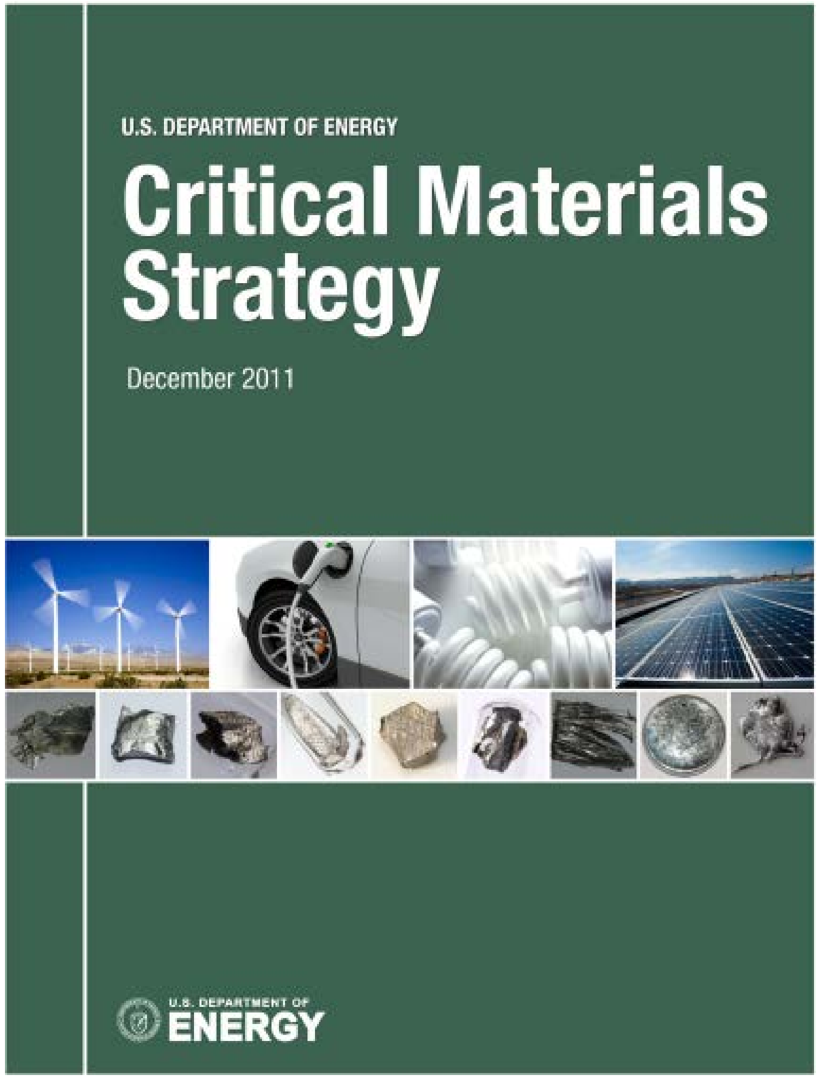
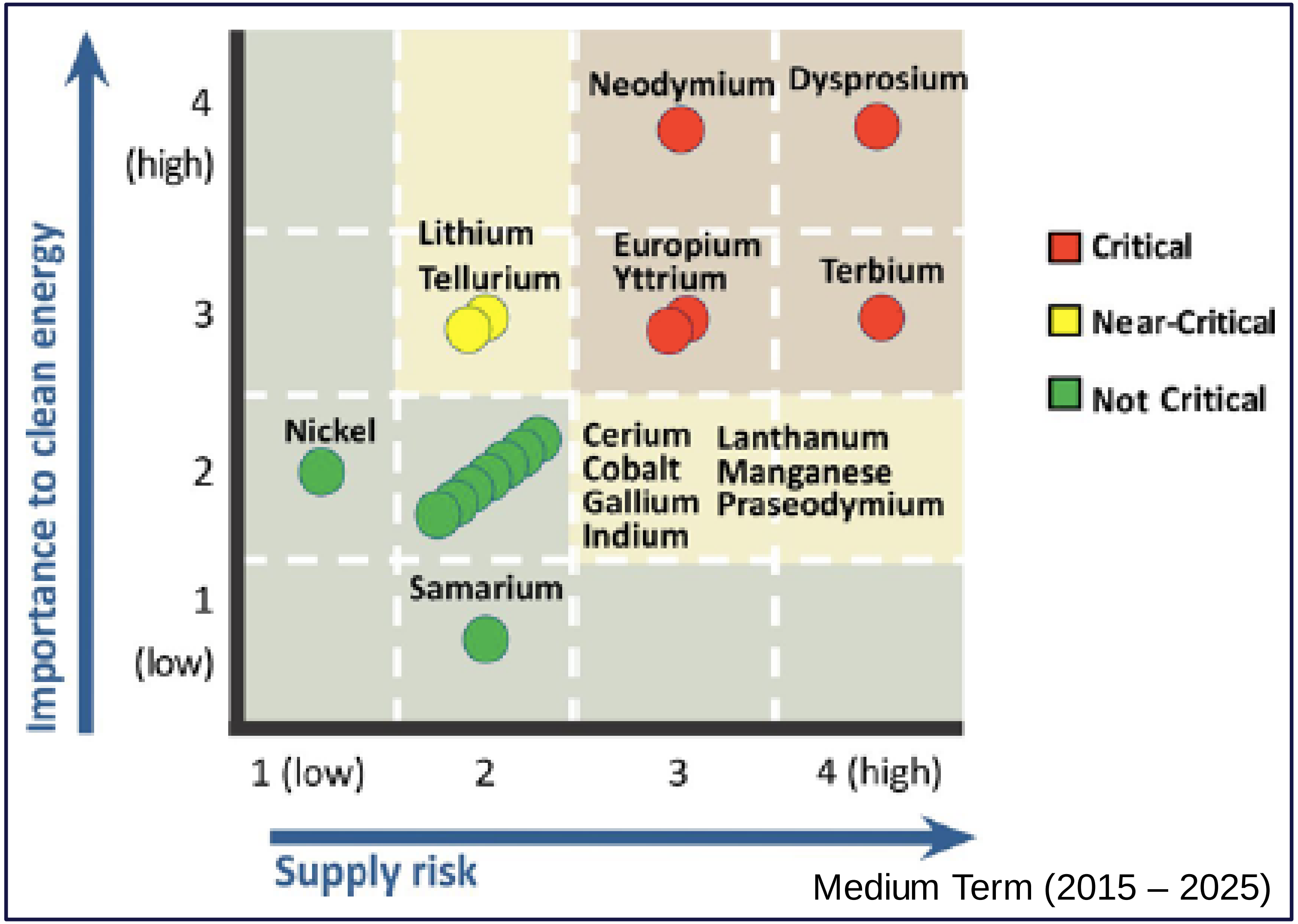
DOE's Critical Materials Analysis





DOE's Critical Materials Strategy

- Diversify supply
- Develop substitutes
- Drive reuse, recycling, and efficient use of materials in manufacturing

NSTC Critical Minerals List (ordered by supply-chain risk)

Mineral Commodity	2018	2021 (Draft)
Gallium	•	•
Niobium	•	•
Cobalt	•	•
Neodymium	•	•
Ruthenium	•	•
Rhodium	•	•
Dysprosium	•	•
Aluminum	•	•
Fluorspar	•	•

Mineral Commodity	2018	2021 (Draft)
Platinum	•	•
Iridium	•	•
Praeseody…	•	•
Cerium	•	•
Lanthanum	•	•
Bismuth	•	•
Yttrium	•	•
Antimony	•	•
Tantalum	•	•

Mineral Commodity	2018	2021 (Draft)
Hafnium	•	•
Tungsten	•	•
Vanadium	•	•
Tin	•	•
Magnesium	•	•
Germanium	•	•
Palladium	•	•
Titanium	•	•
Zinc	•	

