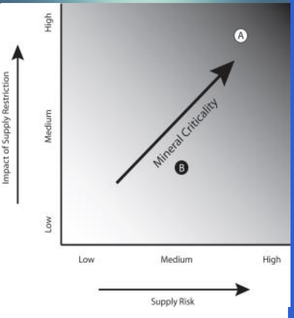
Earth Materials: The Foundation for Development

Dr. Larry Meinert, Editor-in-Chief, Economic Geology, Affiliate Faculty - Colorado School of Mines, and President - Meinert Consulting, USA.

Dr. Nellie Mutemeri, Mining Practice Lead, Mutemeri Consulting and Associate Professor, University of Witwatersrand, South Africa.



Earth Materials for a Sustainable and Thriving Society

UNESCO Lecture Series

United Nations
Educational, Scientific and
Cultural Organization

International
Geoscience
Programme

Organised in collaboration with IUGS and iCRAG

SUSTAINABLE DEVELOPMENT GOALS

1 NO POVERTY

2 ZERO HUNGER

3 GOOD HEALTH AND WELL-BEING

4 QUALITY EDUCATION

5 GENDER EQUALITY

6 CLEAN WATER AND SANITATION

7 AFFORDABLE AND CLEAN ENERGY

8 DECENT WORK AND ECONOMIC GROWTH

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

10 REDUCED INEQUALITIES

11 SUSTAINABLE CITIES AND COMMUNITIES

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

13 CLIMATE ACTION

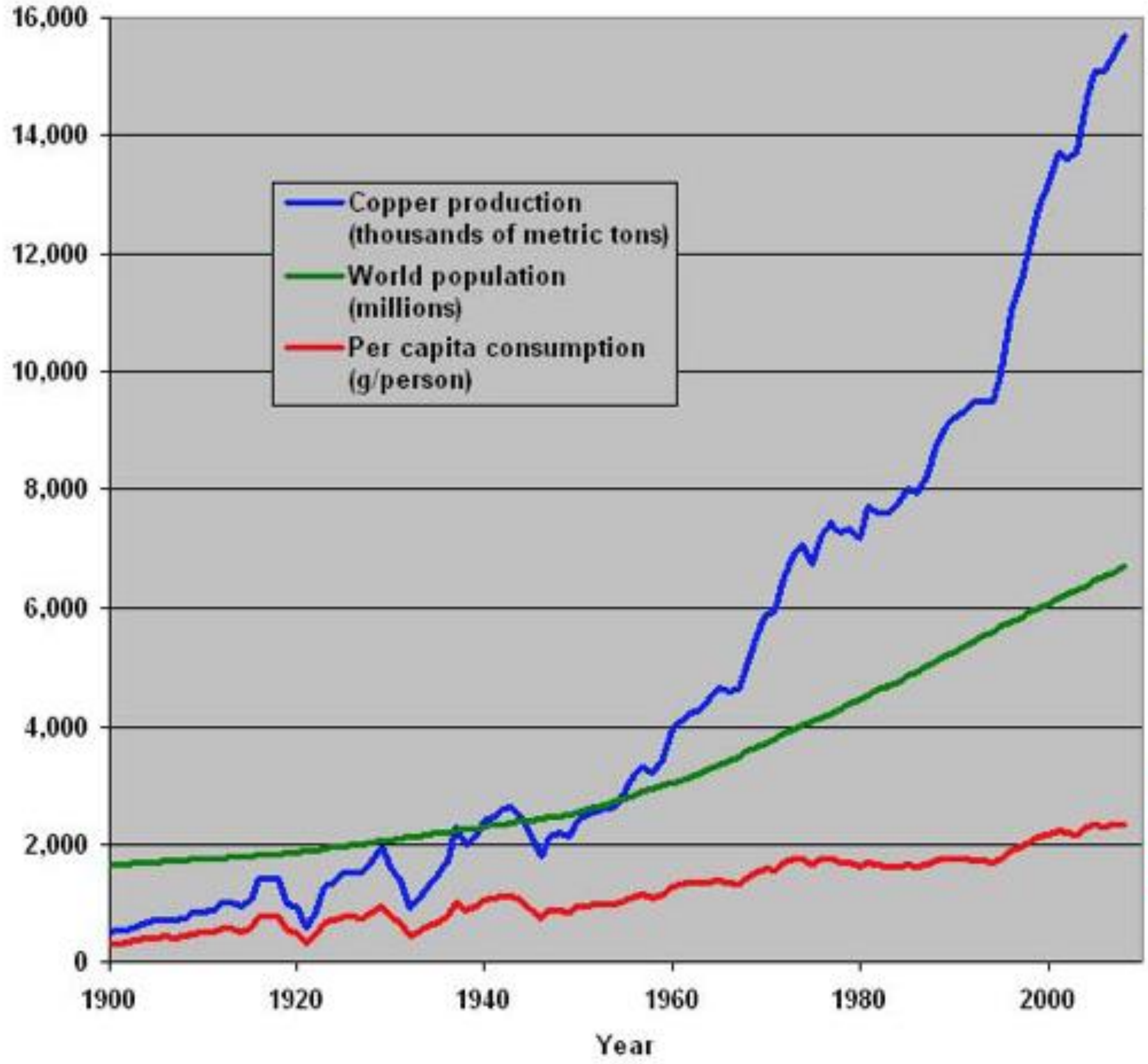
14 LIFE BELOW WATER

15 LIFE ON LAND

16 PEACE, JUSTICE AND STRONG INSTITUTIONS

17 PARTNERSHIPS FOR THE GOALS

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



Copper

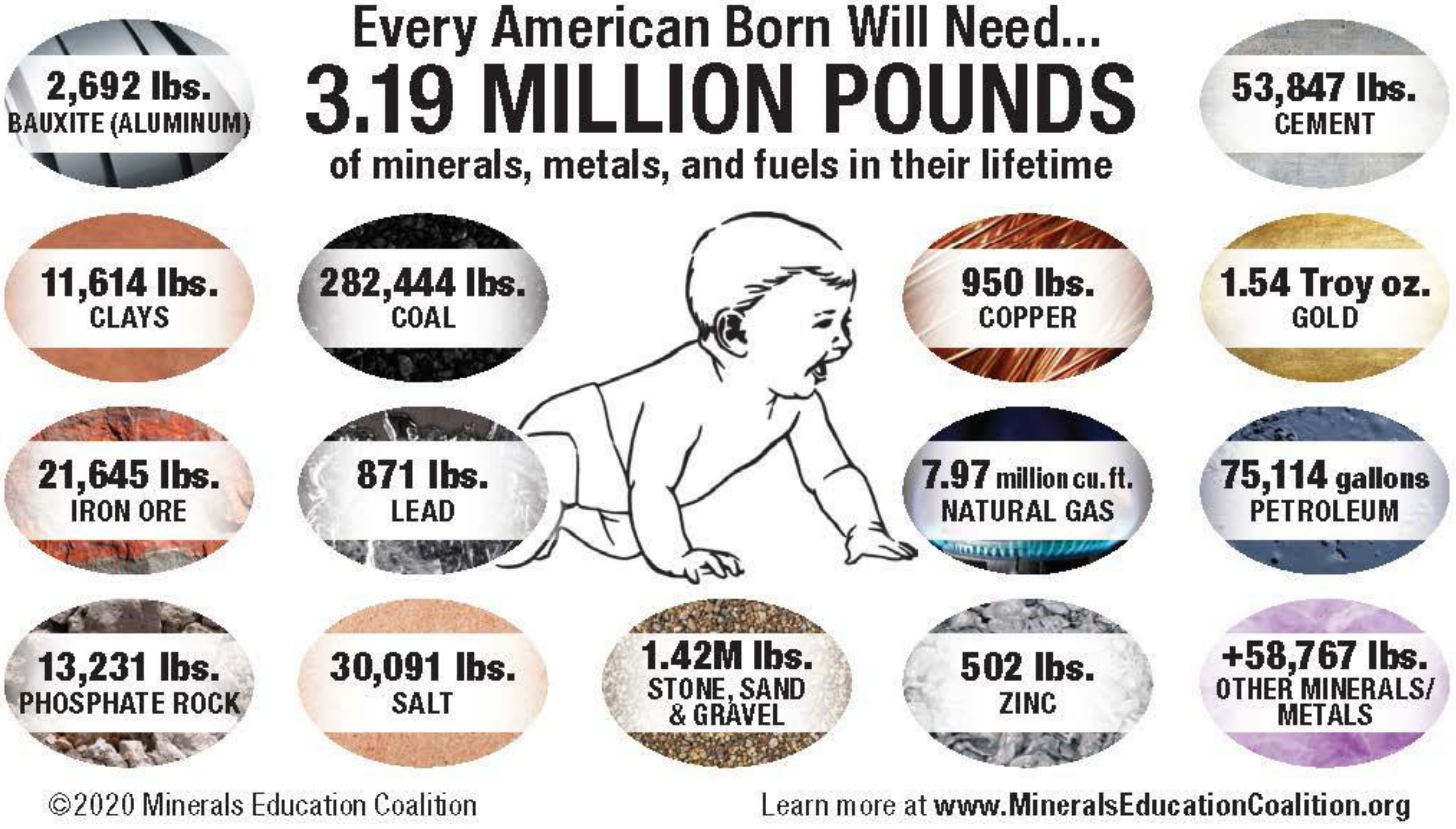
~22X more production than 100 years ago

~4X higher world population than 100 years ago

~6X more per capita consumption than 100 years ago

