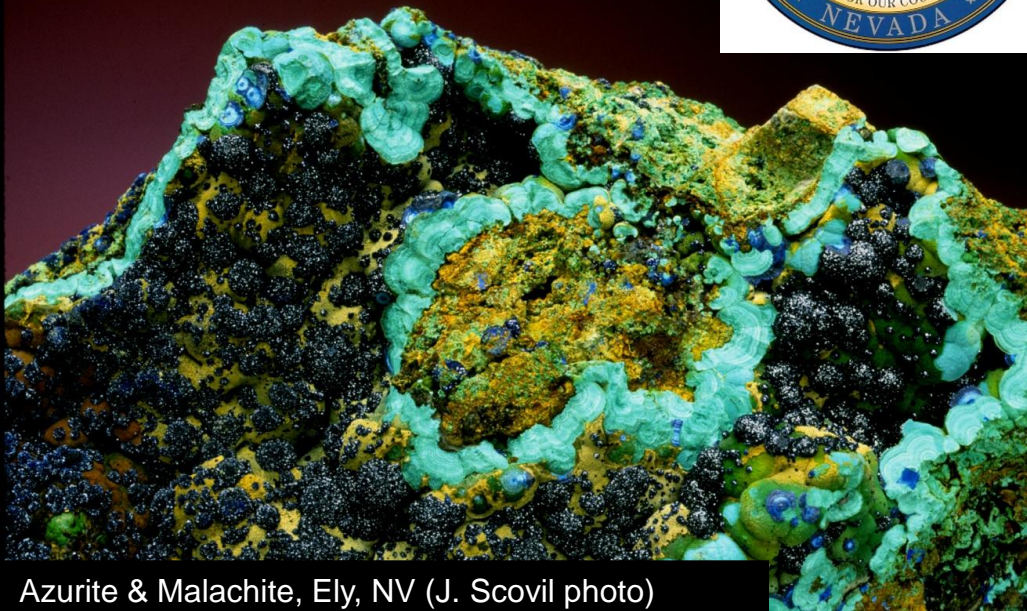


The Importance of Mineral Resources in a National-International Context

Jonathan G. Price

State Geologist Emeritus
Nevada Bureau of Mines and Geology



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

| JONATHAN G. PRICE, LLC | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|------------------------|----------|----------|---------|---------|---------|---------|---------|---------|--------|---------|---------|---------|---------|---------|--------|---------|----------|--------|--------|--------|--------|--------|-------|--------|-------|--------|-------|--------|------|
| H | He | | | | | | | | | | | B | C | N | O | F | Ne | | | | | | | | | | | | |
| 1.00794 | 4.0026 | | | | | | | | | | | 10.811 | 12.011 | 14.007 | 15.999 | 18.998 | 20.180 | | | | | | | | | | | | |
| Li | Be | | | | | | | | | | | Al | Si | P | S | Cl | Ar | | | | | | | | | | | | |
| 6.941 | 9.0122 | | | | | | | | | | | 26.9815 | 28.086 | 30.9738 | 32.066 | 35.453 | 39.948 | | | | | | | | | | | | |
| Na | Mg | | | | | | | | | | | K | Ca | Sc | Ti | V | Cr | Mn | Fe | Co | Ni | Cu | Zn | Ga | Ge | As | Se | Br | Kr |
| 22.9897 | 24.305 | | | | | | | | | | | 39.0983 | 40.078 | 44.9559 | 47.88 | 50.9415 | 51.996 | 54.938 | 55.847 | 58.933 | 58.693 | 63.546 | 65.38 | 69.723 | 72.61 | 74.922 | 76.96 | 79.904 | 83.8 |
| Rb | Sr | Y | Zr | Nb | Mo | Tc | Ru | Rh | Pd | Ag | Cd | In | Sn | Sb | Te | I | Xe | | | | | | | | | | | | |
| 85.4678 | 87.62 | 88.906 | 91.224 | 92.906 | 95.94 | 98.906 | 101.07 | 106.905 | 106.42 | 107.865 | 112.411 | 114.818 | 118.71 | 121.757 | 127.6 | 126.904 | 131.29 | | | | | | | | | | | | |
| Cs | Ba | La | Hf | Ta | W | Re | Os | Ir | Pt | Au | Hg | Tl | Pb | Bi | Po | At | Rn | | | | | | | | | | | | |
| 132.905 | 137.327 | 138.905 | 178.49 | 180.948 | 183.84 | 186.207 | 190.23 | 192.22 | 195.08 | 196.967 | 200.59 | 204.383 | 207.2 | 208.98 | 208.98 | 208.98 | 222.0176 | | | | | | | | | | | | |
| Fr | Ra | Ac | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 223.0 | 226.0254 | 227.0276 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Ce | Pr | Nd | Pm | Sm | Eu | Gd | Tb | Dy | Ho | Er | Tm | Yb | Lu | | | | | | | | | | | | | | | | |
| 140.125 | 140.908 | 144.24 | 144.913 | 150.36 | 151.965 | 157.25 | 158.925 | 162.50 | 164.93 | 167.26 | 168.934 | 173.04 | 174.967 | | | | | | | | | | | | | | | | |
| Th | Pu | U | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 232.0377 | 238.0289 | 238.0289 | | | | | | | | | | | | | | | | | | | | | | | | | | | |

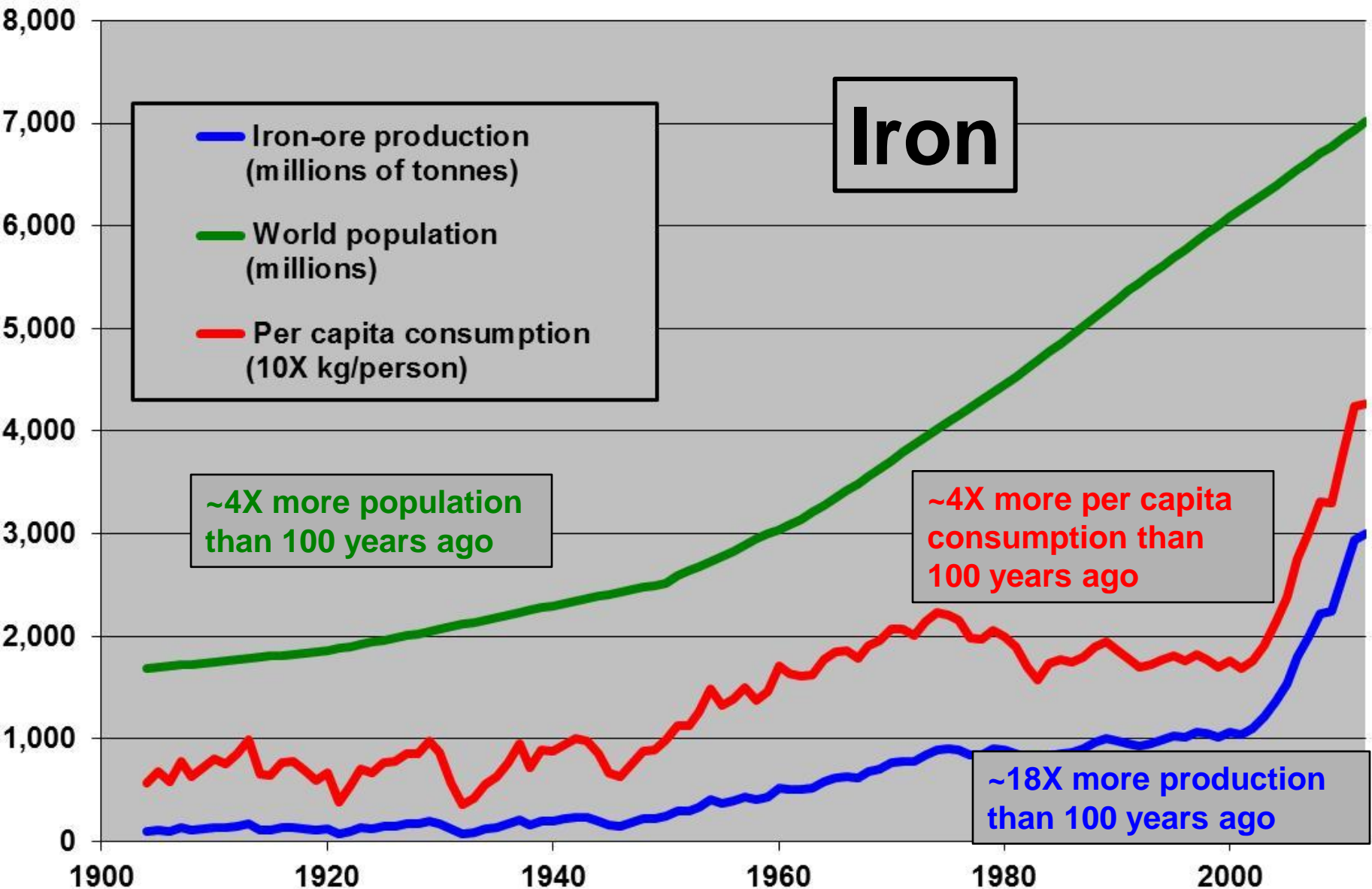
jprice@unr.edu

775-329-8011

The Importance of Mineral Resources in a National-International Context

- **Demand for mineral resources will continue to grow.**
- **We are unlikely to run out of mineral resources (globally).**
- **Nonetheless, there are challenges for the United States.**

Iron



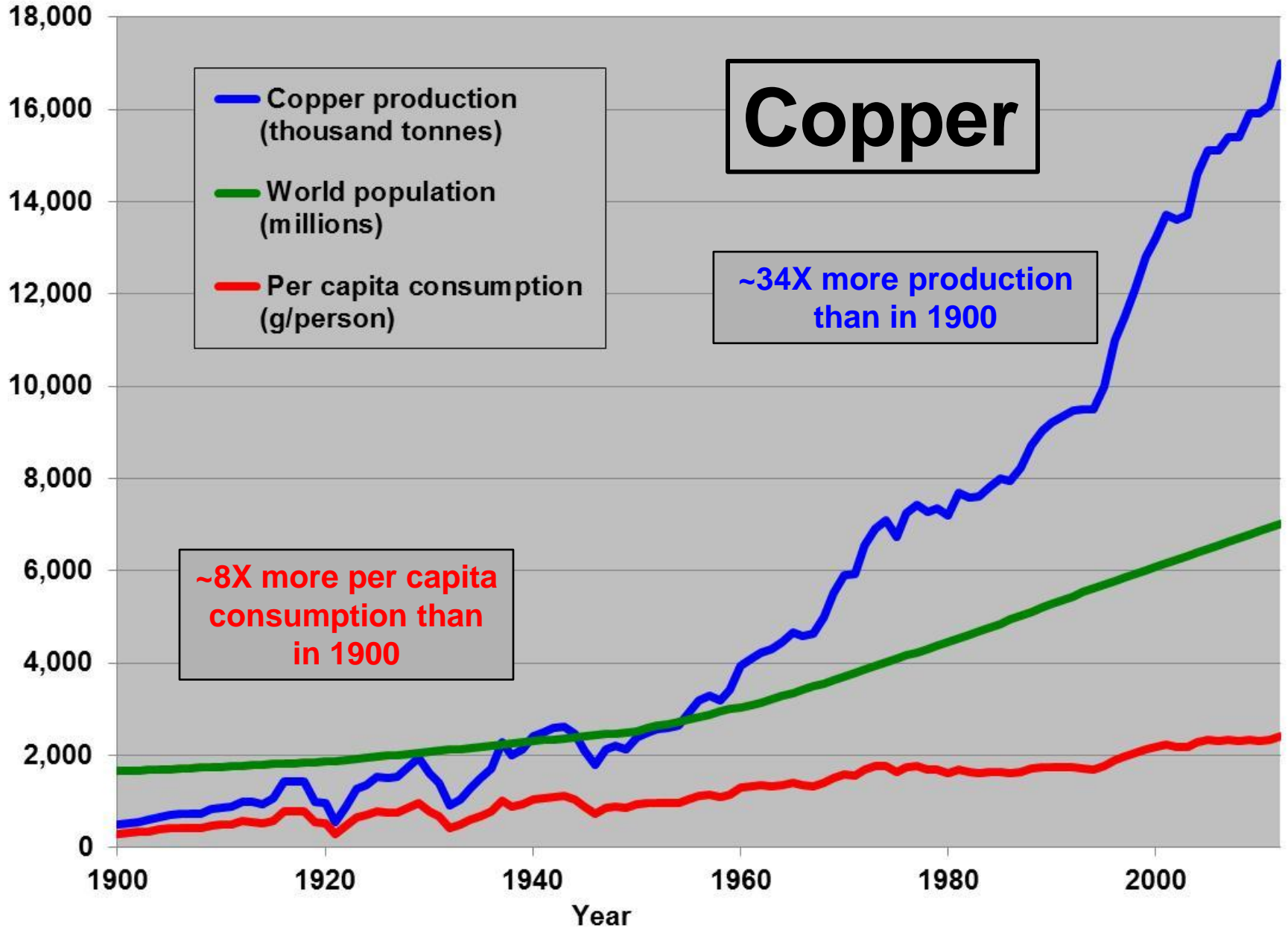
~4X more population than 100 years ago

~4X more per capita consumption than 100 years ago

~18X more production than 100 years ago

Source: USGS, CIA

Demand is high for nearly every mineral resource, due to rising population and average standard of living.



