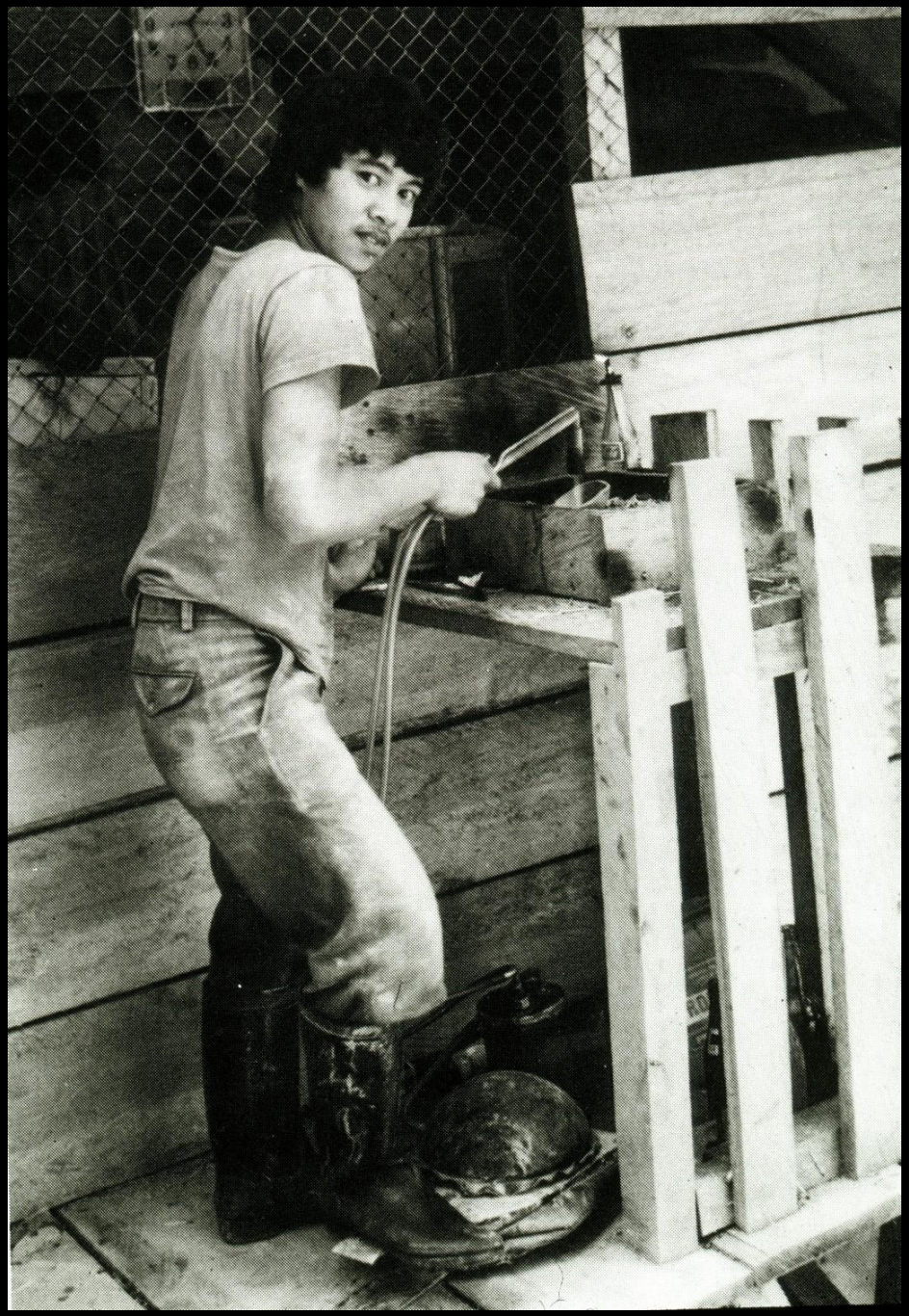


Azurite & Malachite, Ely, NV (J. Scovil photo)

Round Mountain, NV (2007)

Four artisanal miners (galamsey) work unsafely, without personal protective equipment or ground support, near Kyereboso in Ghana in 2008.

Gold mill in Sulawesi (Larry James photo)



Using blowtorch to remove mercury from amalgam, Sulawesi (Larry James photo)

Why explore in Nevada?

Among many other reasons, Nevada is the US leader in gold, barite, and lithium; a significant historical producer of copper, silver, and zinc; and a key source of industrial minerals for construction (gypsum, cement resources, aggregate).