Production statistics mostly from USGS/US BM

Who needs mineral resources?



Every American Born Will Need...

3.19 MILLION POUNDS

of minerals, metals, and fuels in their lifetime

2,692 lbs. BAUXITE (ALUMINUM)

53,847 lbs. CEMENT

11,614 lbs. CLAYS

282,444 lbs. COAL

950 lbs. COPPER

1.54 Troy oz. GOLD

21,645 lbs. IRON ORE

871 lbs. LEAD

7.97 million cu. ft. NATURAL GAS

75,114 gallons PETROLEUM

13,231 lbs. PHOSPHATE ROCK

30,091 lbs. SALT

1.42M lbs. STONE, SAND & GRAVEL

502 lbs. ZINC

+58,767 lbs. OTHER MINERALS/ METALS

Learn more at **www.MineralsEducationCoalition.org**

China used more cement in the last three years than the U.S. used in the entire 20th century.

U.S.

in 100 years

4.5 gigatons

(1901-2000)

CHINA

in 3 years

6.6 gigatons

(2011-2013)

SOURCES: USGS, Cement Statistics 1900-2012; USGS, Mineral Industry of China 1990-2013

Limits to Growth

resources

Article

Mineral Resources: Reserves, Peak Production and the Future

Lawrence D. Meinert *, Gilpin R. Robinson Jr. and Nedal T. Nassar

U.S. Geological Survey, 12201 Sunrise Valley Drive, MS 913, Reston, VA 20192, USA;
grobinso@usgs.gov (G.R.R.); nnassar@usgs.gov (N.T.N.)
* Correspondence: Lmeinert@usgs.gov; Tel.: +1-703-648-6100

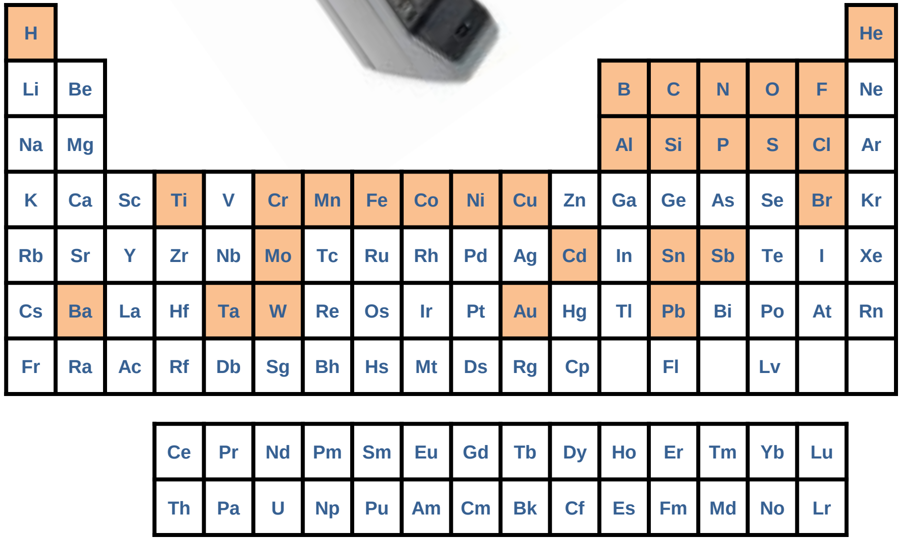
Academic Editor: Mario Schmidt
Received: 22 December 2015 ; Accepted: 16 February 2016 ; Published: 29 February 2016