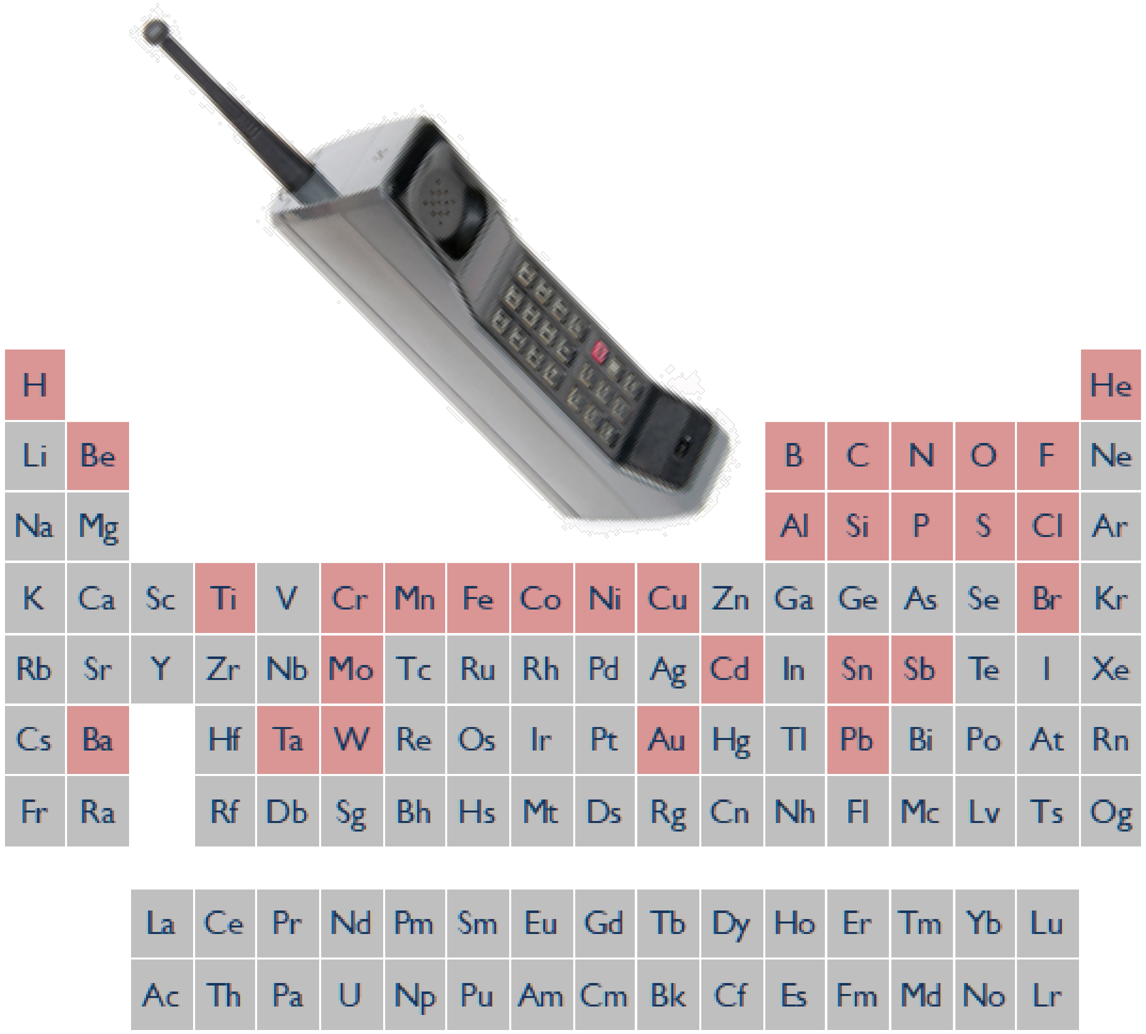
NSTC Critical Minerals List

Mineral Commodity	2018	2021 (Draft)
Graphite	•	•
Chromium	•	•
Arsenic	•	•
Barite	•	•
Indium	•	•
Samarium	•	•
Manganese	•	•
Lithium	•	•
Tellurium	•	•

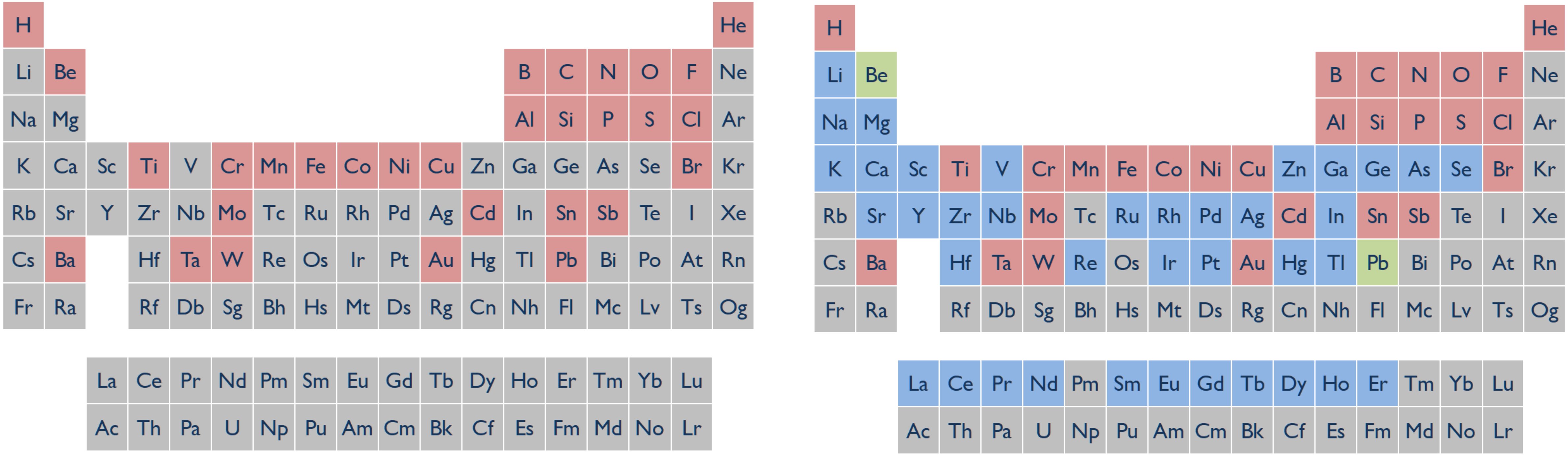
Mineral Commodity	2018	2021 (Draft)
Neodymium	•	•
Nickel		•
Beryllium	•	•
Zirconium	•	•
Aluminum	•	•
Helium	•	
Cesium	•	•
Erbium	•	•
Europium	•	•

Mineral Commodity	2018	2021 (Draft)
Gadolinium	•	•
Holmium	•	•
Lutetium	•	•
Rubidium	•	•
Scandium	•	•
Terbium	•	•
Thulium	•	•
Uranium	•	NA
Ytterbium	•	•

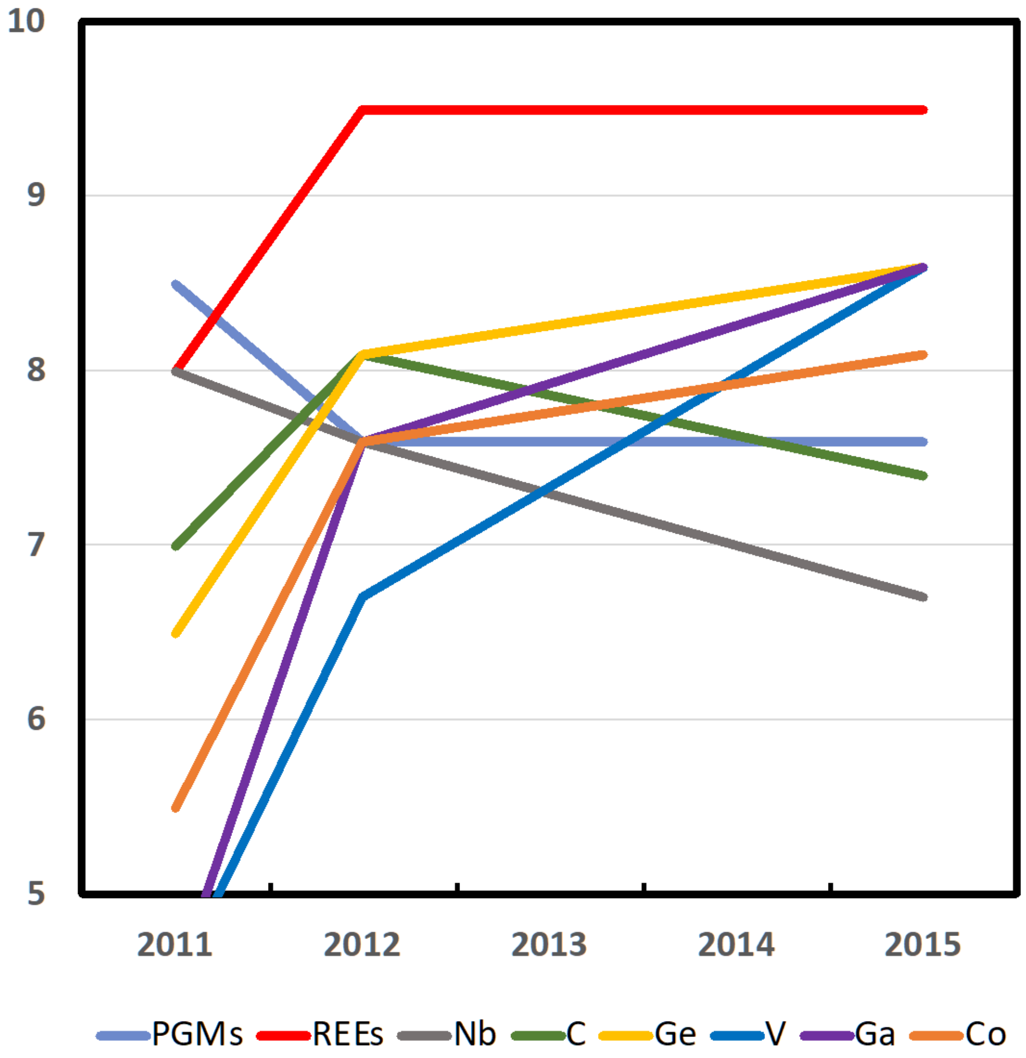
2018: **53** Minerals. 2021: **51** Minerals.



