Center for Industrial Ecology

Yale School of Forestry & Environmental Studies

Rare Earths and Other Scarce Metals: Technologically Vital but Usually Thrown Away

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Industrial Ecology

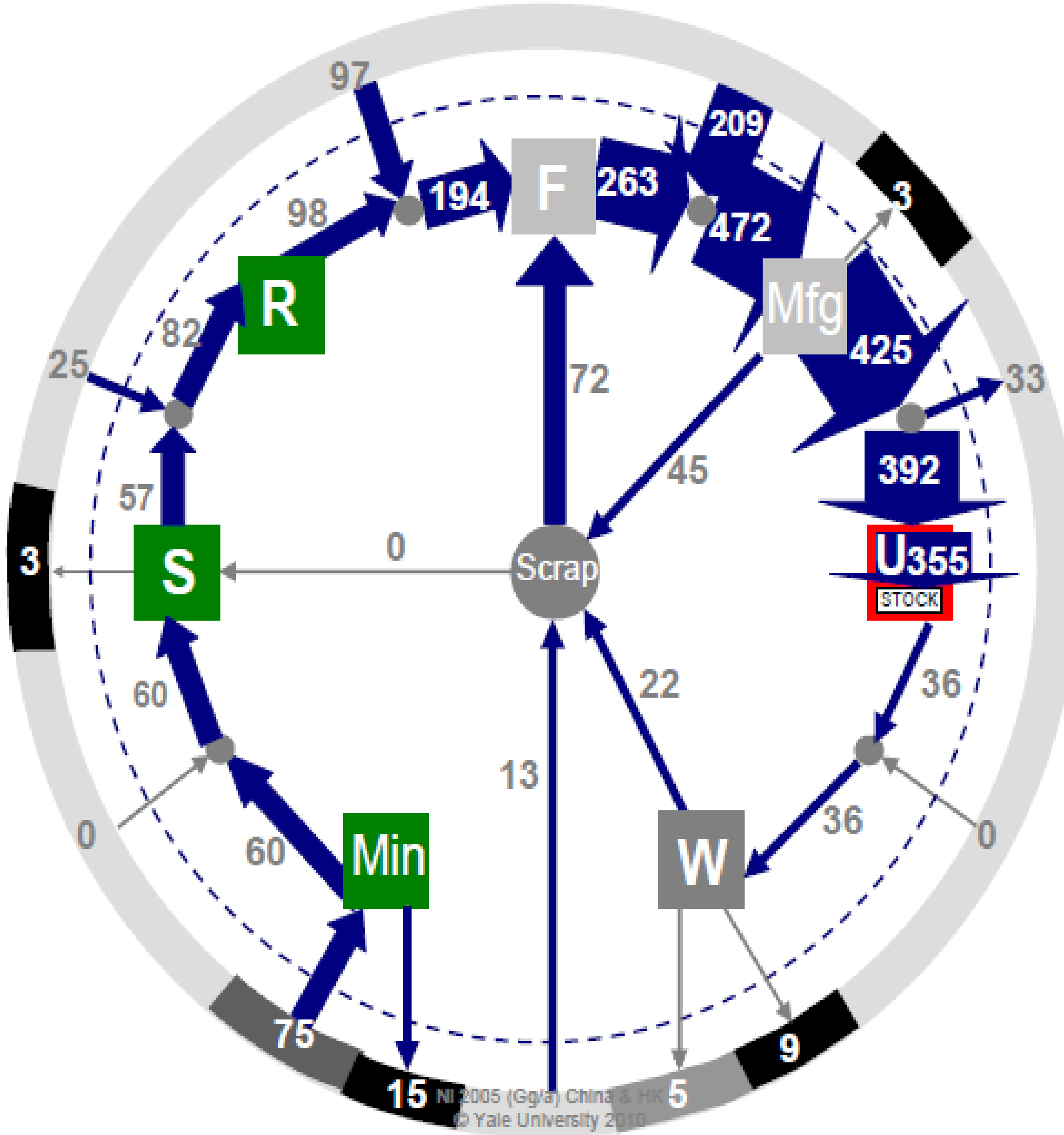
- The study of the human-influenced stocks and flows of resources and energy, from the perspective of resources and the environment