Abstract: The adequacy of mineral resources in light of population growth and rising standards of living has been a concern since the time of Malthus (1798), but many studies erroneously forecast impending peak production or exhaustion because they confuse reserves with "all there is". Reserves are formally defined as a subset of resources, and even current and potential resources are only a small subset of "all there is". Peak production or exhaustion cannot be modeled accurately from reserves. Using copper as an example, identified resources are twice as large as the amount projected to be needed through 2050. Estimates of yet-to-be discovered copper resources are up to 40-times more than currently-identified resources, amounts that could last for many centuries. Thus, forecasts of imminent peak production due to resource exhaustion in the next 20–30 years are not valid. Short-term supply problems may arise, however, and supply-chain disruptions are possible at any time due to natural disasters (earthquakes, tsunamis, hurricanes) or political complications. Needed to resolve these problems are education and exploration technology development, access to prospective terrain, better recycling and better accounting of externalities associated with production (pollution, loss of ecosystem services and water and energy use).

How Are Minerals Important?

Technology is growing more complex…

Old

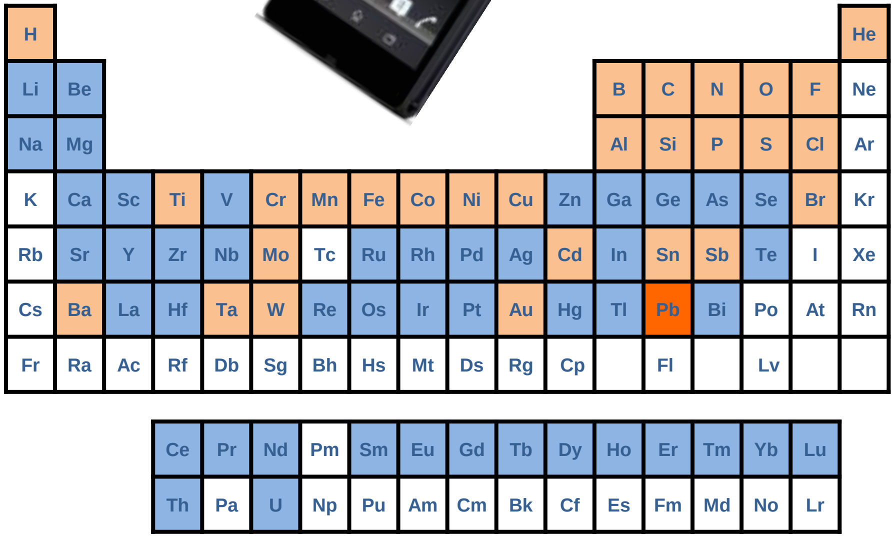


H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cp		Fl		Lv		

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

~30 elements

New



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	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cp		Fl		Lv		

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

~75 elements

Renewable Energy

WIND - Neodymium
- Molybdenum
- Iron Ore

SOLAR - Cadmium, Tellurium, Indium, Germanium, Gallium Selenium, Silicon, Copper

Molycorp Minerals
THE RARE EARTHS COMPANY

UV CUT GLASS
- Cerium

DIESEL FUEL ADDITIVE
- Cerium
- Lanthanum

GLASS AND MIRRORS POLISHING POWDER
- Cerium

LCD SCREEN
- Europium
- Yttrium
- Cerium

COMPONENT SENSORS
- Yttrium

HYBRID NiMH BATTERY
- Lanthanum
- Cerium

HYBRID ELECTRIC MOTOR AND GENERATOR
- Neodymium
- Praseodymium
- Dysprosium
- Terbium

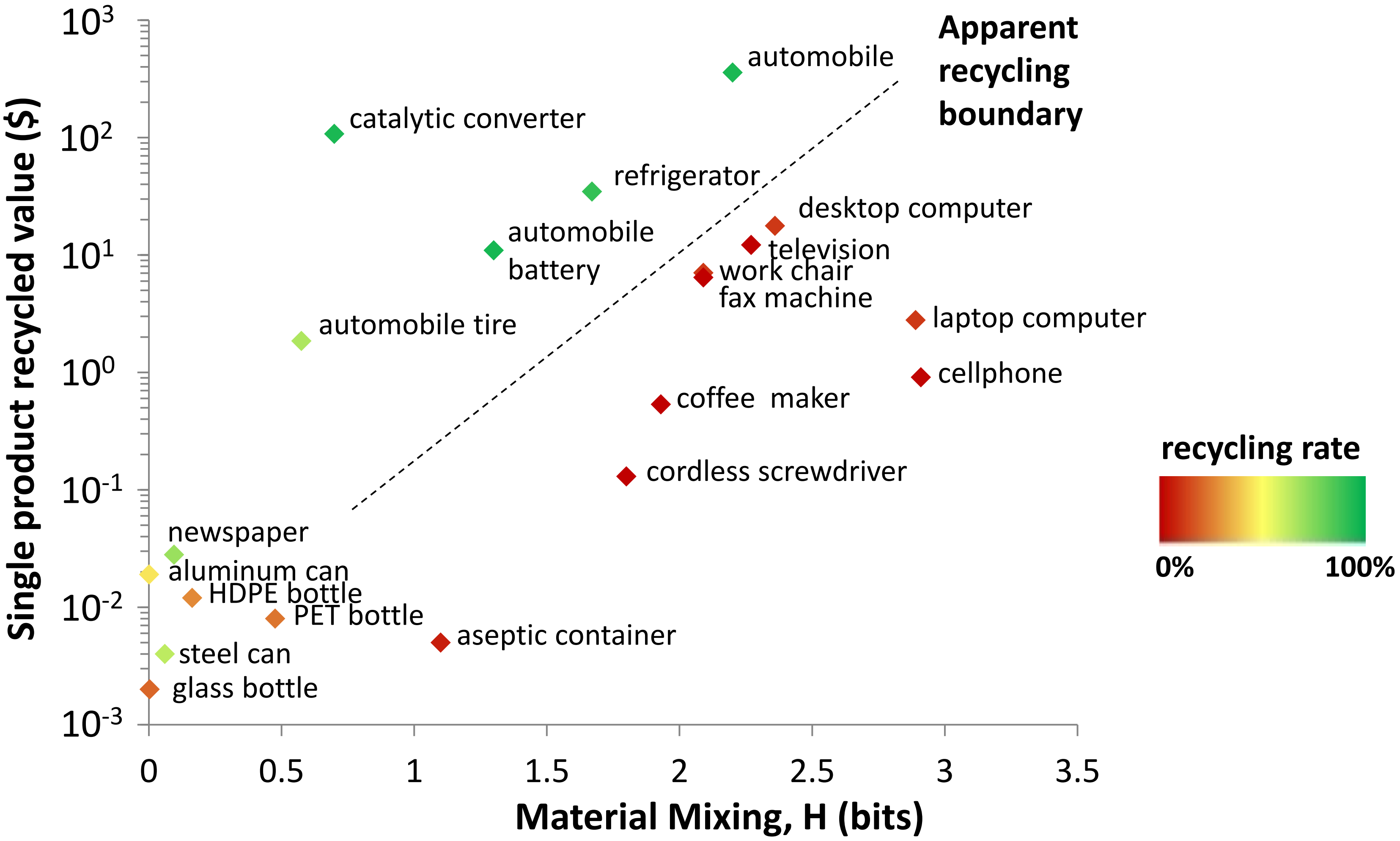
CATALYTIC CONVERTER
- Cerium / Zirconium
- Lanthanum