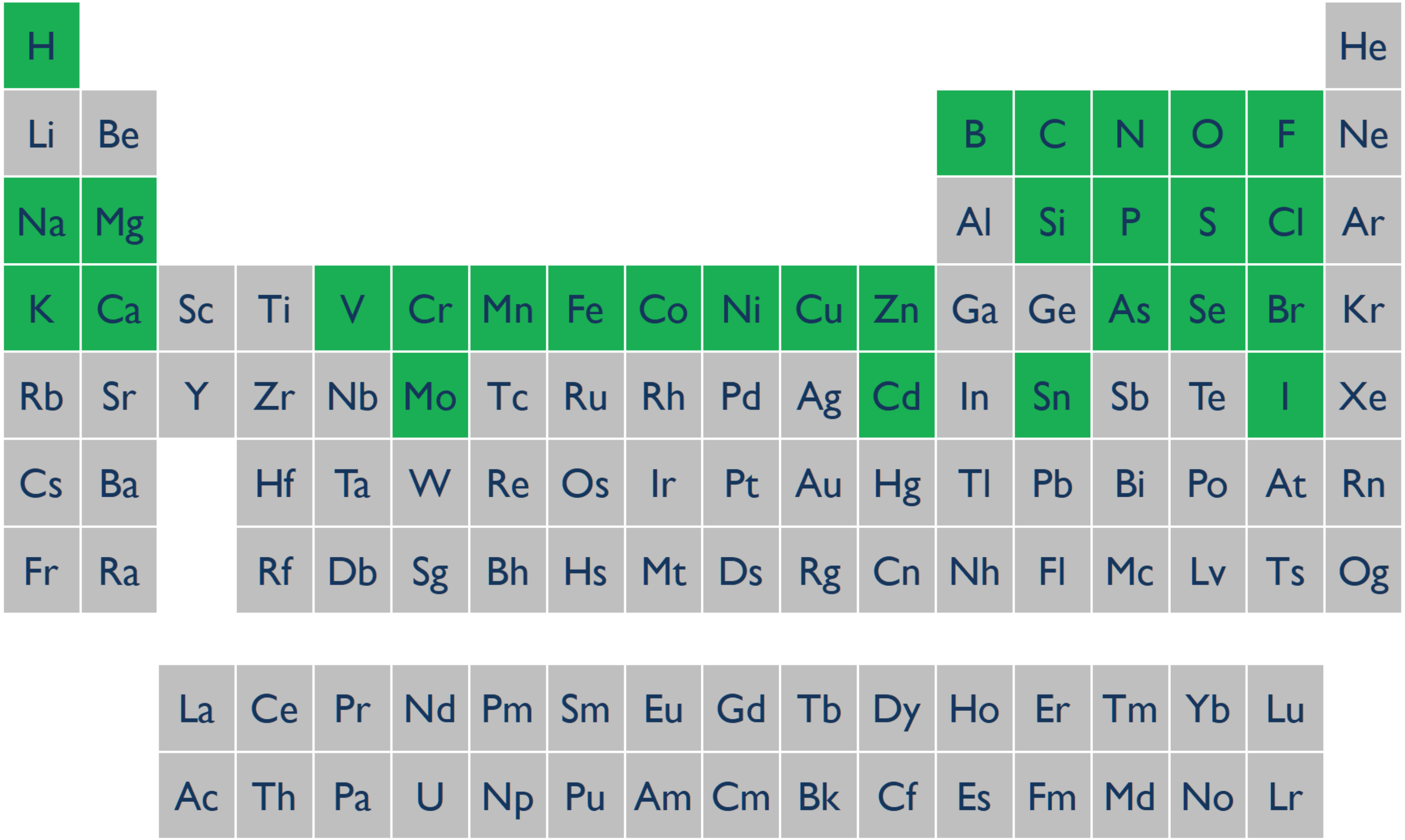
King: *Critical Materials*, Elsevier, 2020. Fig 3-10a,b