Lithium-brine evaporation pond, 2008,
Clayton Valley (Silver Peak), Nevada

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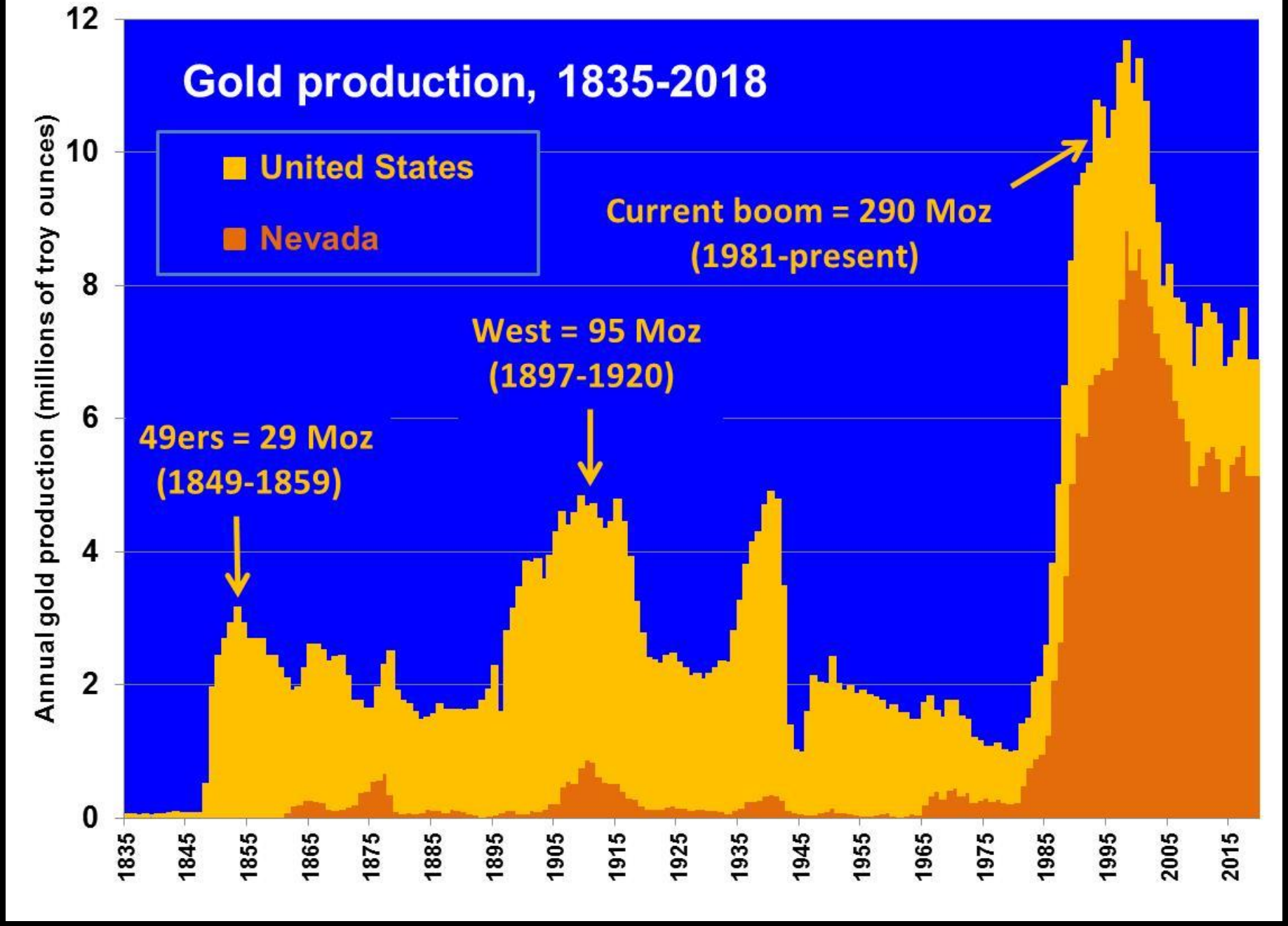


We are in the midst of the biggest gold-mining boom in history.

Thank you!

JONATHAN G. PRICE, LLC
Nevada State Geologist Emeritus
Certified Professional Geologist, Ph.D.
2210 Andromeda Way
Reno, Nevada 89509-3802 USA