25+ ELECTRIC MOTORS THROUGHOUT VEHICLE
- Nd Magnets

HEADLIGHT GLASS
- Neodymium

Toyota Prius

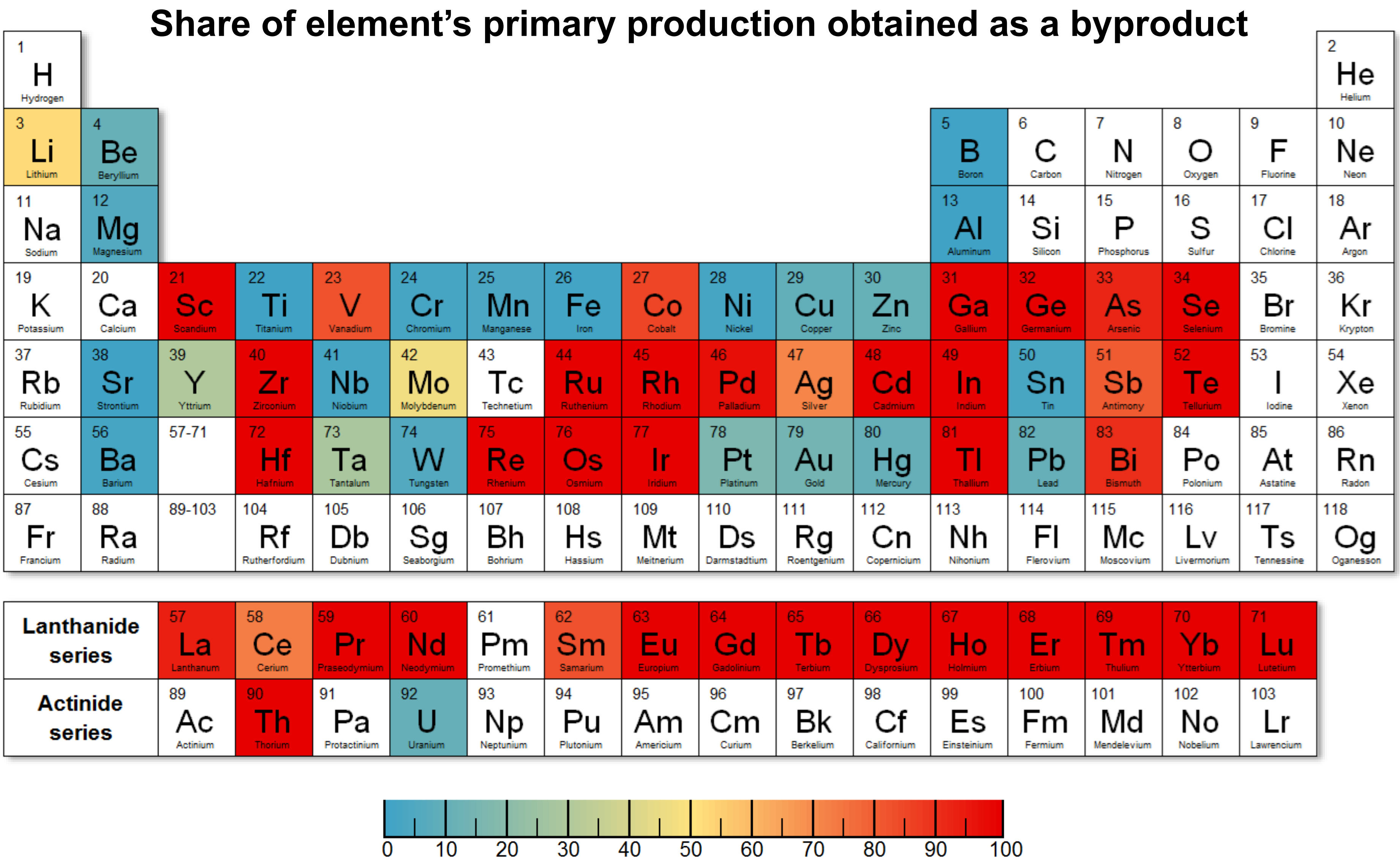
Increasing product complexity poses challenges for recycling.



(average # of binary separation steps needed to obtain any material from the mixture)

Adapted from: Dahmus, J. B.; Gutowski, T. G., What Gets Recycled: An Information Theory Based Model for Product Recycling. *Environ. Sci. Technol.* 2007, *41*, (21), 7543-7550.

Many of the minerals necessary for advanced technologies are recovered mainly or only as byproducts.