King: *Critical Materials*, Elsevier, 2020. Fig 3-10a,b



King: *Critical Materials*, Elsevier, 2020. Fig 3-2

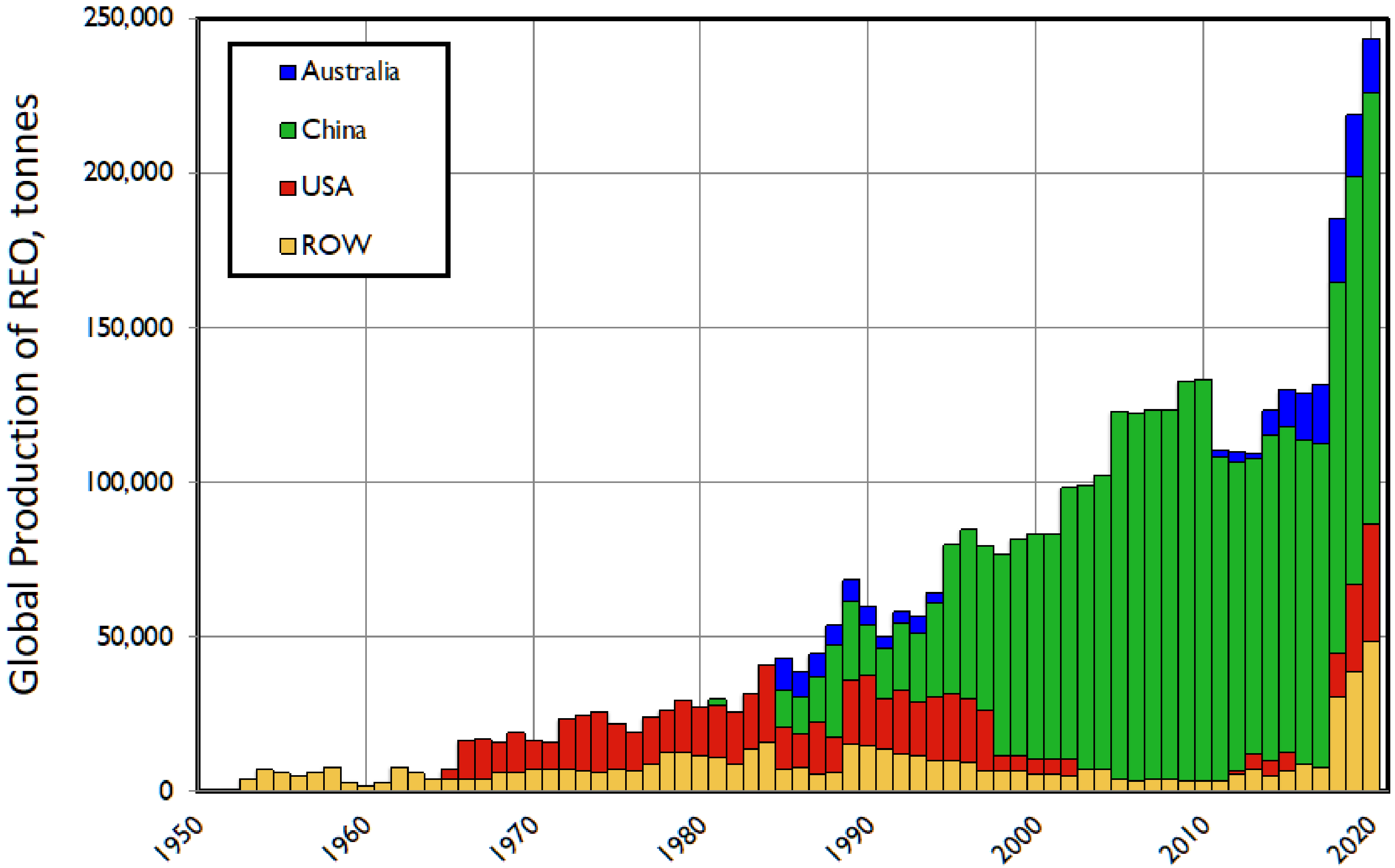


King: *Critical Materials*, Elsevier, 2020. Fig 8-1

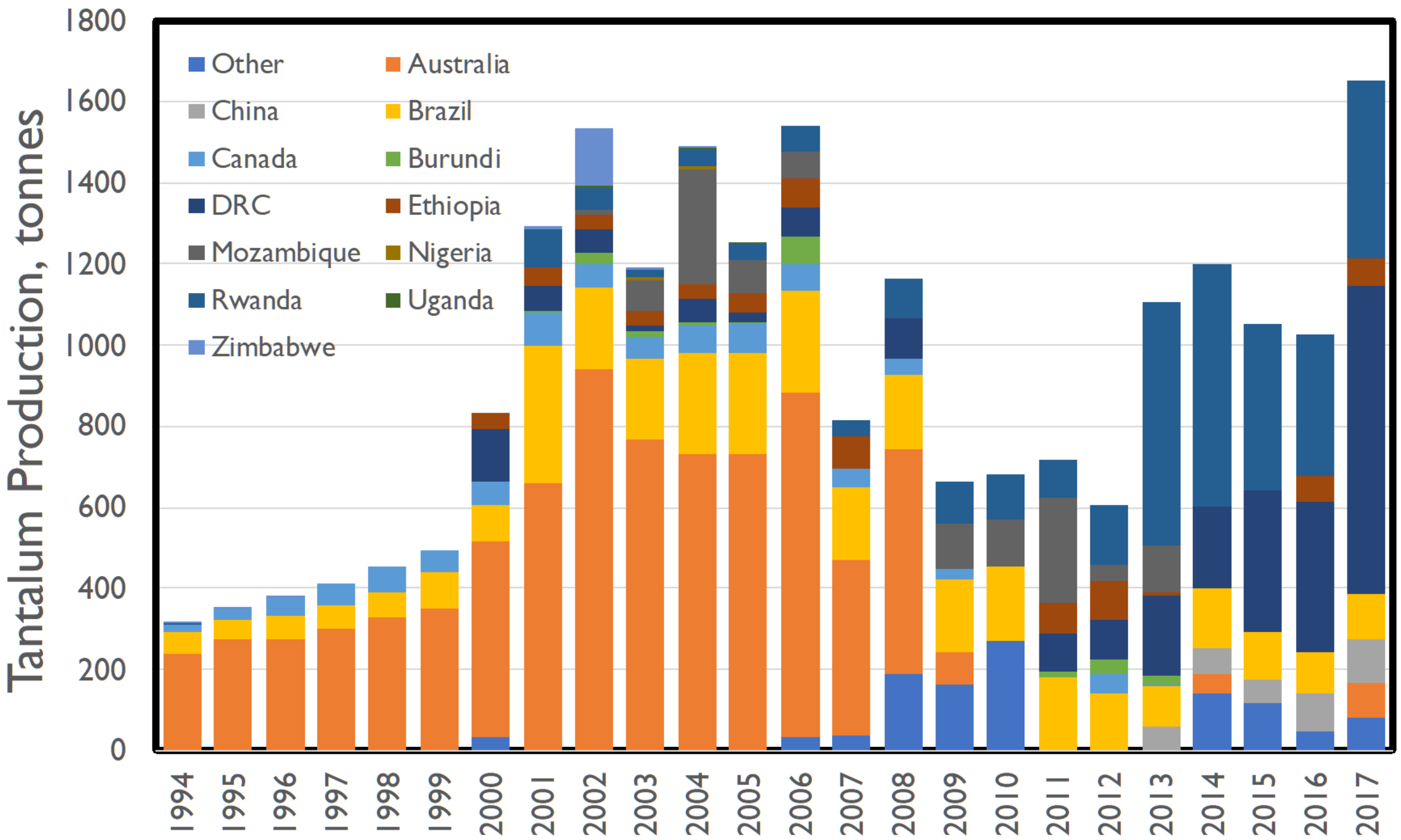
Extra Slides

Observations

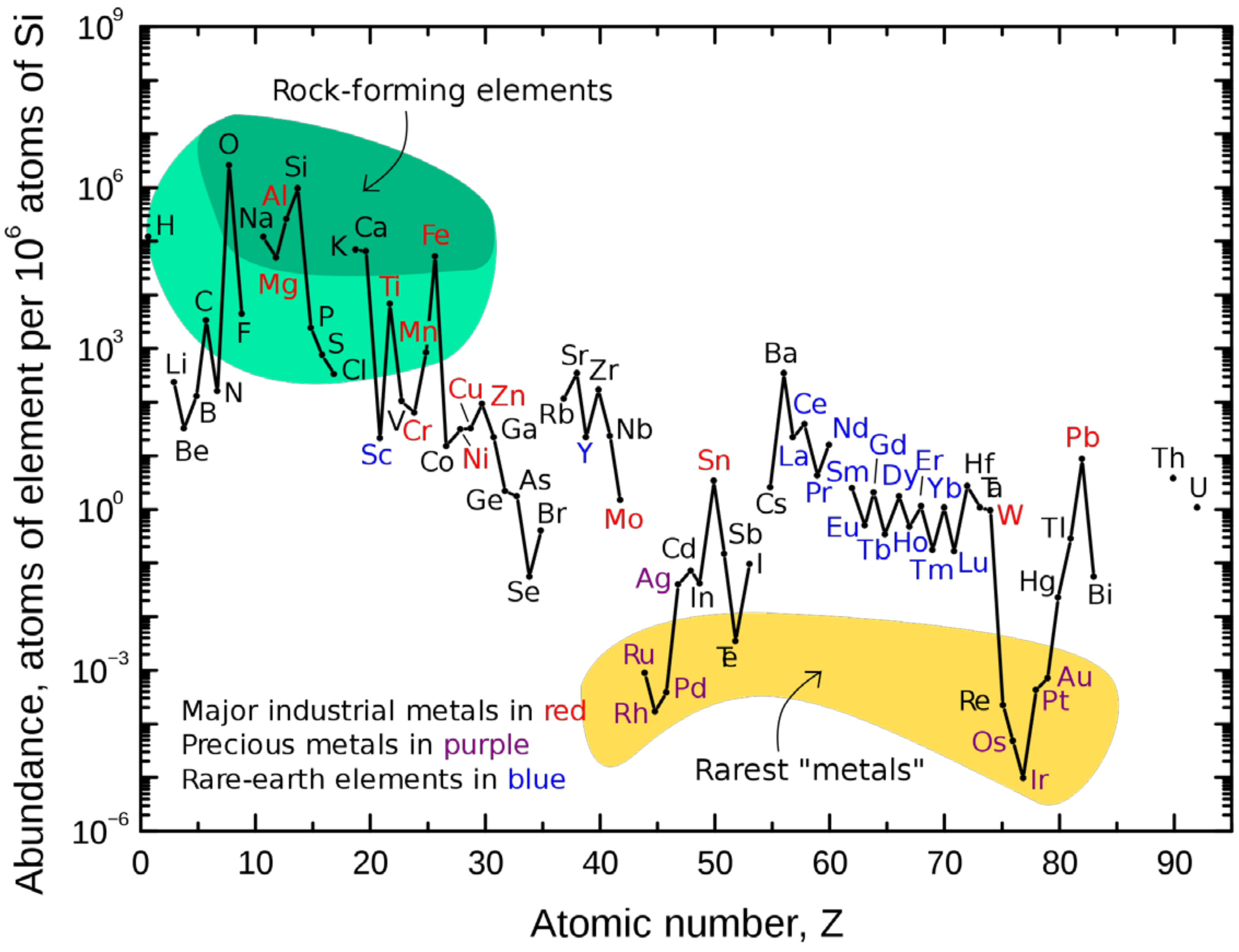
- In the short term, technology reacts to materials availability.
  - Technology evolution can be retarded or sidetracked for lack of materials, e.g. $Nd_2Fe_{14}B$
  - Technology evolution can also be accelerated, e.g. LED lighting.
  - If materials are reliably available, they will be used. Scandium?
- In the longer term, materials availability reacts to the potential for new uses.