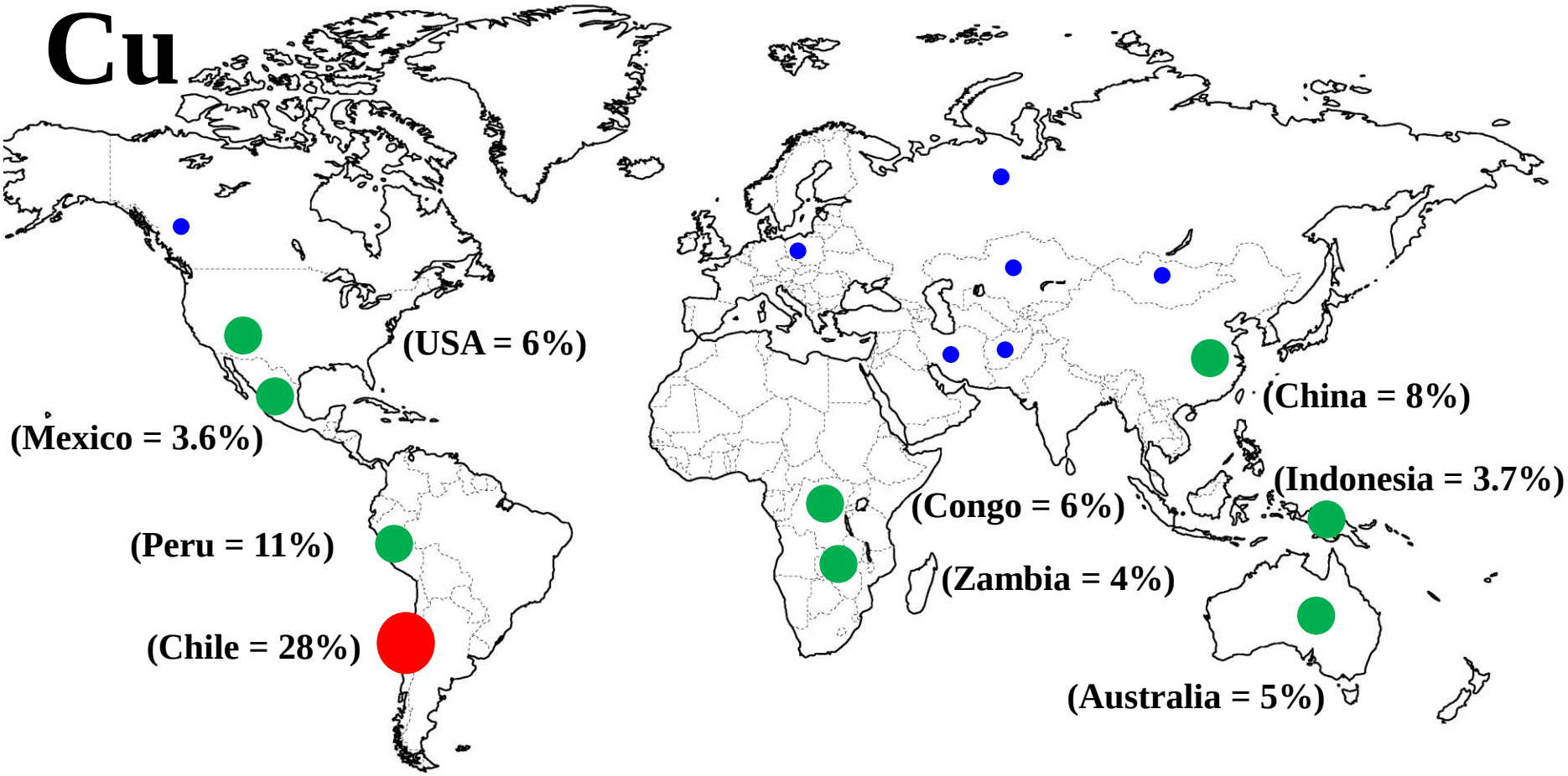
Cell: 775-200-8077

jprice@unr.edu

1 H 1.00794																	2 He 4.0026
3 Li 6.941	4 Be 9.0122											5 B 10.811	6 C 12.011	7 N 14.0067	8 O 15.9994	9 F 18.9984	10 Ne 20.180
11 Na 22.9898	12 Mg 24.305											13 Al 26.9815	14 Si 28.086	15 P 30.9738	16 S 32.066	17 Cl 35.453	18 Ar 39.948
19 K 39.0983	20 Ca 40.078	21 Sc 44.9559	22 Ti 47.88	23 V 50.9415	24 Cr 51.996	25 Mn 54.938	26 Fe 55.847	27 Co 58.933	28 Ni 58.693	29 Cu 63.546	30 Zn 65.39	31 Ga 69.723	32 Ge 72.61	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.8
37 Rb 85.4678	38 Sr 87.62	39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.94	43 *Tc* 97.9	44 Ru 101.07	45 Rh 102.9055	46 Pd 106.42	47 Ag 107.8682	48 Cd 112.411	49 In 114.818	50 Sn 118.71	51 Sb 121.757	52 Te 127.60	53 I 126.904	54 Xe 131.29
55 Cs 132.905	56 Ba 137.327	57 La 138.9055	72 Hf 178.49	73 Ta 180.948	74 W 183.84	75 Re 186.207	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.967	80 Hg 200.59	81 Tl 204.383	82 Pb 207.2	83 Bi 208.98	84 *Po* 208.98	85 *At* 209.99	86 ***Rn*** 222.0176
87 *Fr* 223.02	88 ***Ra*** 226.0254	89 *Ac* 227.0278															