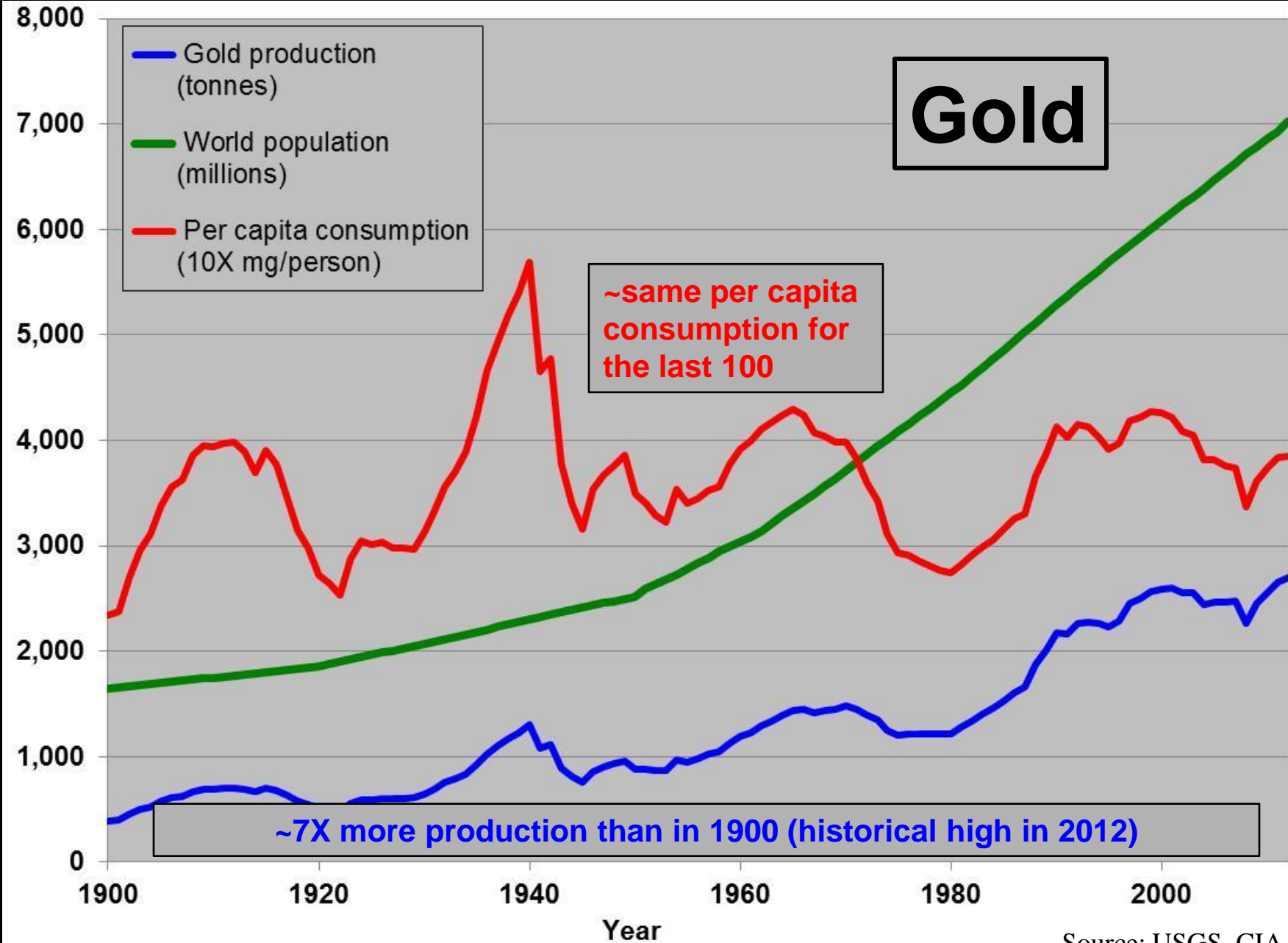
Source: USGS, CIA

Demand is high for nearly every mineral resource.

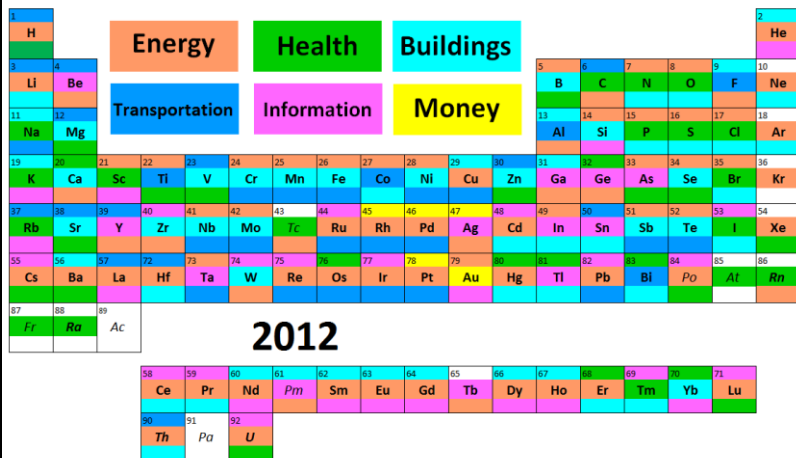
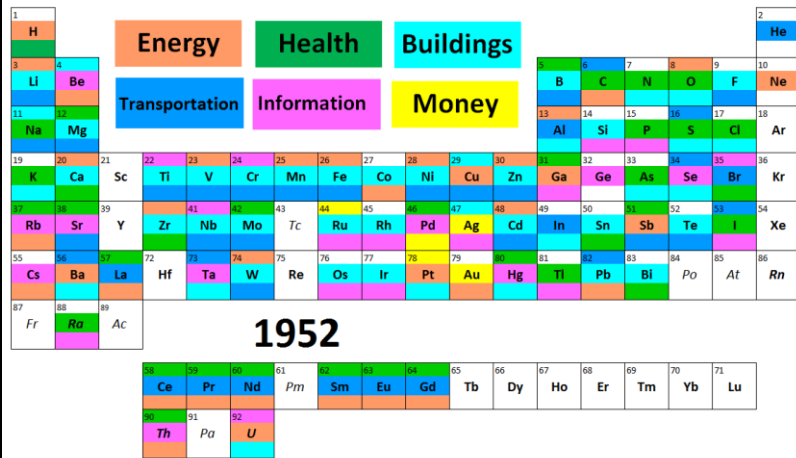
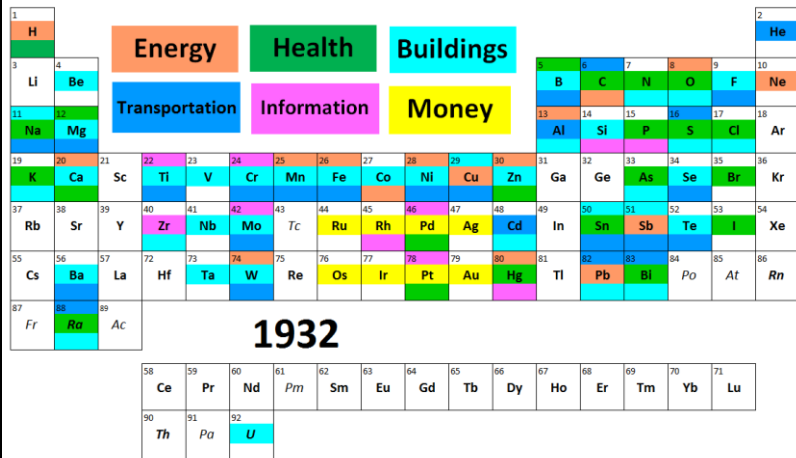


Photo copyrighted by Michael Collier, from the AGI website, Rio Tinto/Kennecott Utah Copper mine; the remaining resource as of 16 May 2008 = 3.06 million metric tons of Cu

Global copper production in 2012 (17.0 million metric tons) equaled over 100 years of production from the Bingham Canyon mine in Utah (17.0 million metric tons).



Demand is high for nearly every mineral resource.



The number of mineral commodities in demand for products in society has increased markedly in the last 80 years.

Source: USGS data

Economic geologists have been quite successful in finding more ore deposits in known areas.



2013

The Round Mountain gold mine in Nevada (volcanic-rock-hosted deposit) discovered in 1904, has yielded 13 million ounces of gold from 1977 to 2012 – continuous record of discovery around the initial deposit.

Gold production, 1835-2012

Annual gold production (millions of troy ounces)

■ United States
■ Nevada

The current boom (1981-2012) = 247M oz Au

(mostly Carlin and other Nevada deposits = 174M oz)

Goldfield (NV), Black Hills (SD), Cripple Creek (CO), porphyry Cu (AZ & UT) = 95M oz Au