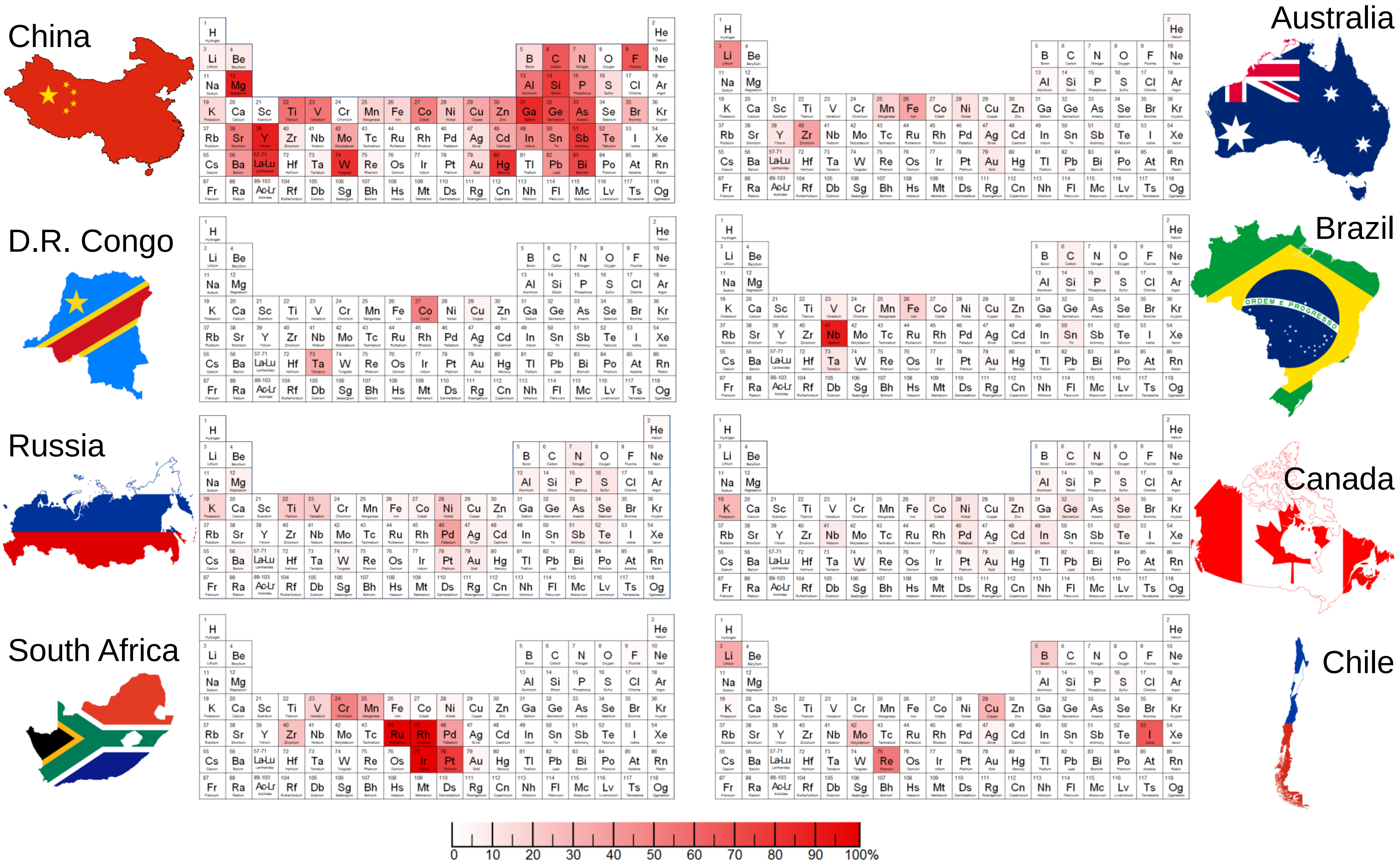


Share of element's primary production obtained as a byproduct

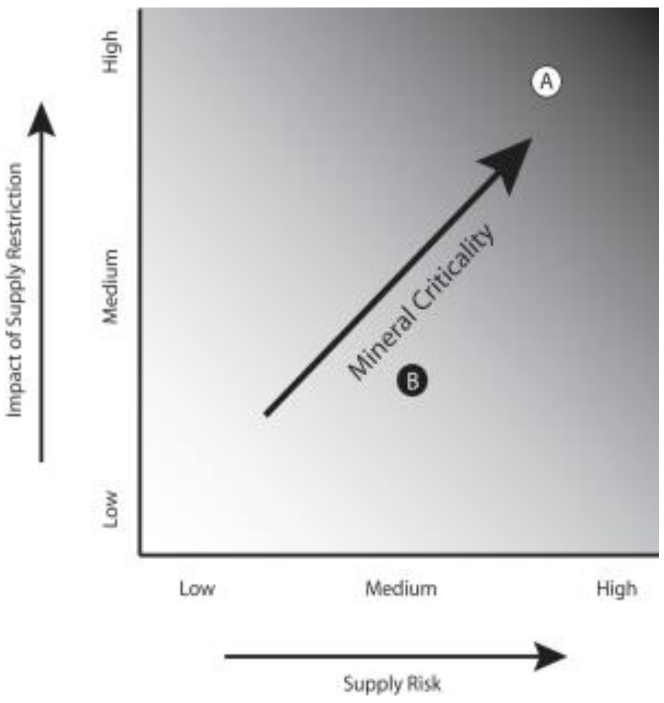
Source: Nassar, N.T., Graedel, T.E., and Harper, E.M., 2015, By-product metals are technologically essential but have problematic supply: *Science Advances*, v. 1, no. 3, p. e1400180.