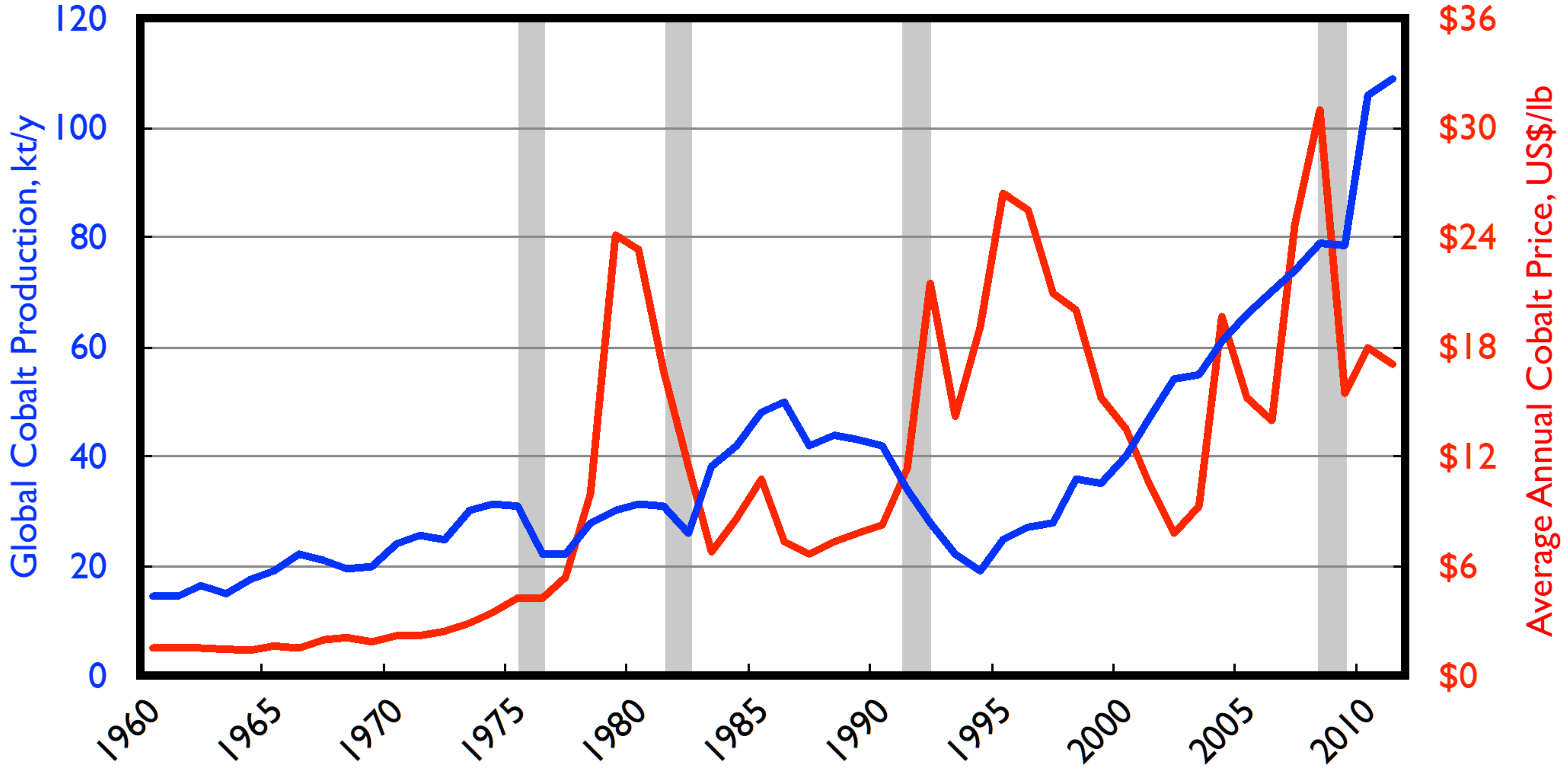
King: *Critical Materials*, Elsevier, 2020. Fig 4-2 (Updated)



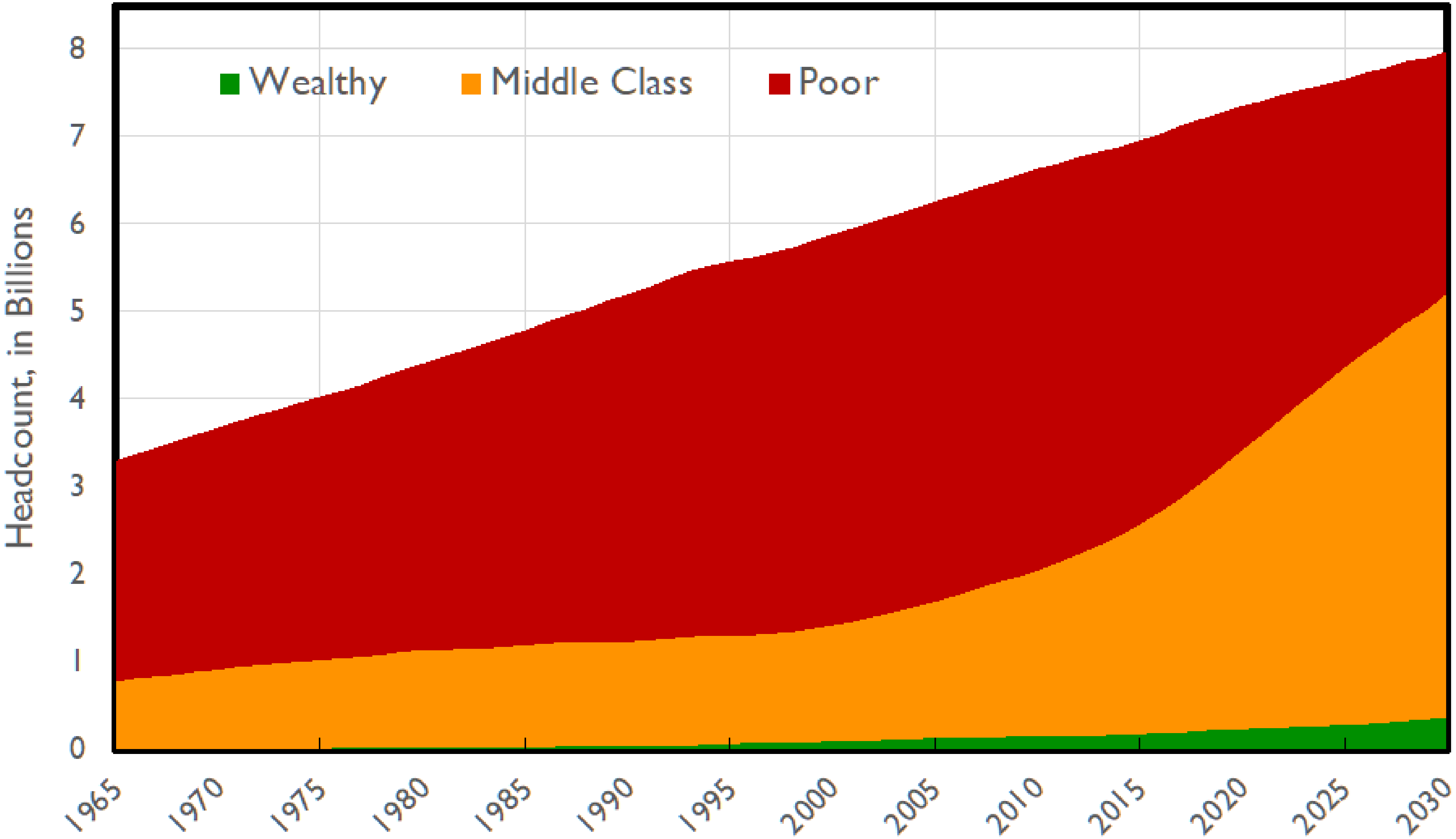
King: *Critical Materials*, Elsevier, 2020. Fig 2-4



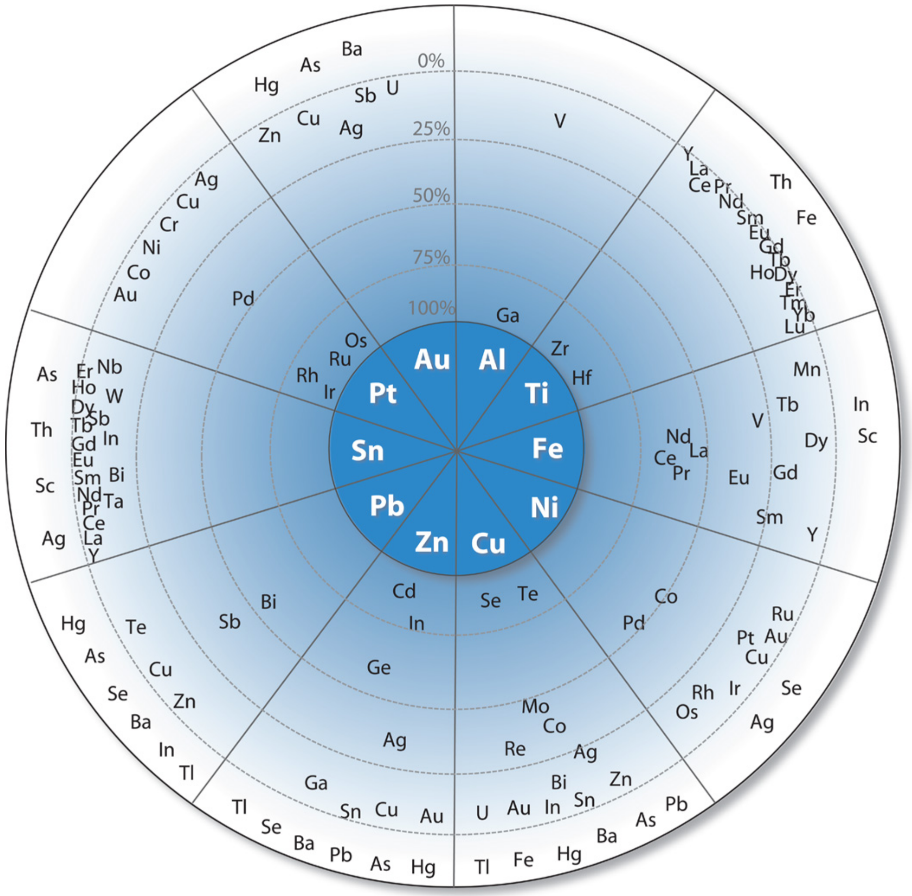
King: *Critical Materials*, Elsevier, 2020. Fig 1-2