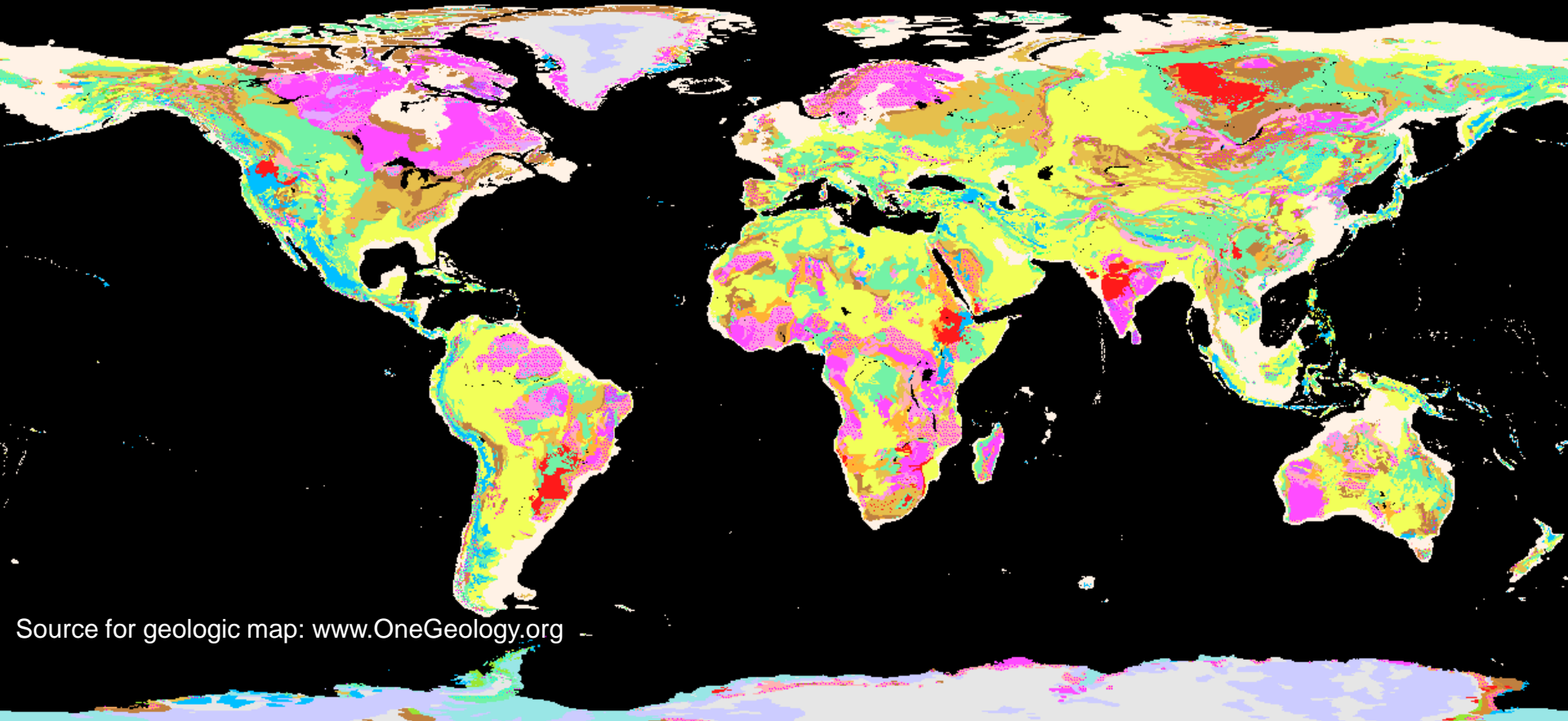
'49ers = 29M oz Au

1835 1845 1855 1865 1875 1885 1895 1905 1915 1925 1935 1945 1955 1965 1975 1985 1995 2005

Discoveries continue to feed the biggest gold boom in US and world history.

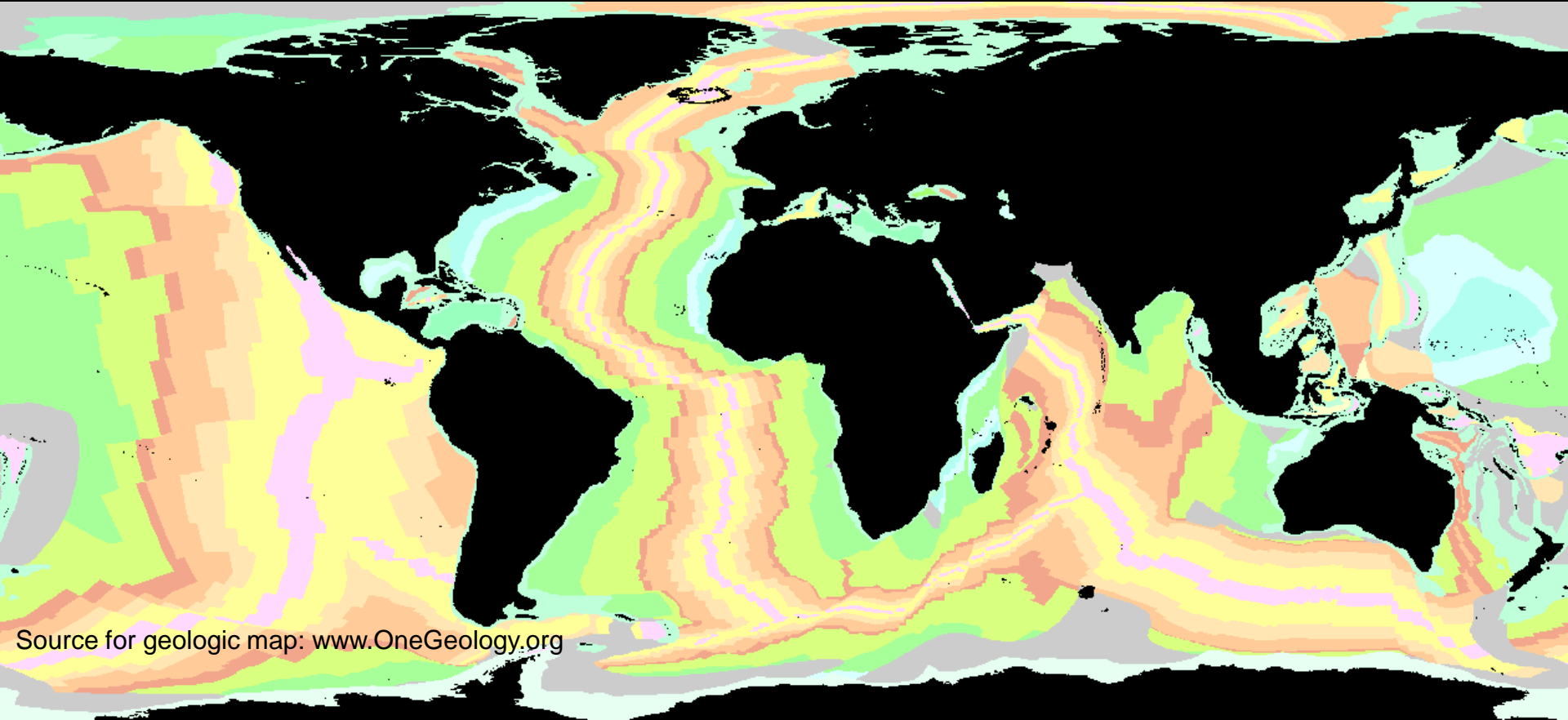
Archean (2.5 to 4.0 Ga) – **Au, Ni, U**

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



Discoveries continue to be made in traditional terrains, such as Precambrian cratons, throughout the world – limits are political and economic, not technical.

Jurassic to Recent oceanic crust – potential for ore deposits of manganese nodules (Mn, Ni, Co, Cu), massive sulfide deposits & seafloor vents (Cu, Zn, Pb, Au, Ag), and phosphate nodule deposits (P)



We have barely started to explore the oceans – political and legal challenges are probably more important than technical challenges.

Economic geologists have been quite successful in finding more ore deposits in known areas, deposits in new areas, and new types of deposits.



Large open-pit nickel operation at the Mount Keith mine, Western Australia.

Examples of some **new types** of ore deposits recognized and brought into production in the last 55 years.

Deposit type

Type locality (year discovered) and new features

Carlin Au

Carlin, Nevada (**1961**): disseminated gold in sedimentary rocks

Roll-front U

Wyoming, Kazakhstan (**1960s**): redox boundaries in sandstones

**Granite-hosted U
Unconformity U**

Rössing, Namibia (**1960s**): U-rich granite

Rabbit Lake, Saskatchewan (**1968**): high-grade U near unconformities

Disseminated Ni

Mt. Keith, W. Australia (**1969**): disseminated Ni sulfides in komatiitic lava channels

Iron oxide Cu-Au

Olympic Dam, S. Australia (**1975**): iron-oxide-rich ores in huge regional alteration systems

Intrusion-related Au

Fort Knox, Alaska (**1980s**): Au in granitic rocks, without Cu

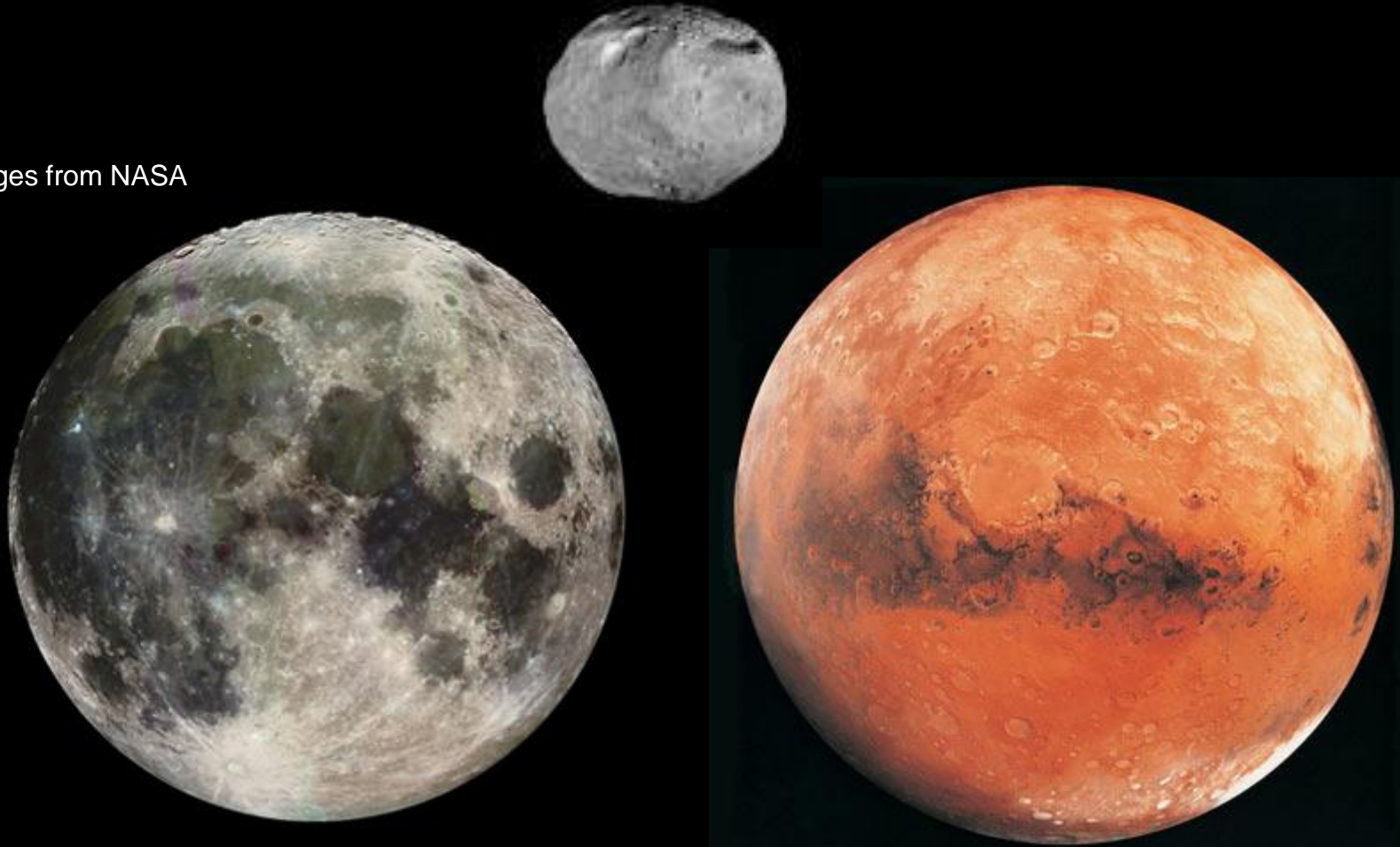
Ion Absorption REE

South China (**1980s**): low-grade REEs with kaolinite in weathered granites

More new types of ore deposits will be discovered in the future...

We may not need to worry about mining on the Moon, Mars, or asteroids for some time.