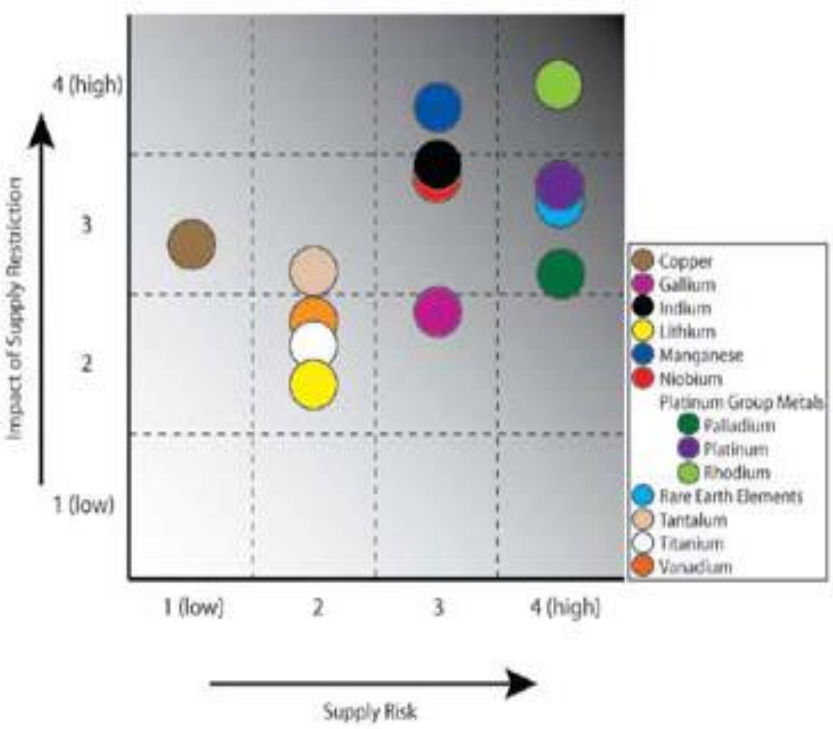
Production of many mineral commodities is highly concentrated in a few countries.

Share of each element’s global production from various countries



A critical mineral as defined in a 2008 U.S. National Academy of Sciences report is one that is both essential in use and subject to the risk of supply restriction





The assessment of **Criticality** (C) is based on the geometric mean of three fundamental indicators:

1) Supply risk (*R*)
2) Production growth (*G*)
3) Market dynamics (*M*)

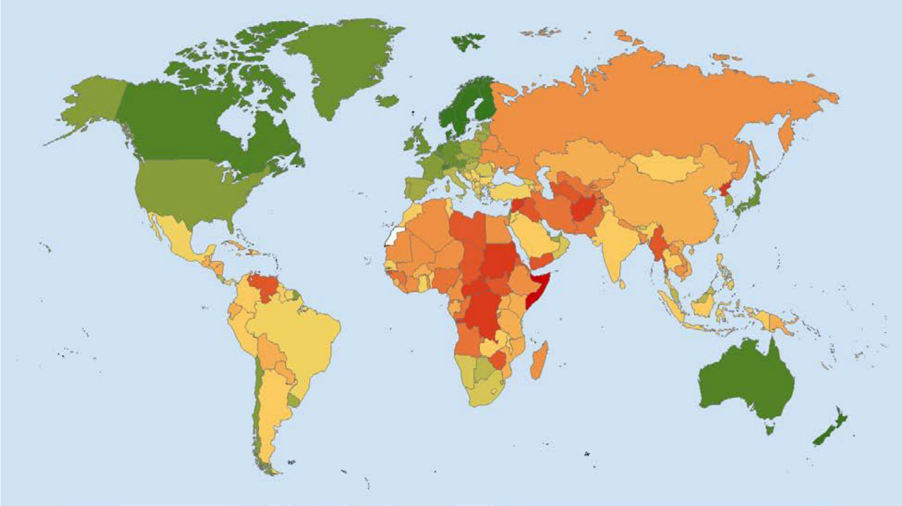
$$C = \sqrt[3]{R \cdot G \cdot M}$$

Where:

$$R^r_{m,t} = \sum S^2_{m,t,i}\, \Gamma_{t,i}$$

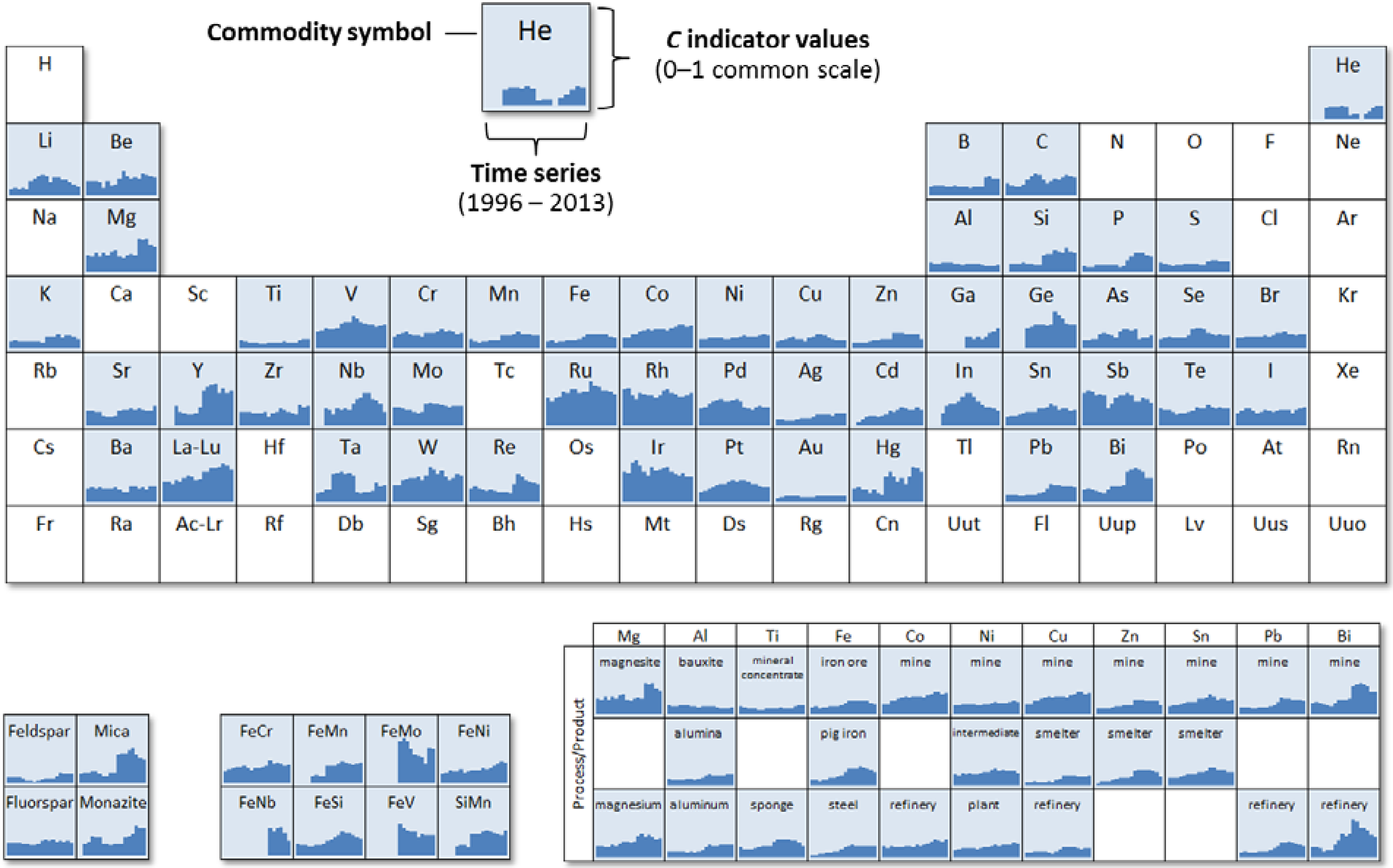
$$G^r_{m,t} = \left(\frac{Q_{m,t}}{Q_{m,t'}}\right)^{\frac{1}{t-t'}}$$