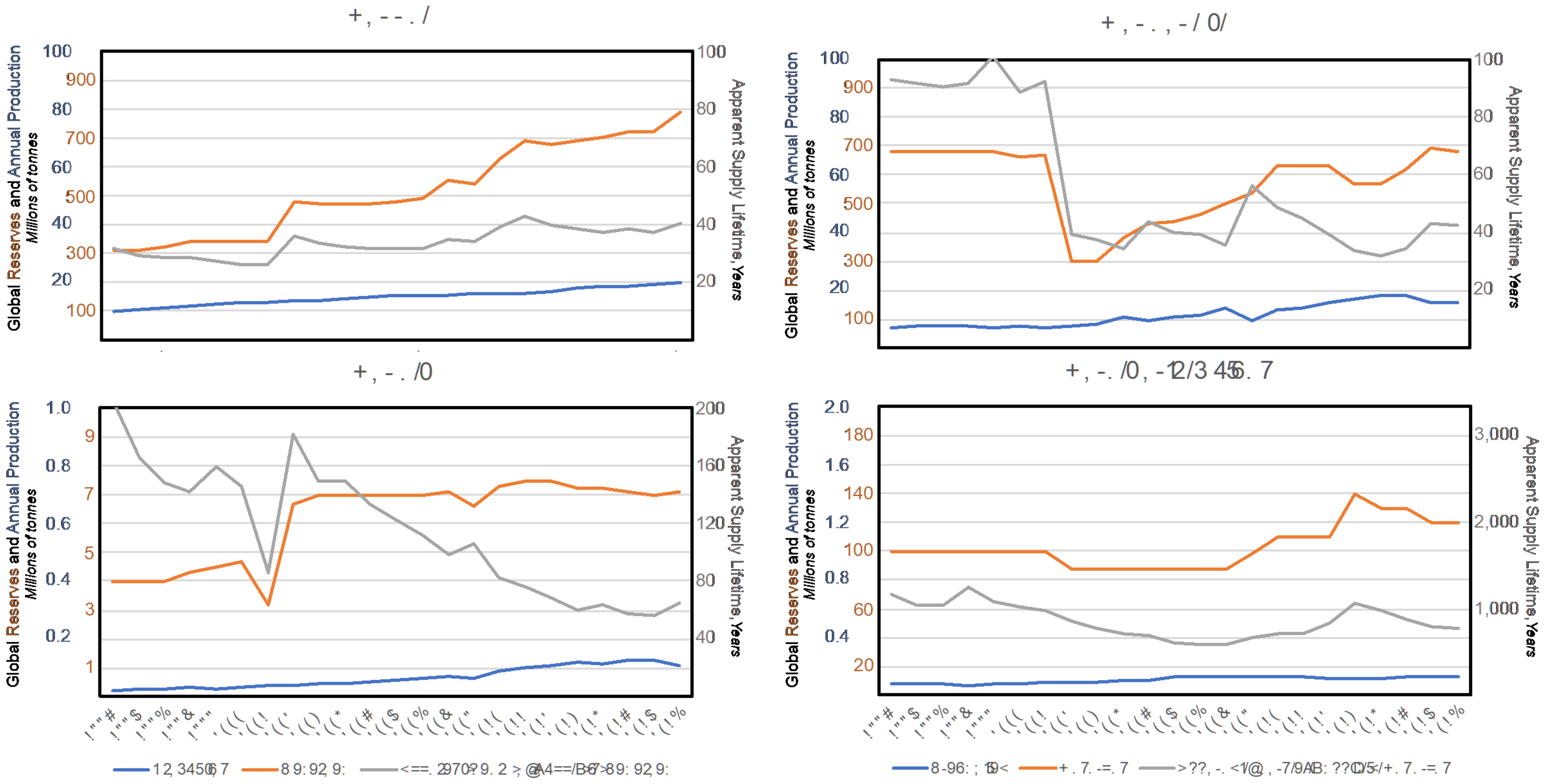
King: *Critical Materials*, Elsevier, 2020. Fig 2-3