Images from NASA



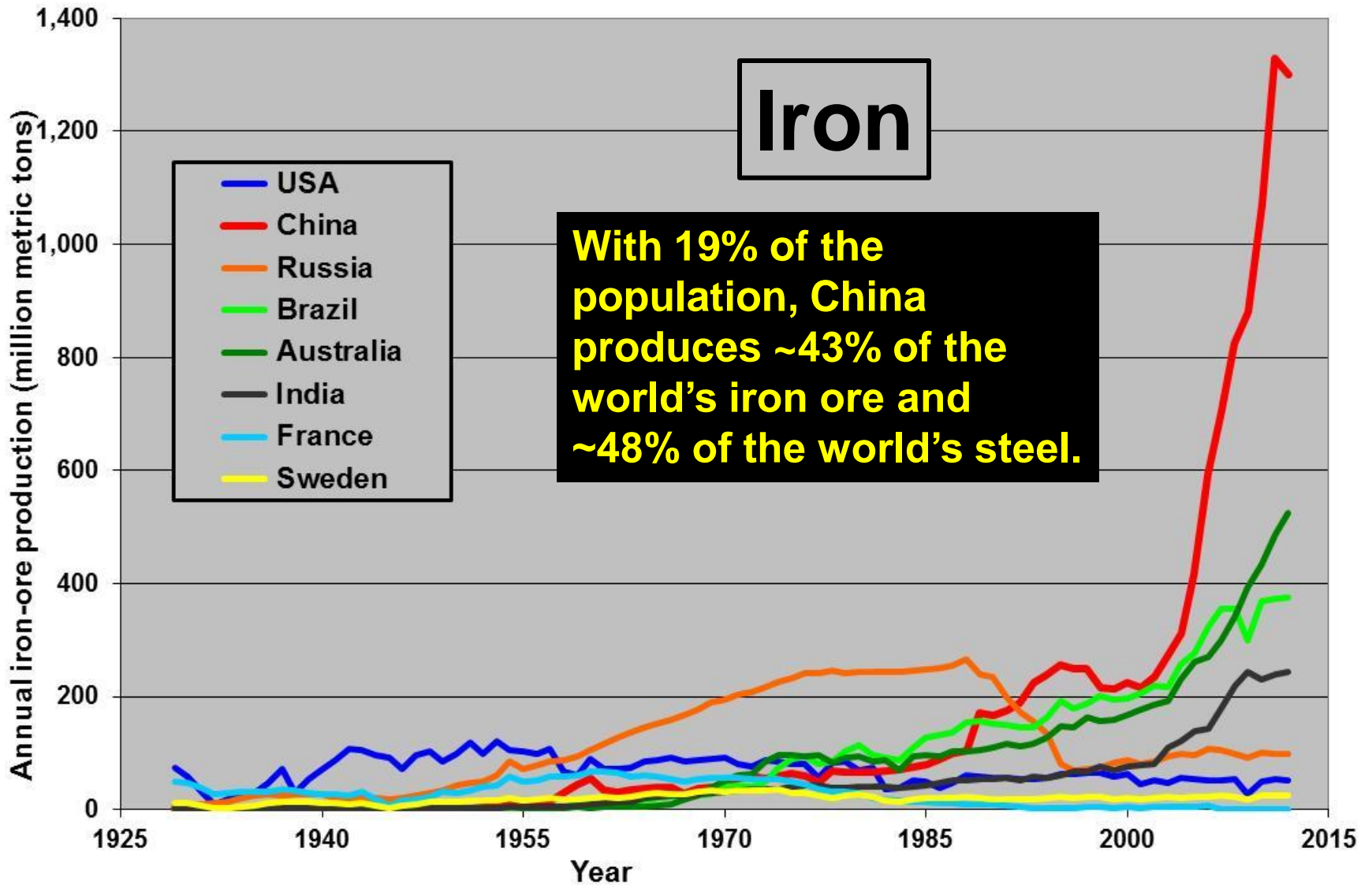
Though thinking about how ore deposits might form on such bodies could help us be more imaginative on Earth!

The Importance of Mineral Resources in a National-International Context

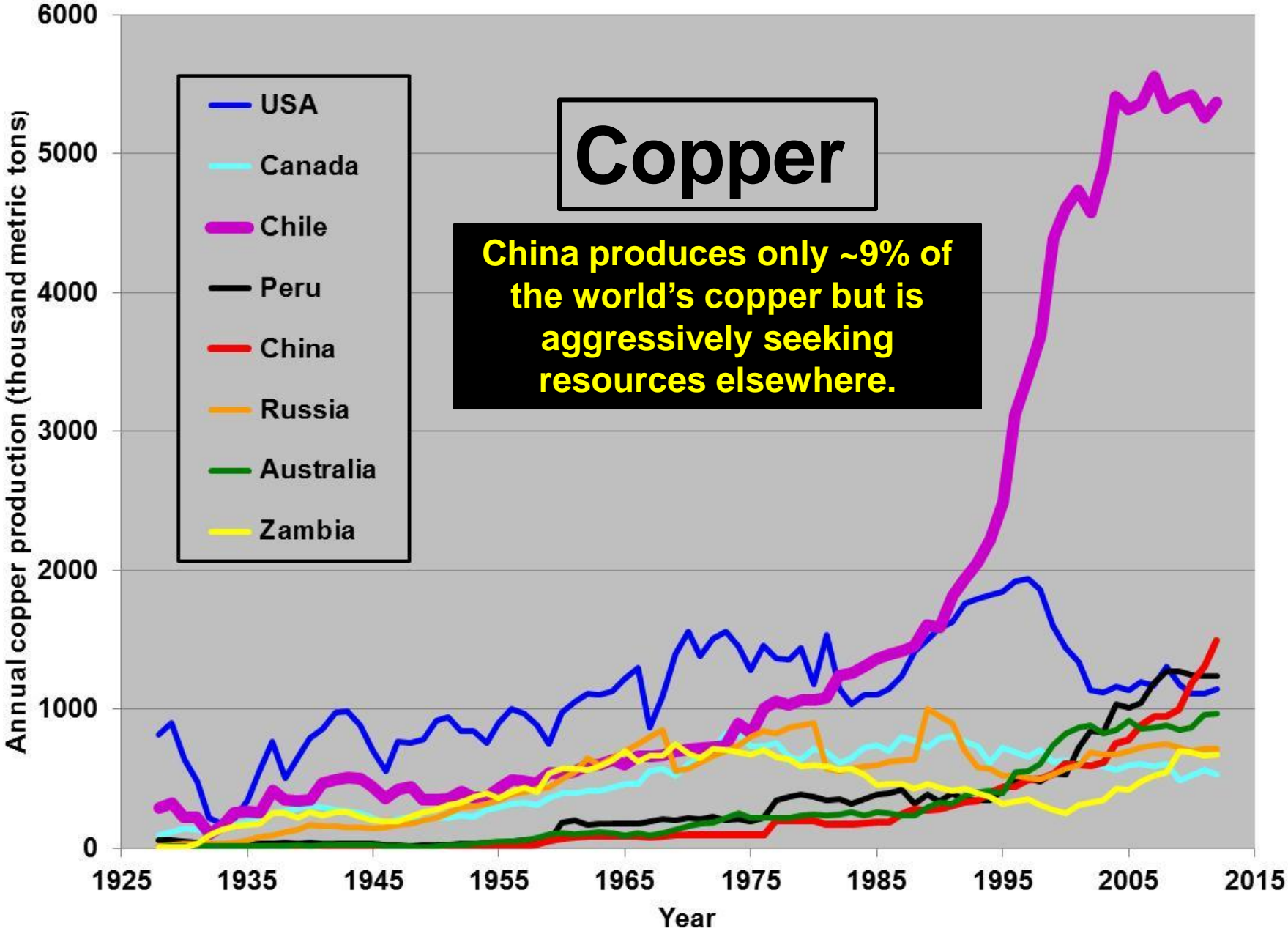
- Demand for mineral resources will continue to grow.
- We are unlikely to run out of mineral resources (globally).
- **Nonetheless, there are challenges for the United States.**

Challenges for the United States

**China is #1
in terms of mineral-resource production.**

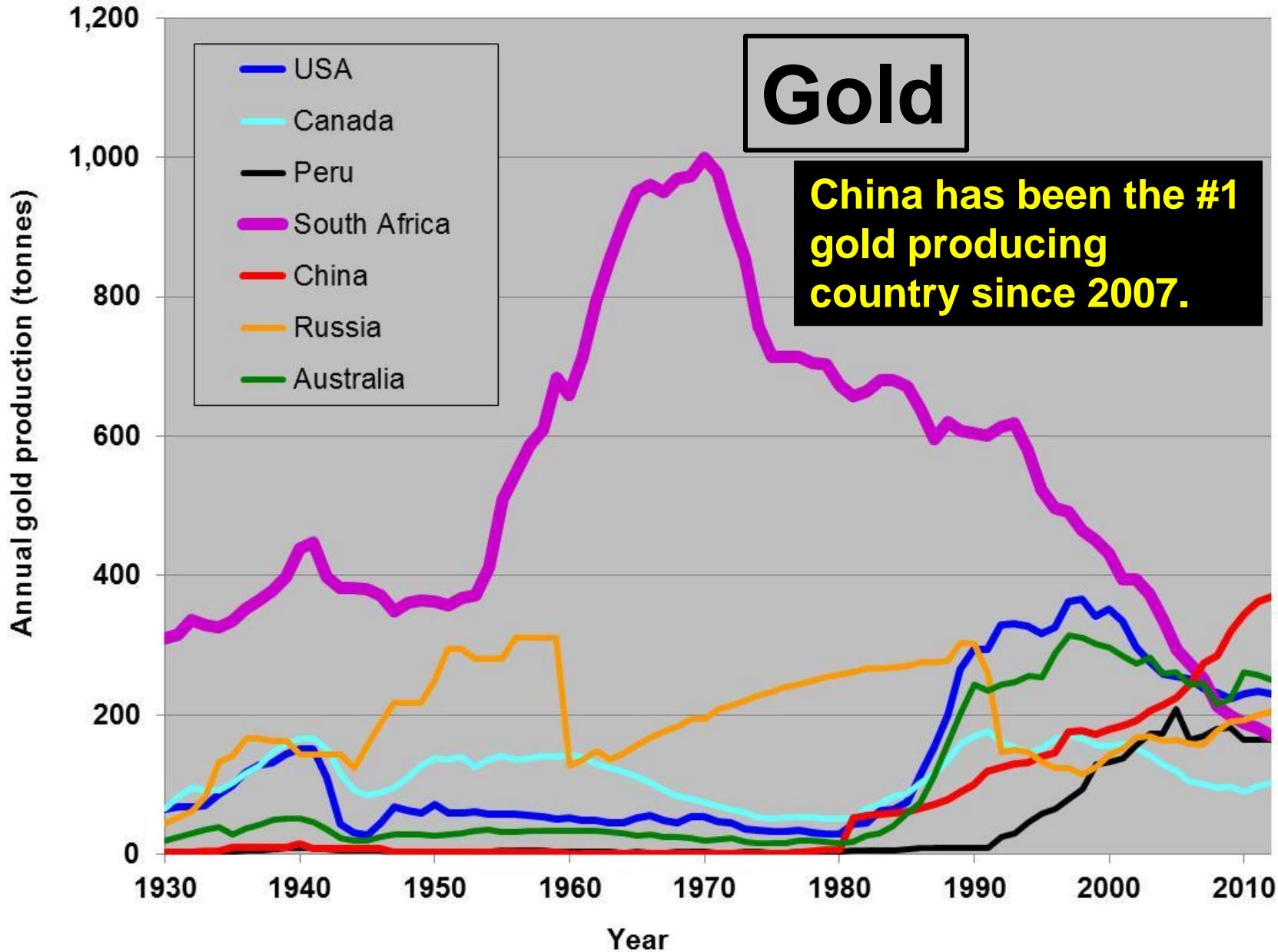


China's economy continues to boom, although 2012 iron-ore production suggests a slowdown.



Gold

China has been the #1 gold producing country since 2007.