$$M^r_{m,t} = \frac{\sqrt{\frac{\sum_{t'}^{t}\left(P_{m,t} - \bar{P}_{m,t:t'}\right)^2}{t-t'}}}{\bar{P}_{m,t:t'}}$$



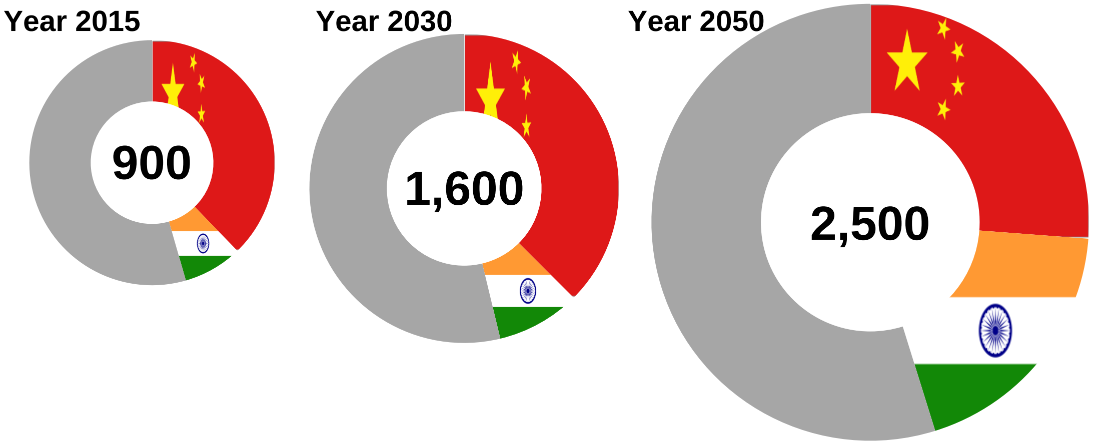
Composite Worldwide Governance Indicators

Criticality (*C*) indicator values for all commodities



Demand for dysprosium in air conditioners (A/C) alone could exceed current mine production by 2050.

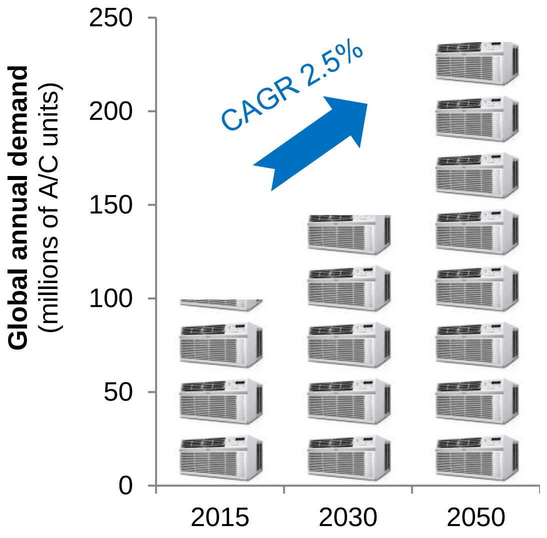
Forecasted number of A/C units (in millions) in-use globally



Source: Shah, N., Wei, M., Letschert, V., and Phadke, A., 2015, Benefits of Leapfrogging to Superefficiency and Low Global Warming Potential Refrigerants in Room Air Conditioning: Lawrence Berkeley National Laboratory.

Demand for A/C is expected to grow considerably, especially in Asia.

Source: Constantinides, S., 2016, Market outlook for ferrite, rare earth, and other permanent magnets: Arnold Magnetic Technologies.

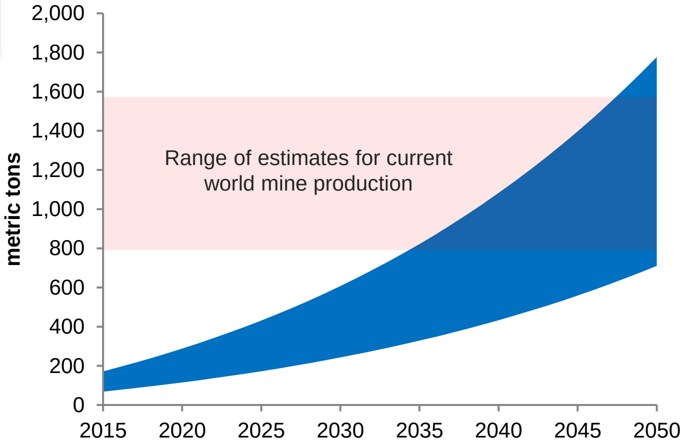


Rare earth permanent magnets (PM) are used in reluctance type motors in A/C to achieve **~20% efficiency gains**

Source: Constantinides, S., 2016, Market outlook for ferrite, rare earth, and other permanent magnets: Arnold Magnetic Technologies.