King: *Critical Materials*, Elsevier, 2020. Fig 3-8

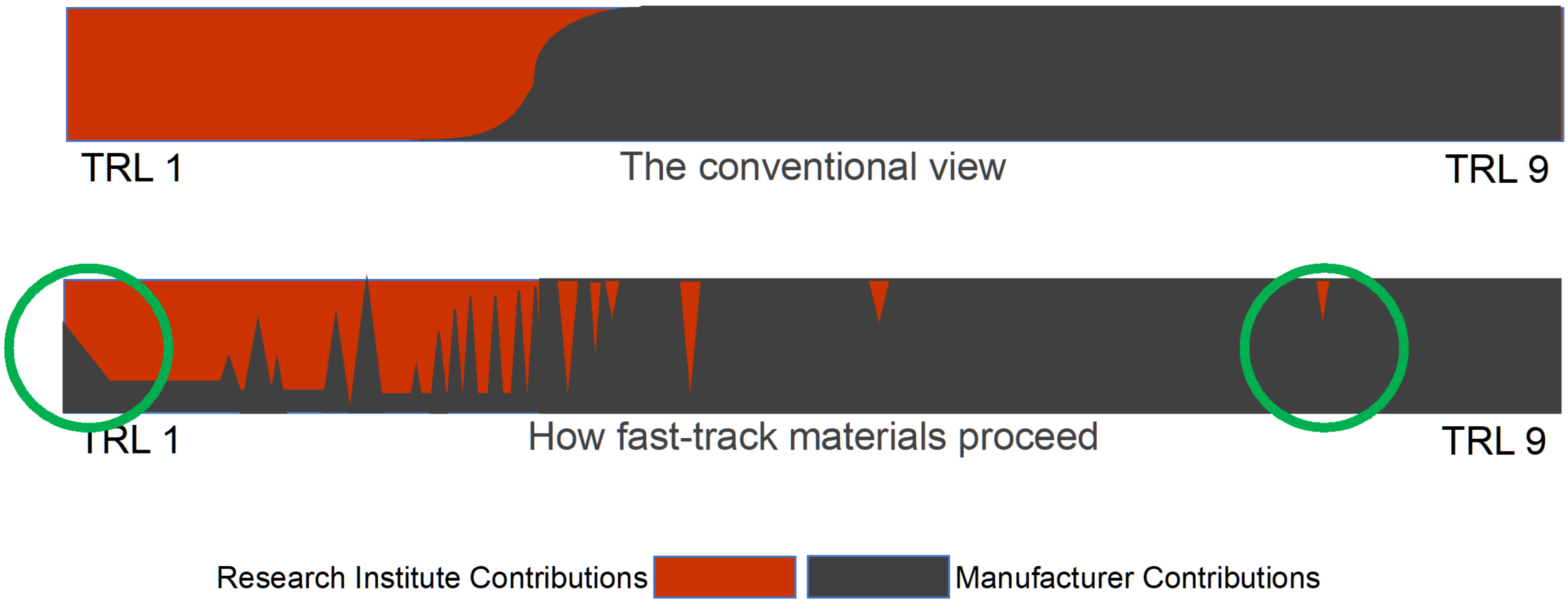


King: *Critical Materials*, Elsevier, 2020. Fig 3-15



King: *Critical Materials*, Elsevier, 2020. Fig 3-16

Interactions between research institutes and industry

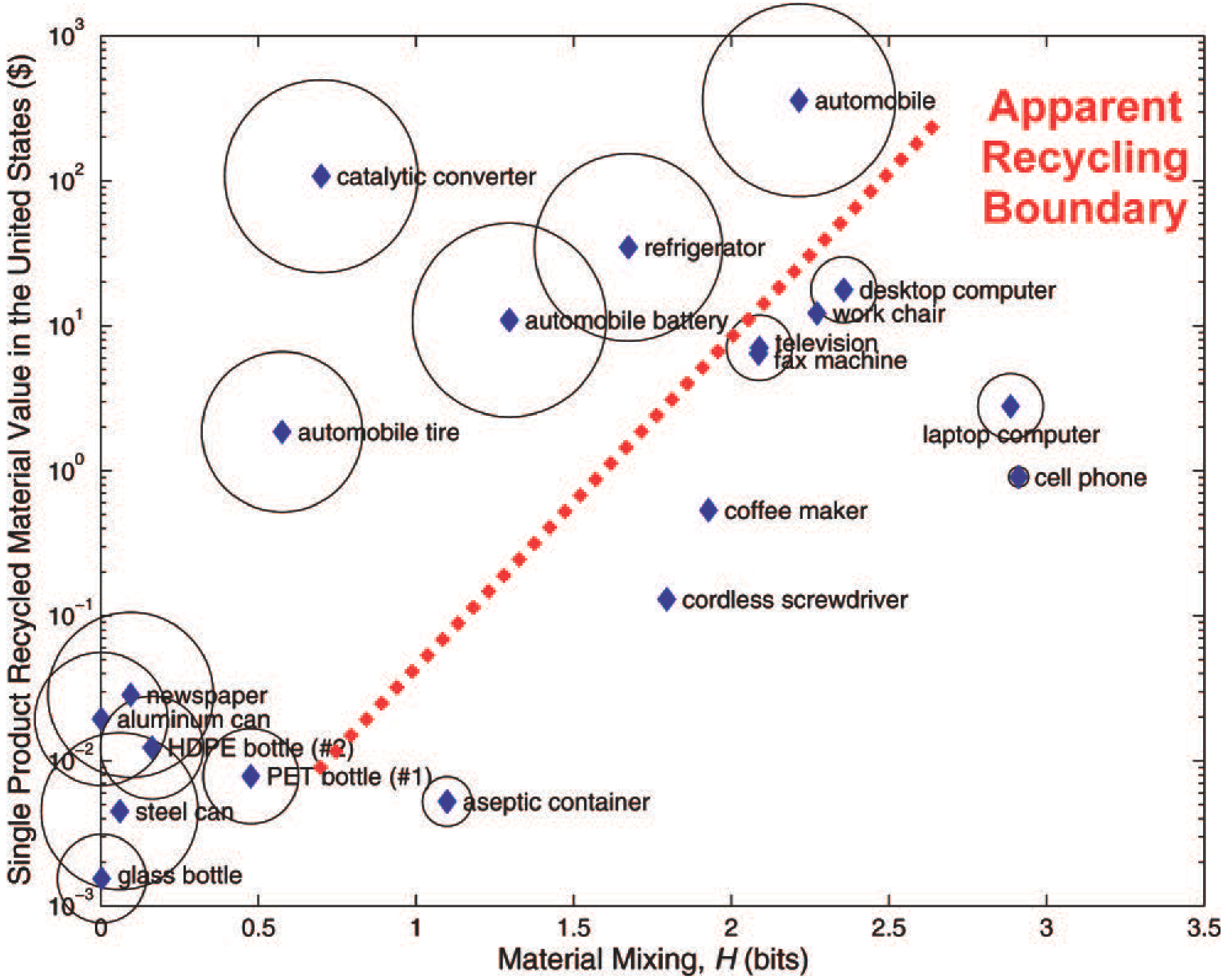


King: *Critical Materials*, Elsevier, 2020. Fig 5-9

The logistical challenge of dilute sources

Source Concentration	500 ppm	1,000 ppm	100,000 ppm
Tonnes of feedstock required to produce 1 t of TREO	2,000	1,000	10
Truckloads (of 20 t each) required to produce 1 t of TREO	100	50	0.5

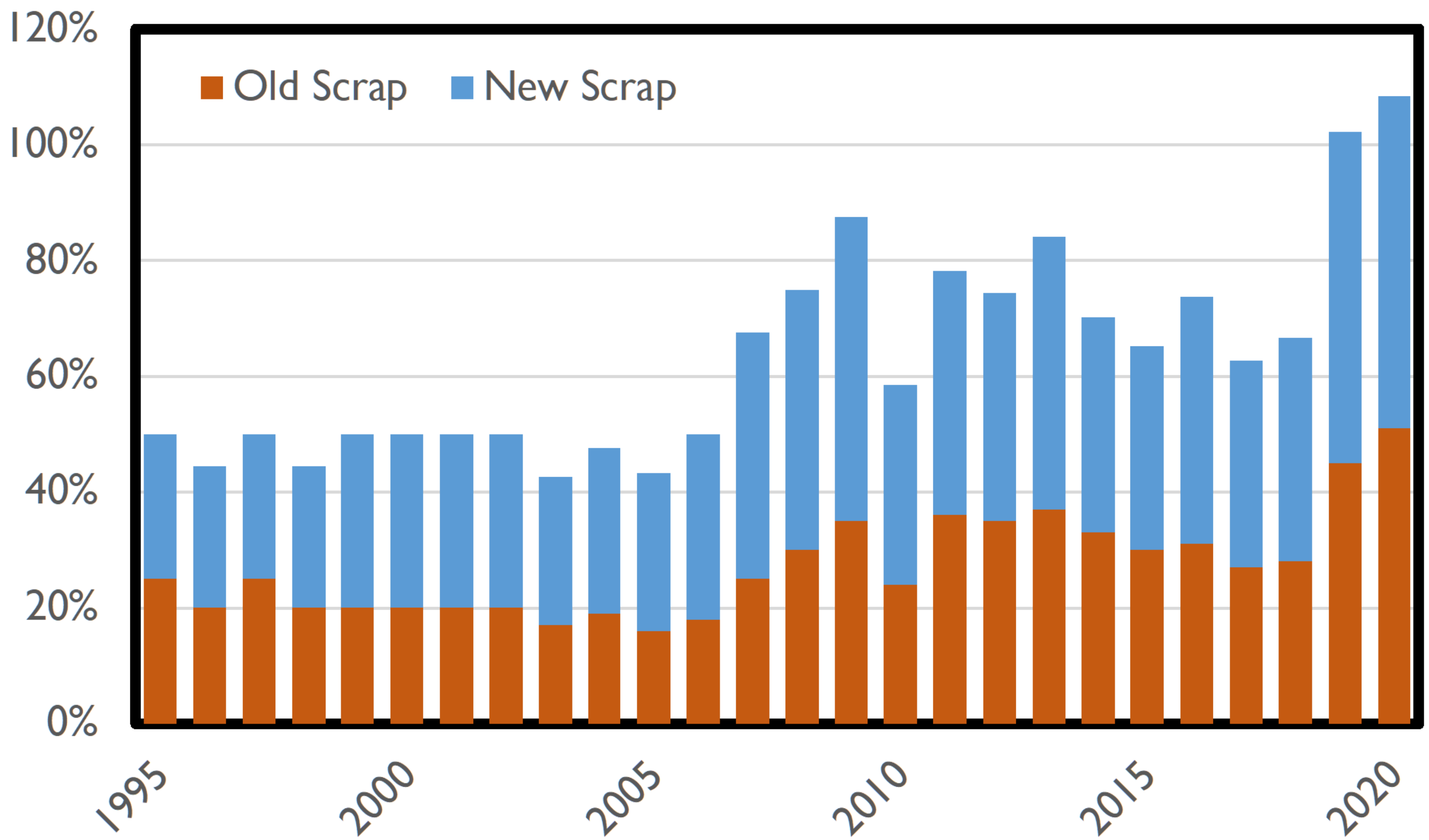
The production of a modest 10,000 t of REO per year would require one truckload of feedstock, *plus* all of the chemicals needed to process it, *plus* the removal of all of the waste, roughly *every minute of every working day*.