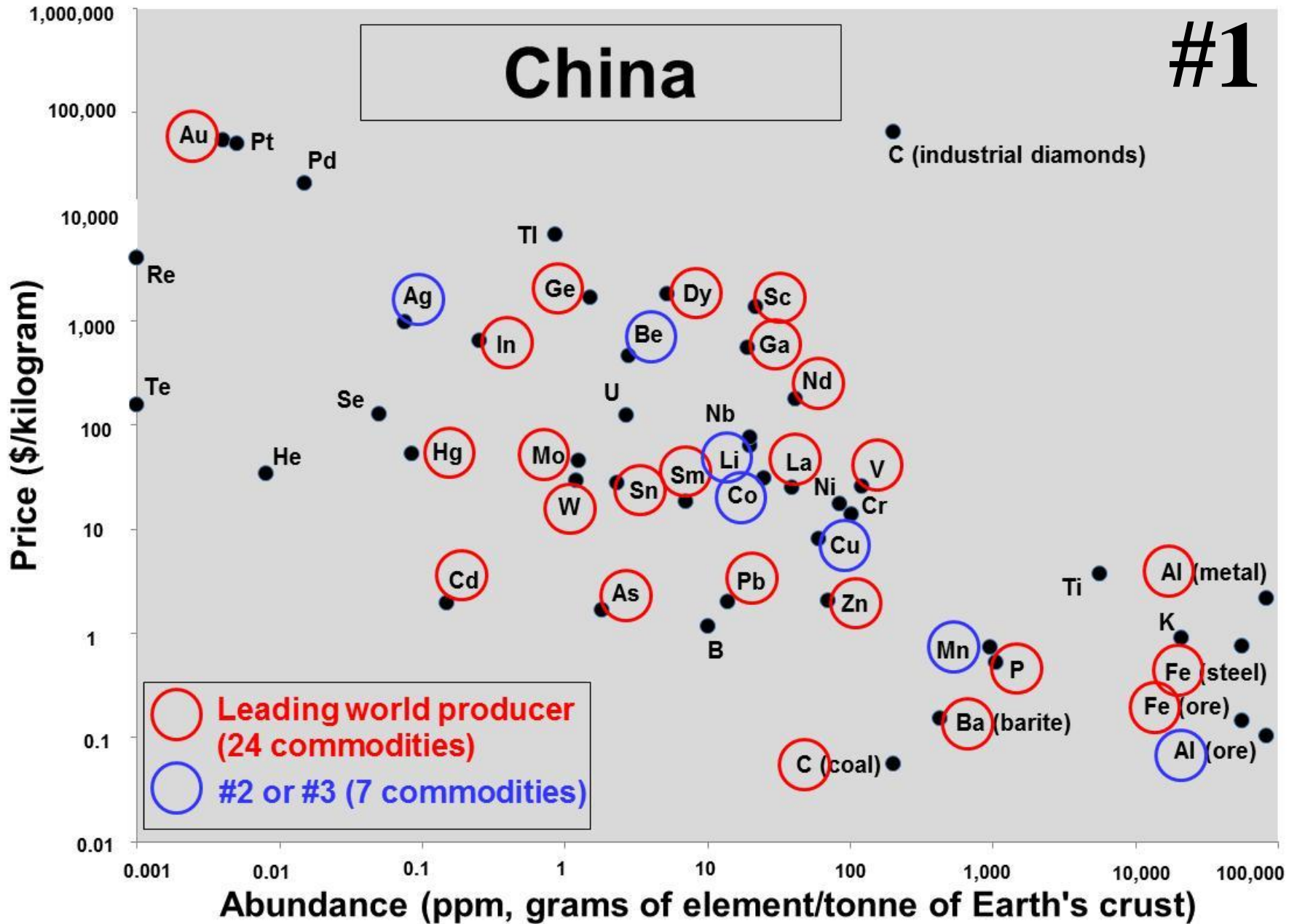


In production of 46 mineral commodities, China ranks well above all others.

| 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 | 24 | 31 |
| USA | 2 | 16 |
| Australia | 2 | 13 |
| Russia | 1 | 10 |
| Canada | 1 | 9 |
| Chile | 3 | 6 |
| South Africa | 3 | 6 |
| Kazakhstan | 1 | 4 |
| Brazil | 1 | 3 |
| Congo | 1 | 2 |

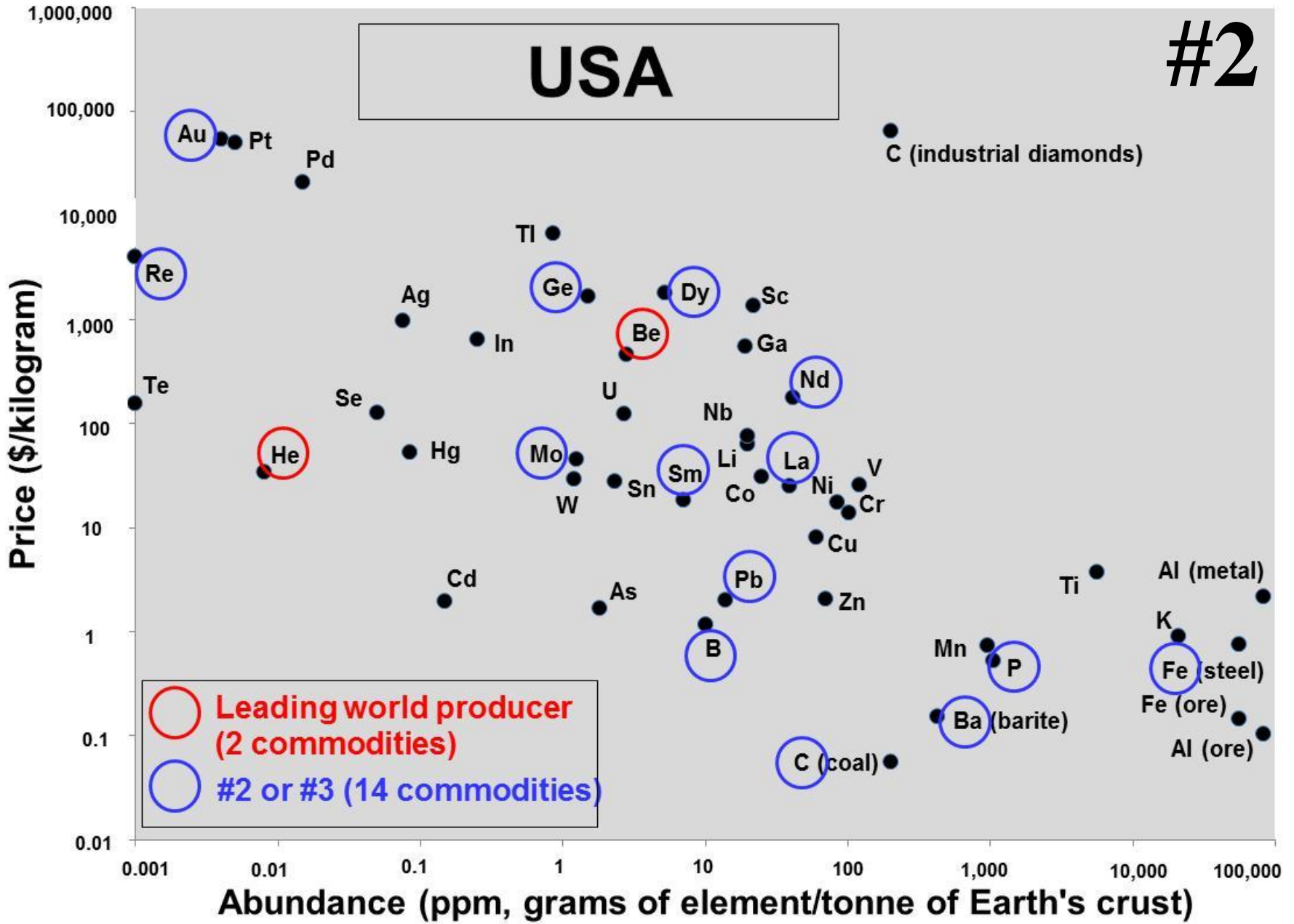
China

#1



USA

#2

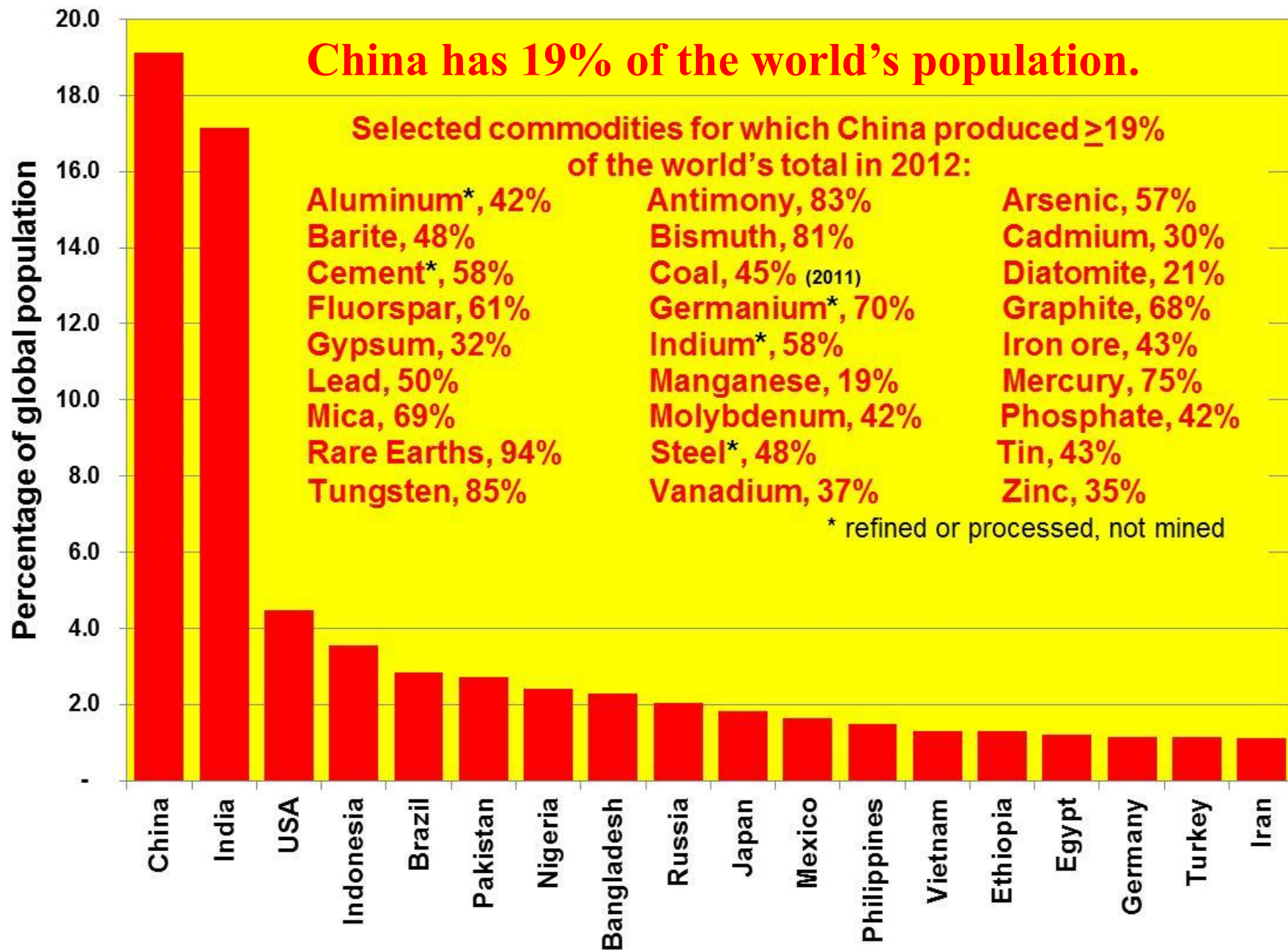


China has 19% of the world's population.