58 Ce 140.115	59 Pr 140.908	60 Nd 144.24	61 *Pm* 144.913	62 Sm 150.36	63 Eu 151.965	64 Gd 157.25	65 Tb 158.925	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.934	70 Yb 173.04	71 Lu 174.967
90 ***Th*** 232.038	91 *Pa* 231.036	92 ***U*** 238.0289											

Cu



World's leading producer

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Other countries with production or major reserves

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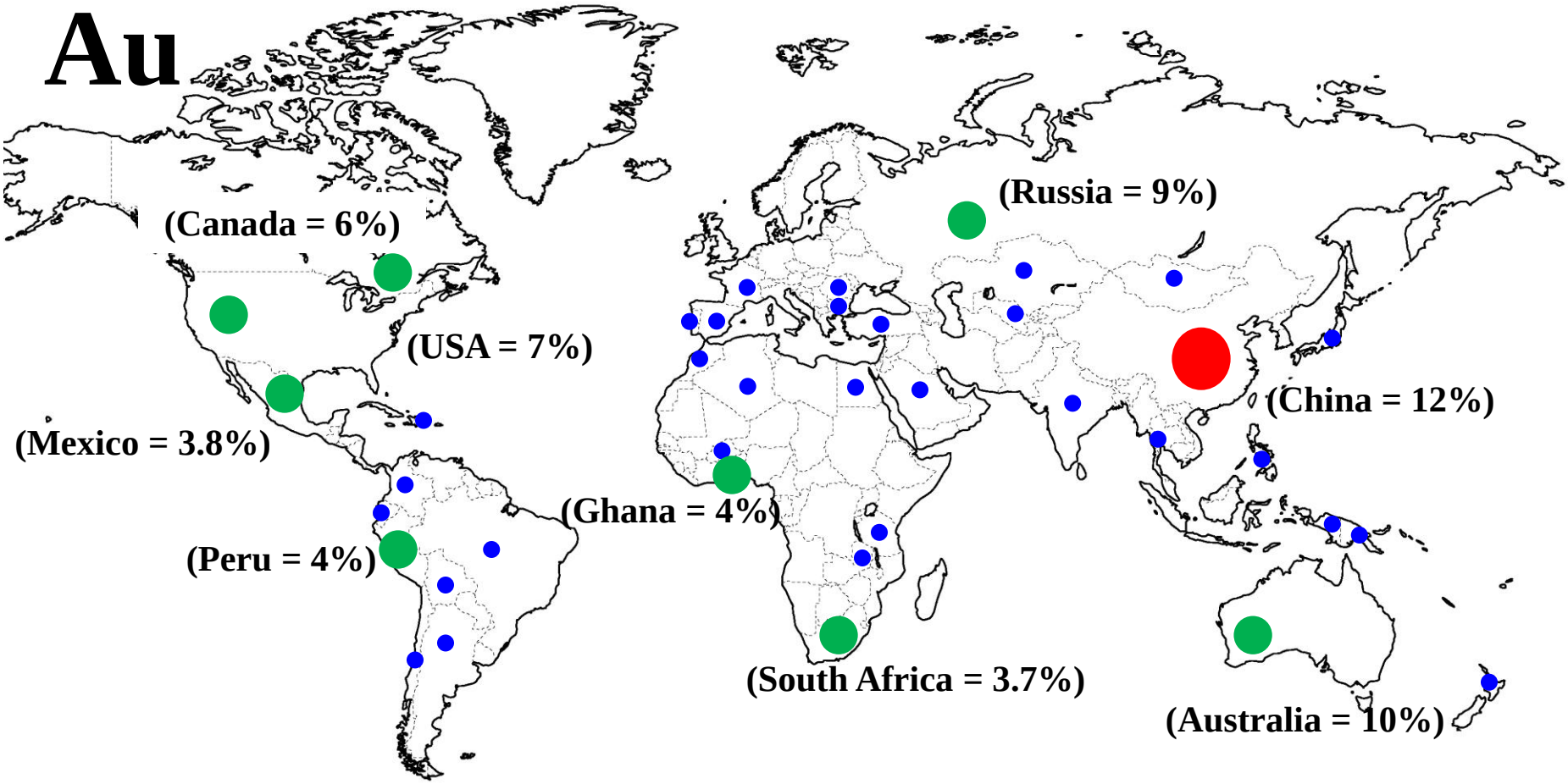
Resources are global.

Au



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Resources are global, but China is Number One.