Approx. 100-250 grams of NdFeB magnets (with 3% Dy) are used for each A/C unit that uses PM

Forecasted dysprosium (Dy) annual demand for A/C



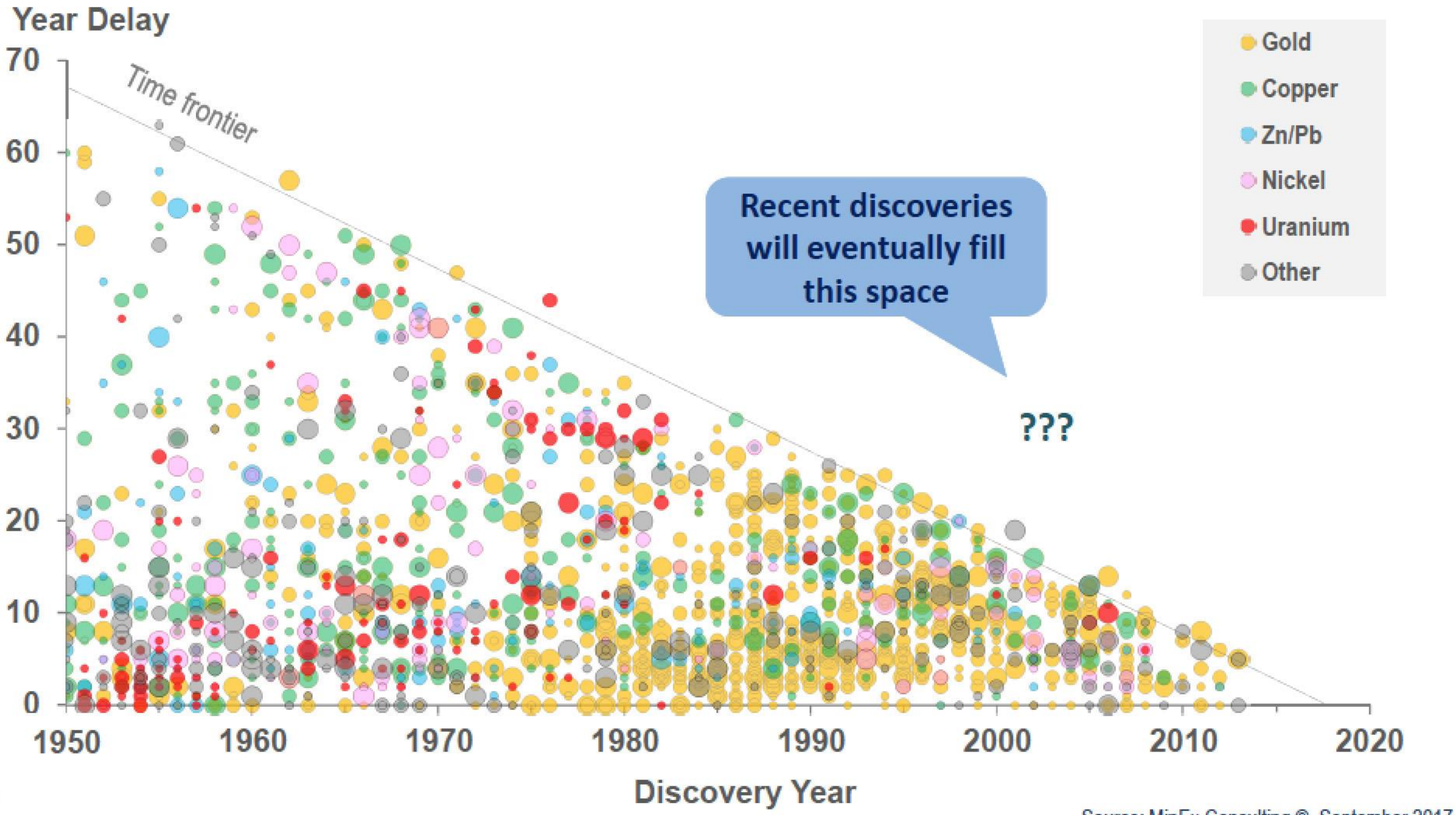
Notes: Calculation of annual A/C unit demand are based on a stocks and flow obsolescence replacement model to achieved noted in-use stocks for years 2015, 2030, and 2050 assuming a Weibull lifespan distribution with a scale parameter of 14.4 and a shape parameter of 2.4 for the lifespan of the A/C units. Calculation of Dy demand assumed 100-250 grams of NdFeB magnet with 3% Dy content per AC unit and a global penetration rate of PM in A/C increasing linearly from 23% in 2015 to 100% in 2050.

Where will those materials come from?

- Even though there is little danger of material exhaustion, there is a very real danger of supply disruption.
- Critical means you need it, strategic means you don’t have it.
- Mineral resource discovery is not automatic – it takes time, money, and training (education) to find new resources
- Even with exploration success – you can decide ***whether*** to mine something but not ***where*** to mine it - mineral deposits are part of nature

Delay between Discovery and Development

All Commodities : All Countries 1950-2016



Source: MinEx Consulting © September 2017

Note: Bubble size refers to Moderate-, Major- and Giant-sized discoveries

Main Points:

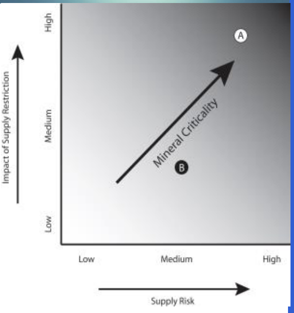
- As world population and standards of living increase, new resources are needed

- Recycling, even if 100% efficient, cannot supply entire need

- More efficient or innovative manufacturing and technology can help, but cannot supply entire need

- “Circular Economy” can help but cannot supply entire need

- Complete life cycle analysis needs to include upstream (exploration, discovery, and production) as well as downstream (manufacturing, recycling, disposal) parts of the materials cycle – education is critical



Earth Materials: The Foundation for Development

Dr. Larry Meinert, Editor-in-Chief, Economic Geology, Affiliate Faculty - Colorado School of Mines, and President - Meinert Consulting, USA.

Dr. Nellie Mutemeri, Mining Practice Lead, Mutemeri Consulting and Associate Professor, University of Witwatersrand, South Africa.

Earth Materials for a Sustainable and Thriving Society

UNESCO Lecture Series

United Nations
Educational, Scientific and
Cultural Organization

International
Geoscience
Programme

Organised in collaboration with IUGS and iCRAG