Selected commodities for which China produced $\geq 19\%$ of the world's total in 2012:

| | | |
|------------------|------------------|----------------|
| Aluminum*, 42% | Antimony, 83% | Arsenic, 57% |
| Barite, 48% | Bismuth, 81% | Cadmium, 30% |
| Cement*, 58% | Coal, 45% (2011) | Diatomite, 21% |
| Fluorspar, 61% | Germanium*, 70% | Graphite, 68% |
| Gypsum, 32% | Indium*, 58% | Iron ore, 43% |
| Lead, 50% | Manganese, 19% | Mercury, 75% |
| Mica, 69% | Molybdenum, 42% | Phosphate, 42% |
| Rare Earths, 94% | Steel*, 48% | Tin, 43% |
| Tungsten, 85% | Vanadium, 37% | Zinc, 35% |

* refined or processed, not mined



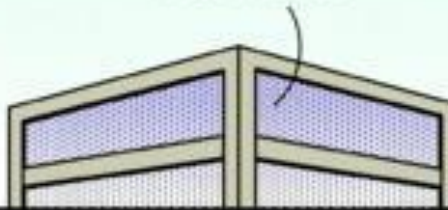
Rare Earth Elements (REEs)

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.



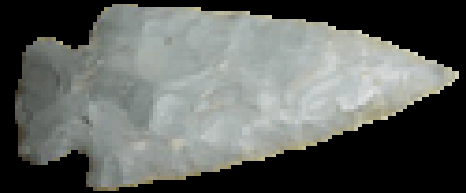
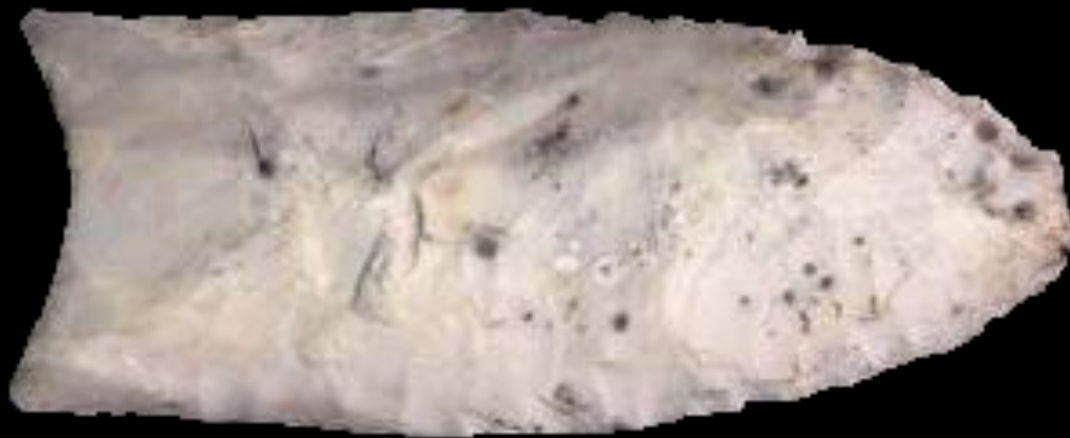
$\text{CuIn}_x\text{Ga}_{(1-x)}\text{Se}_2$, CdTe , GaAs , Ag , and $\text{Si}_{1-x}\text{Ge}_x$
for **solar panels**

$\text{Fe}_{14}(\text{Nd,Dy})_2\text{B}$, SmCo_5 , and $\text{Sm}_2\text{Co}_{17}$
for magnets, e.g., in **wind turbines**

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

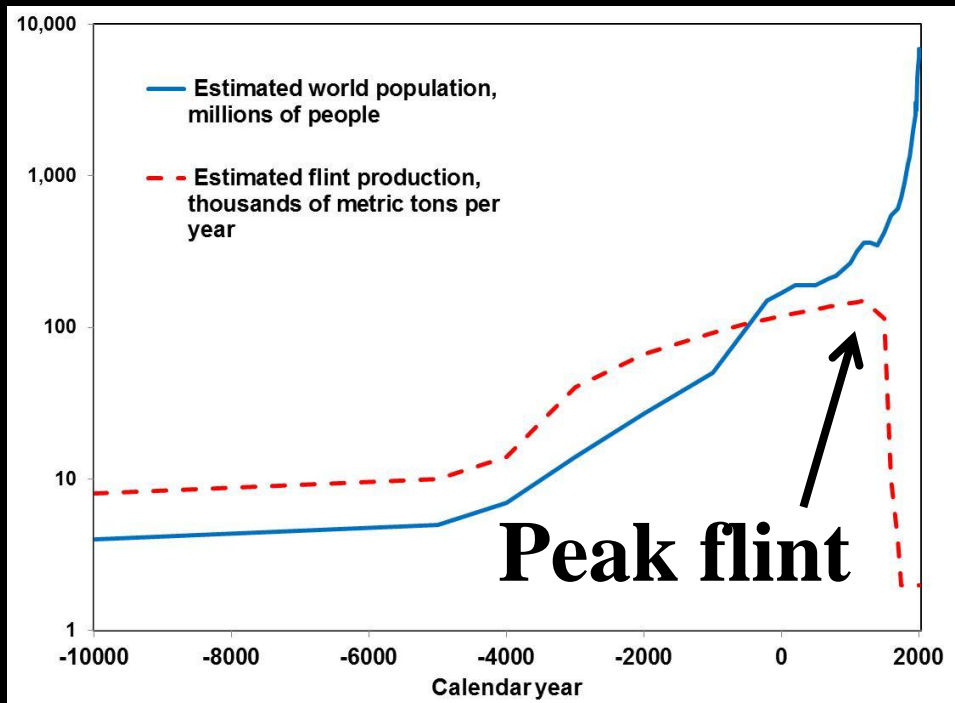
Pt, Pd for catalysts in **fuel cells**

Tb, Eu in **fluorescent lights**




Arrowhead clipart from www.firstpeople.us

**Critical and strategic minerals
do change with time.**



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] | |
| 65 Tb Terbium 58.92534 | | 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 | | | | | |

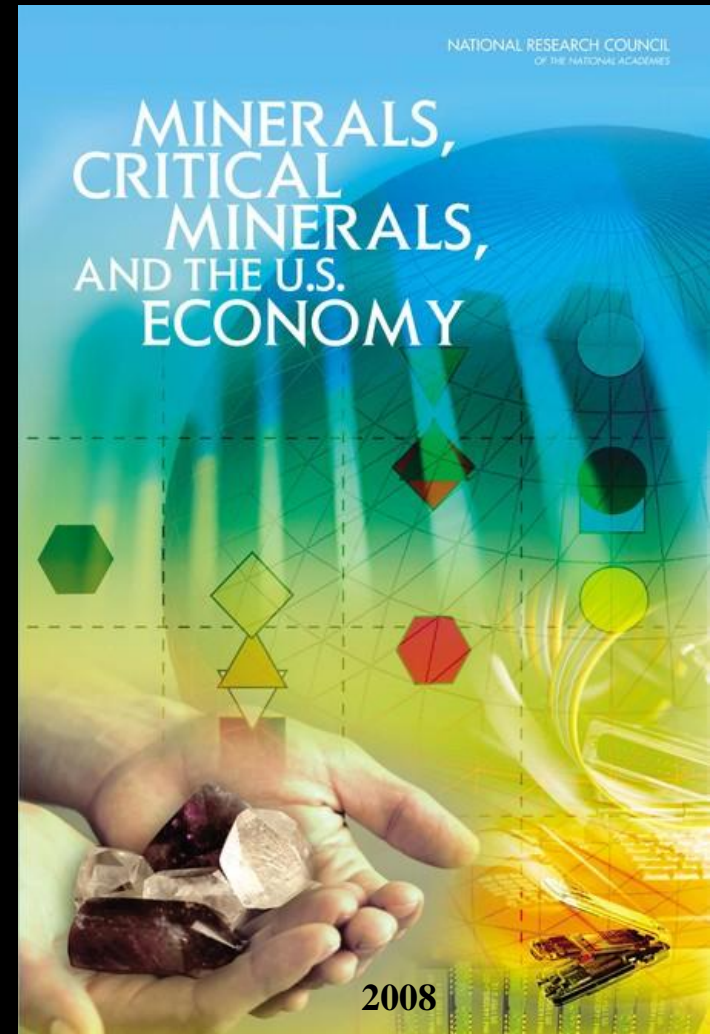
Securing Materials for Emerging Technologies

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



2011

What minerals will be critical for the country?



2008

HARDROCK MINING ON FEDERAL LANDS

**Will the USA be a
major producer of
mineral resources
in the future?**

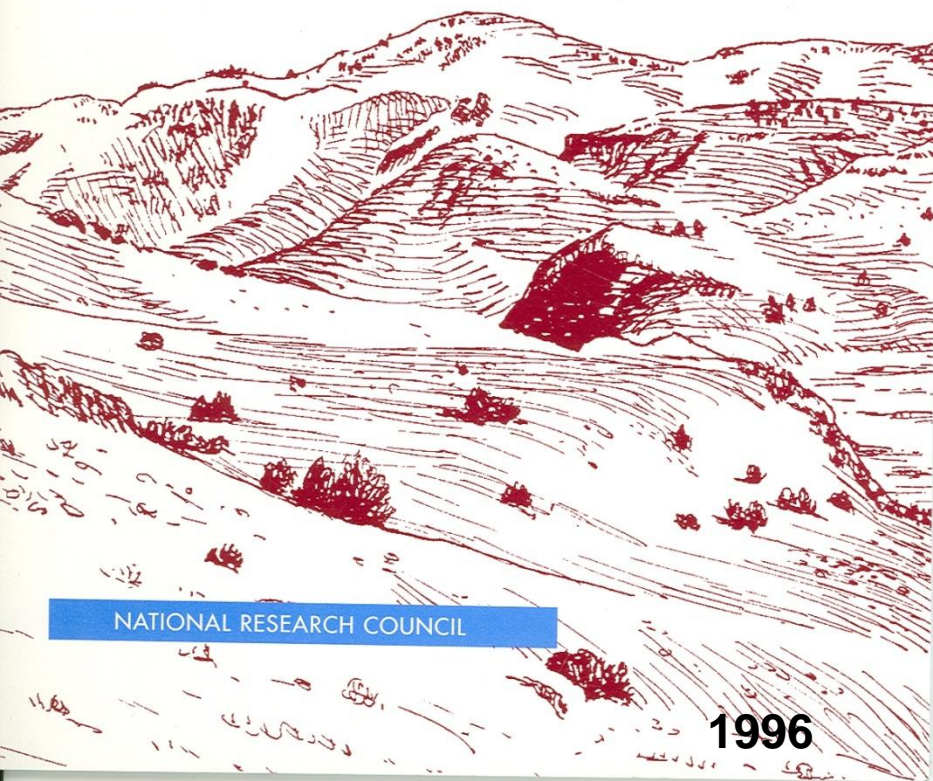


NATIONAL RESEARCH COUNCIL

1999

MINERAL RESOURCES AND SUSTAINABILITY

challenges for earth scientists



NATIONAL RESEARCH COUNCIL

1996

Will the USA be a major producer of mineral resources in the future?

Or will we, perhaps by default, practice “environmental imperialism” – export the negative environmental, health, safety, aesthetic, and cultural aspects of mining to other countries?