King: *Critical Materials*, Elsevier, 2020. Fig 7-1

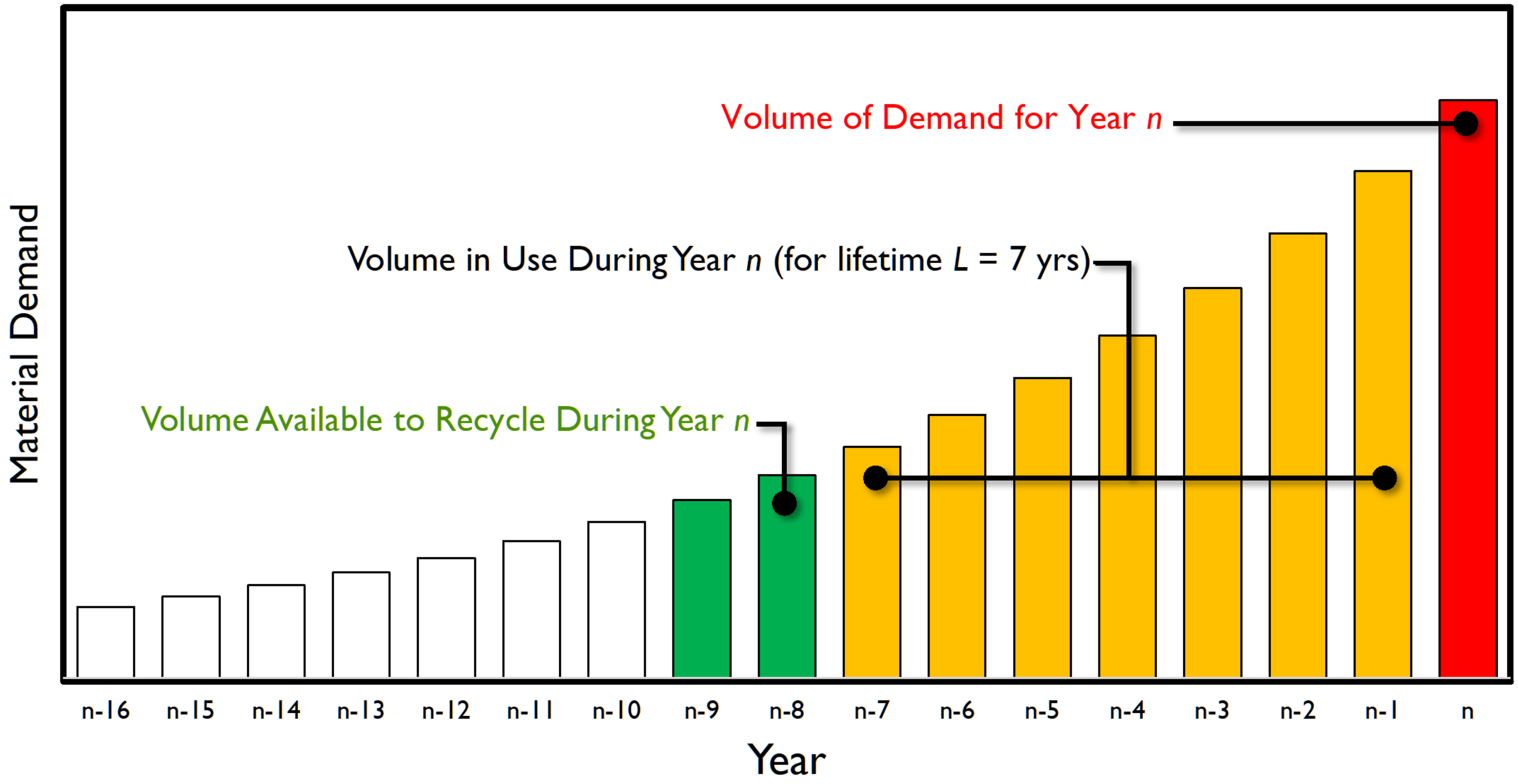
Material value and device complexity set limits on what gets recycled.

Original figure from J.B. Dahmus, T.G. Gutowski, What Gets Recycled: An Information Theory Based Model for Product Recycling, *Environmental Science & Technology*, 41 (2007) 7543-7550. © 2007, American Chemical Society. Used with permission.



King: *Critical Materials*, Elsevier, 2020. Fig 7-2 (updated)

The fraction of total US annual aluminum demand that has been met by recycled material, from 1995 to 2020.



King: *Critical Materials*, Elsevier, 2020. Fig 7-3

How much of the need can be met by recycling?

$$F_R = E_c E_e / (1+G)^{L+1}$$

- F_R = fraction of current need that can be met by recycling
  - E_c = efficiency of collection
  - E_e = efficiency of extraction
  - G = annual rate of demand growth
  - L = product lifetime, in years

How much can recycling contribute?

Material	E_c	E_e	G	L	F_R
Aluminum	50%	100%	6%	1	44%
REE	30%	99%	13%	6	13%

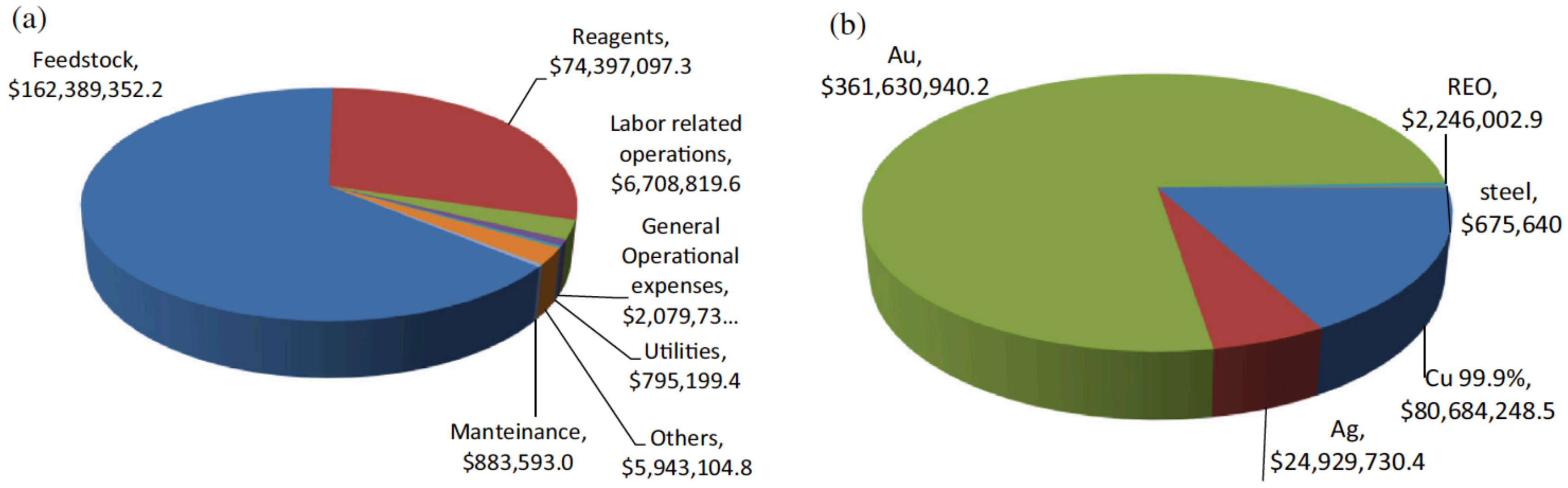


Fig. 3. Operational (a), and revenue (b), cost distribution for the second year of operation for the BCS process.

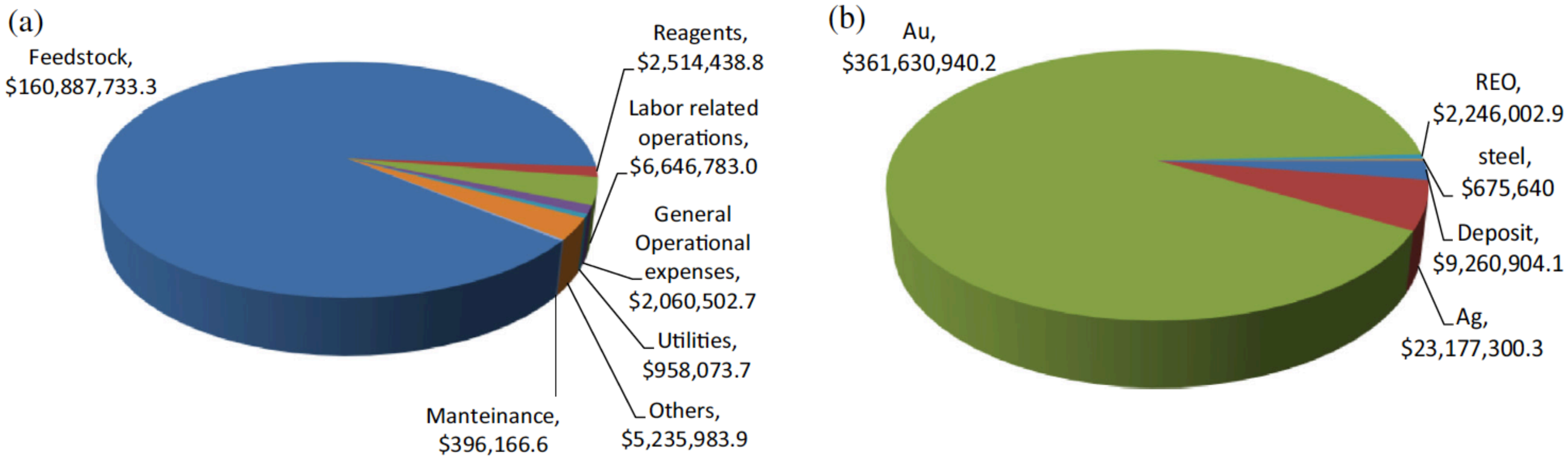


Fig. 4. (a) Operational and (b) revenue cost distribution for the second year of operation of the ER process.

- Comparing costs and revenues for two different processes for recovering metals from electronic scrap.
- Note, *inter alia*, that feedstock acquisition is, by far, the biggest cost for either process.

L.A. Diaz and T.E. Lister, *Waste Management* **74** (2018) 384-392

Deng Xiaoping

Paramount Leader,
People's Republic of China, 1978-'89.

The Middle East has oil;
China has rare earths.

From a speech given to an agricultural collective in Jiangxi, PRC, *January 1992*