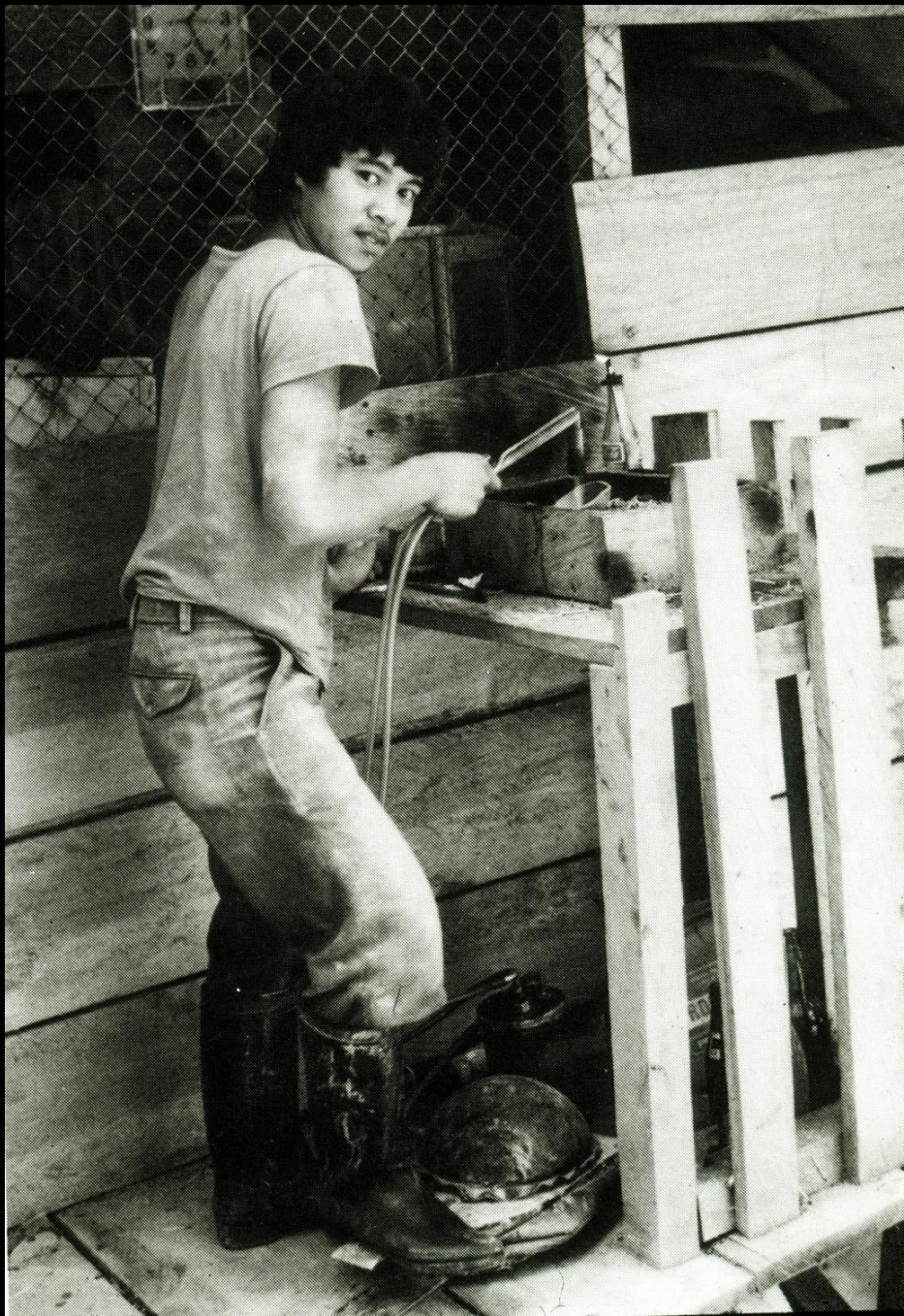
Artisanal mining outside the US will likely continue as a health, safety, and environmental challenge for society, governments, and industry worldwide.



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

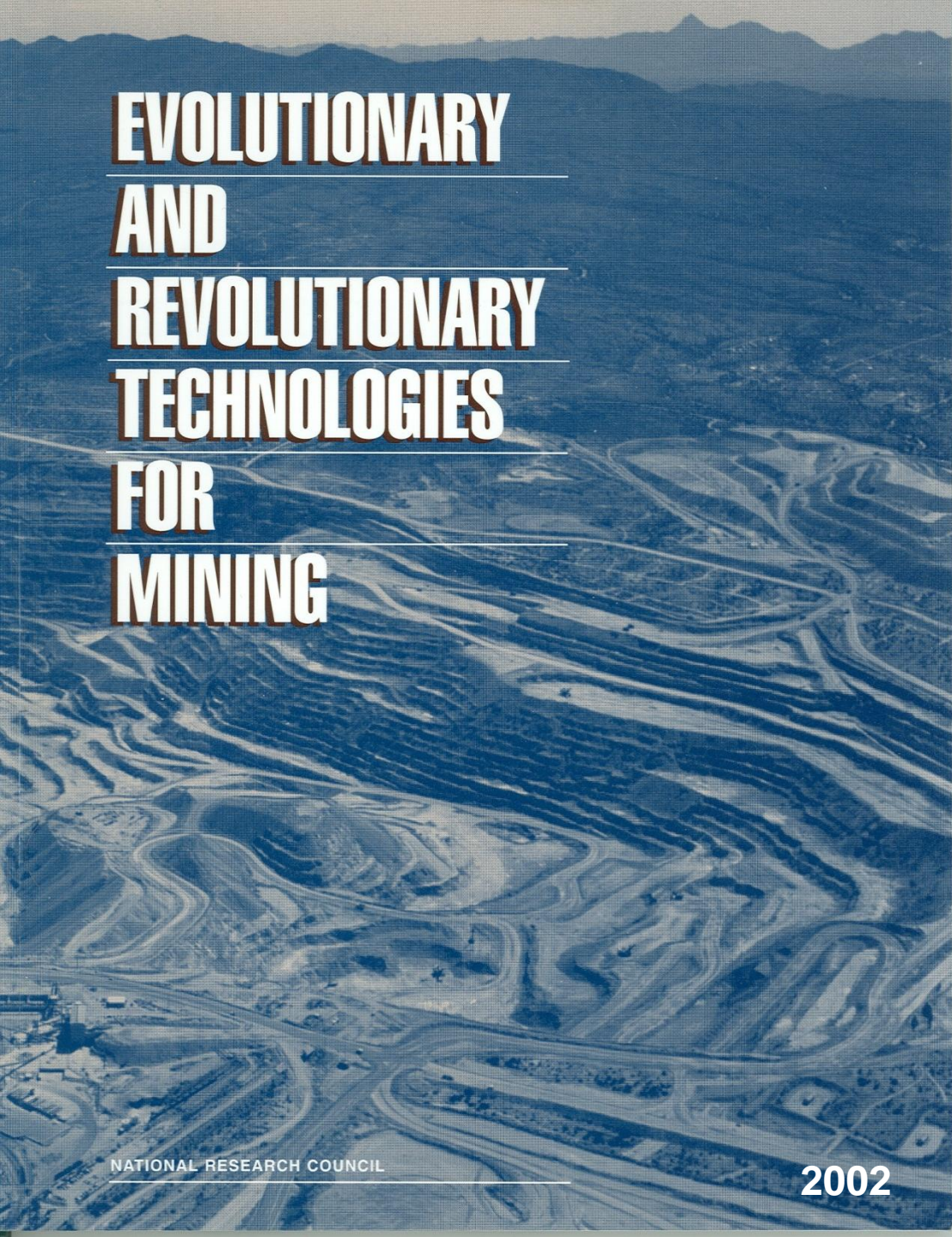


Gold mill in Sulawesi (Larry James photo)



**Recent reports
(Science Oct. 2013)
state that 70% of Hg
pollution worldwide is
from artisanal mining.**

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



**EVOLUTIONARY
AND
REVOLUTIONARY
TECHNOLOGIES
FOR
MINING**

**Will the US
government invest in
research needed to
discover, extract,
and process mineral
resources in an
environmentally
responsible manner?**



NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

MATERIALS COUNT

The Case for
Material Flows Analysis

Will the US government invest in research on improving the rate of recycling of mineral resources, and on finding substitutes for mineral resources that become too expensive for commercial or other applications?

2004

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).

| | | | | | | | | | | | | | | | | | | | | | | | |
|-----------------|-----------------|-----------------|----------|----------|----------|-----------------|----------|----------|----------|----------|----------|----------|----------|----------|-----------------|-----------------|-----------------|----------|----------|---------|---------|----------|----------|
| 1 H | | | | | | | | | | | | | | | | | 2 He | | | | | | |
| 3 Li | 4 Be | | | | | | | | | | | | | | | | | 5 B | 6 C | 7 N | 8 O | 9 F | 10 Ne |
| 11 Na | 12 Mg | | | | | | | | | | | | | | | | | 13 Al | 14 Si | 15 P | 16 S | 17 Cl | 18 Ar |
| 19 K | 20 Ca | 21 Sc | 22 Ti | 23 V | 24 Cr | 25 Mn | 26 Fe | 27 Co | 28 Ni | 29 Cu | 30 Zn | 31 Ga | 32 Ge | 33 As | 34 Se | 35 Br | 36 Kr | | | | | | |
| 37 Rb | 38 Sr | 39 Y | 40 Zr | 41 Nb | 42 Mo | 43 <i>Tc</i> | 44 Ru | 45 Rh | 46 Pd | 47 Ag | 48 Cd | 49 In | 50 Sn | 51 Sb | 52 Te | 53 I | 54 Xe | | | | | | |
| 55 Cs | 56 Ba | 57 La | 72 Hf | 73 Ta | 74 W | 75 Re | 76 Os | 77 Ir | 78 Pt | 79 Au | 80 Hg | 81 Tl | 82 Pb | 83 Bi | 84 <i>Po</i> | 85 <i>At</i> | 86 <i>Rn</i> | | | | | | |
| 87 <i>Fr</i> | 88 <i>Ra</i> | 89 <i>Ac</i> | | | | | | | | | | | | | | | | | | | | | |

| | | | | | | | | | | | | | |
|-----------------|-----------------|----------------|-----------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| 58 Ce | 59 Pr | 60 Nd | 61 <i>Pm</i> | 62 Sm | 63 Eu | 64 Gd | 65 Tb | 66 Dy | 67 Ho | 68 Er | 69 Tm | 70 Yb | 71 Lu |
| 90 <i>Th</i> | 91 <i>Pa</i> | 92 <i>U</i> | | | | | | | | | | | |

Source: Graedel et al. (2011)

Emerging Workforce Trends in the U.S. Energy and Mining Industries

A CALL TO ACTION



Do we have, and are we training, the people needed to ensure the US can meet its mineral and energy needs?

2013

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

Geologic Mapping

Future Needs

Committee on Geologic Mapping

Board on Earth Sciences

*Commission on Physical Sciences, Mathematics, and
Resources*

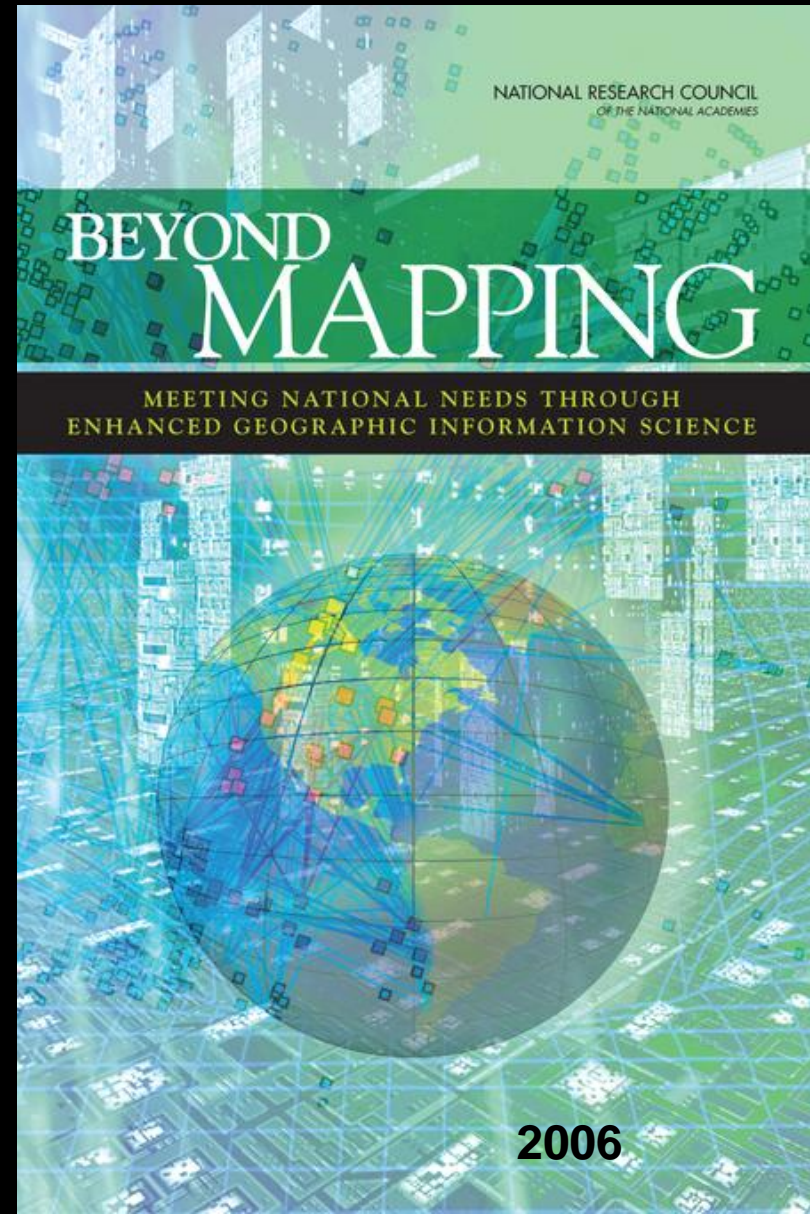
National Research Council

NATIONAL ACADEMY PRESS

Washington, D.C.

1988

Will the US and other governments support the basic research, including geologic mapping, needed to understand where resources are likely to be found?



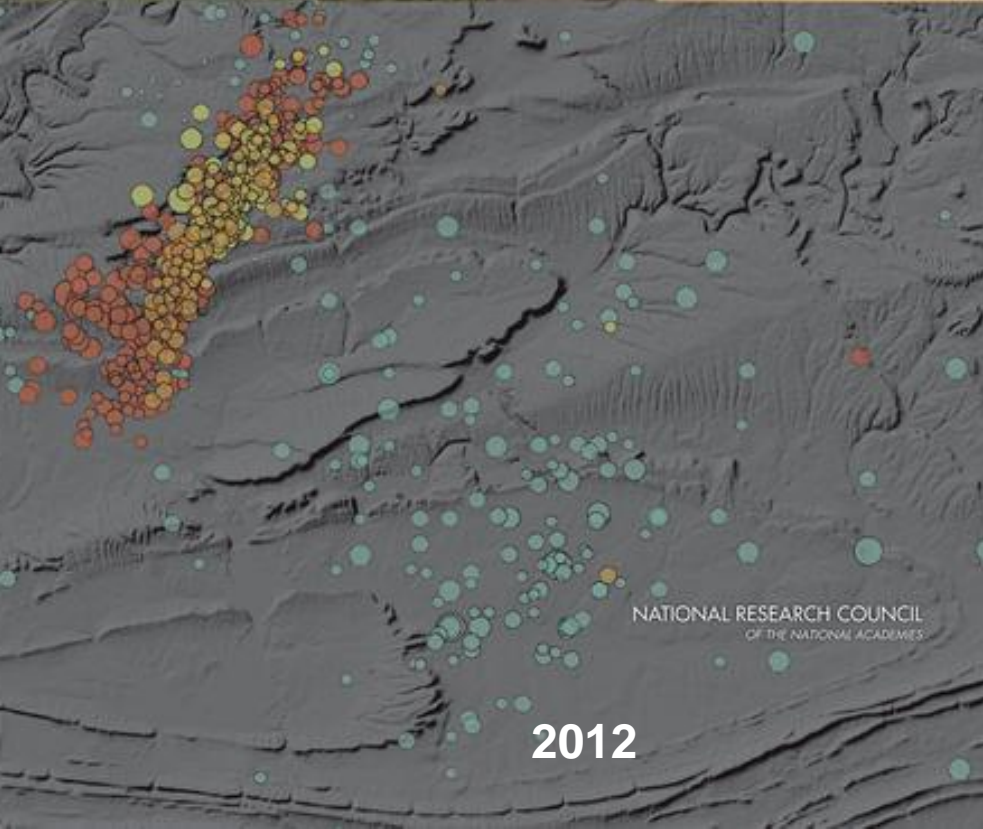
Geoscience Data and Collections

NATIONAL RESOURCES IN PERIL

Will the US and other governments support the preservation of geological data and collections that stimulate discovery?



Induced Seismicity Potential in ENERGY TECHNOLOGIES



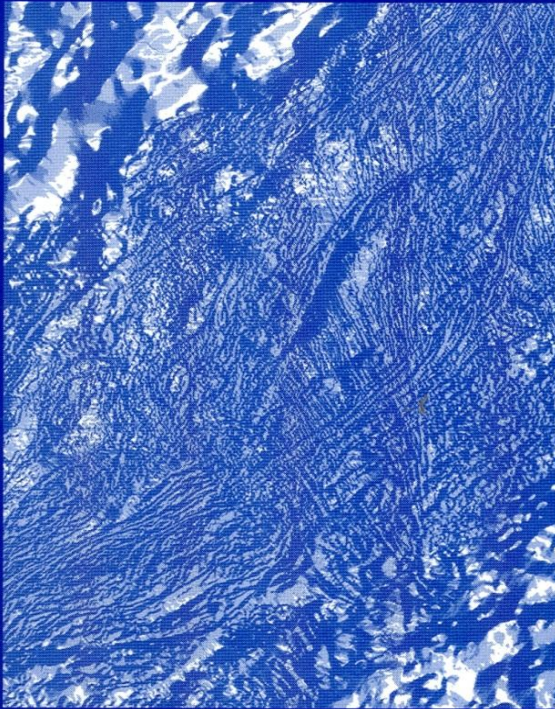
NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

2012

**What may be the
unintended
consequences of
new mineral
resource
production ?**

Mineral Resources and Society

A Review of the U.S. Geological Survey's
Mineral Resource Surveys Program Plan



NATIONAL RESEARCH COUNCIL 1996

FUTURE ROLES AND OPPORTUNITIES FOR THE U.S. GEOLOGICAL SURVEY



2001

NATIONAL RESEARCH COUNCIL

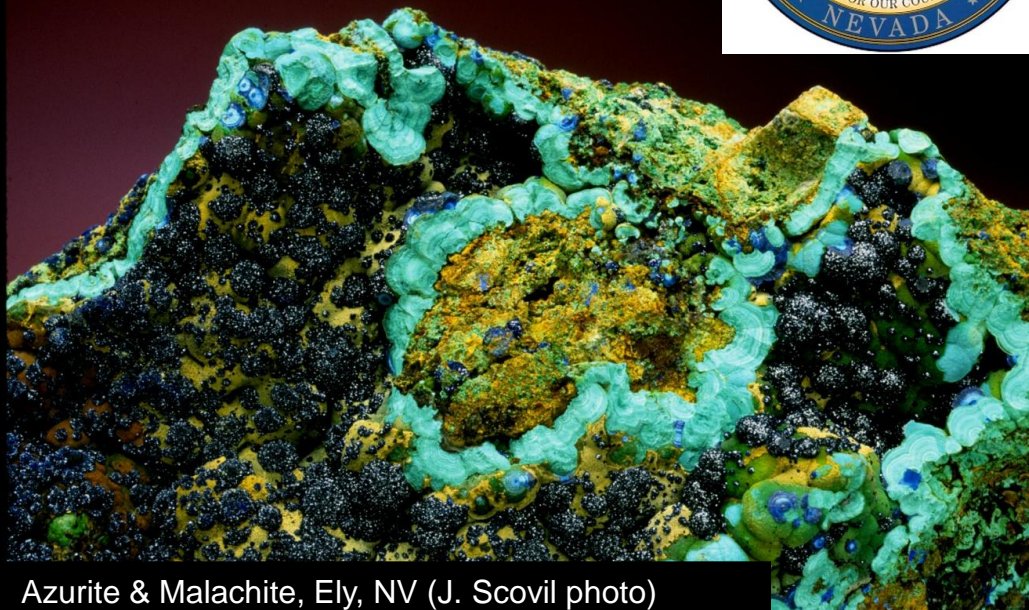
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State Geologist Emeritus
Nevada Bureau of Mines and Geology



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

JONATHAN G. PRICE, LLC

| | | | | | | | | | | | | | | | | | | | | | | |
|----------|----------|----------|--------|---------|--------|---------|--------|---------|--------|---------|---------|---------|---------|--------|--------|---------|----------|--------|--|--|--|--------|
| H | He | | | | | | | | | | | | | | | | | | | | | He |
| 1.00794 | 4.0026 | | | | | | | | | | | | | | | | | | | | | 4.0026 |
| Li | Be | B | C | N | O | F | Ne | | | | | | | | | | | Ne | | | | |
| 6.941 | 9.0122 | 10.811 | 12.011 | 14.007 | 15.999 | 18.998 | 20.180 | | | | | | | | | | | 20.180 | | | | |
| Na | Mg | Al | Si | P | S | Cl | Ar | | | | | | | | | | | Ar | | | | |
| 22.990 | 24.305 | 26.9815 | 28.086 | 30.9738 | 32.066 | 35.453 | 39.948 | | | | | | | | | | | 39.948 | | | | |
| K | Ca | Sc | Ti | V | Cr | Mn | Fe | Co | Ni | Cu | Zn | Ga | Ge | As | Se | Br | Kr | | | | | |
| 39.0983 | 40.078 | 44.9559 | 47.88 | 50.9415 | 51.996 | 54.938 | 55.847 | 58.933 | 58.693 | 63.546 | 65.38 | 69.723 | 72.61 | 74.922 | 76.96 | 79.904 | 83.8 | | | | | |
| Rb | Sr | Y | Zr | Nb | Mo | Tc | Ru | Rh | Pd | Ag | Cd | In | Sn | Sb | Te | I | Xe | | | | | |
| 85.4678 | 87.62 | 88.906 | 91.224 | 92.906 | 95.94 | 97.9 | 101.07 | 101.063 | 106.42 | 107.868 | 112.411 | 114.818 | 118.71 | 127.27 | 127.6 | 126.904 | 131.29 | | | | | |
| Cs | Ba | La | Hf | Ta | W | Re | Os | Ir | Pt | Au | Hg | Tl | Pb | Bi | Po | At | Rn | | | | | |
| 132.905 | 137.327 | 138.905 | 178.49 | 180.948 | 183.84 | 186.207 | 190.23 | 192.22 | 195.08 | 196.967 | 200.59 | 204.383 | 207.2 | 208.98 | 208.98 | 208.98 | 222.0176 | | | | | |
| Fr | Ra | Ac | | | | | | | | | | | | | | | | | | | | |
| 223.0 | 226.0254 | 227.028 | | | | | | | | | | | | | | | | | | | | |
| Ce | Pr | Nd | Pm | Sm | Eu | Gd | Tb | Dy | Ho | Er | Tm | Yb | Lu | | | | | | | | | |
| 140.12 | 140.908 | 140.908 | 144.24 | 144.913 | 150.36 | 151.965 | 157.25 | 158.925 | 162.50 | 164.93 | 167.26 | 173.04 | 174.967 | | | | | | | | | |
| Th | Pu | U | | | | | | | | | | | | | | | | | | | | |
| 232.0377 | 238.0289 | 238.0289 | | | | | | | | | | | | | | | | | | | | |

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