- The field that quantifies the anthropocene

Automotive Industry: Hybrid vehicle technology is dependent upon the Rare Earths

Source: Molycorp

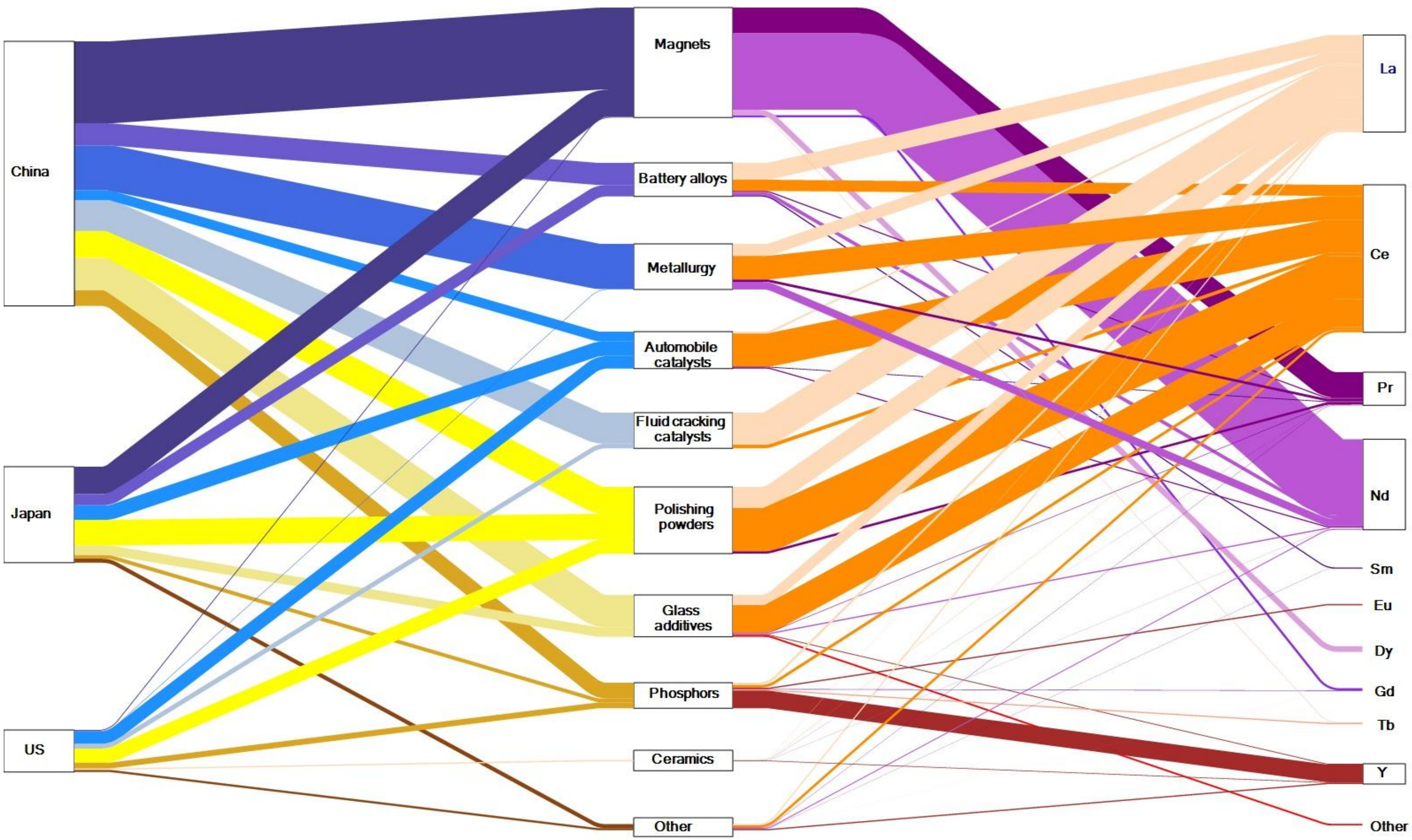
China & Hong Kong, 2005



Source: B. Reck and S. Rotter, *J. Ind. Ecol.*, *16*, 518-528, 2012.

Units are Gg Ni

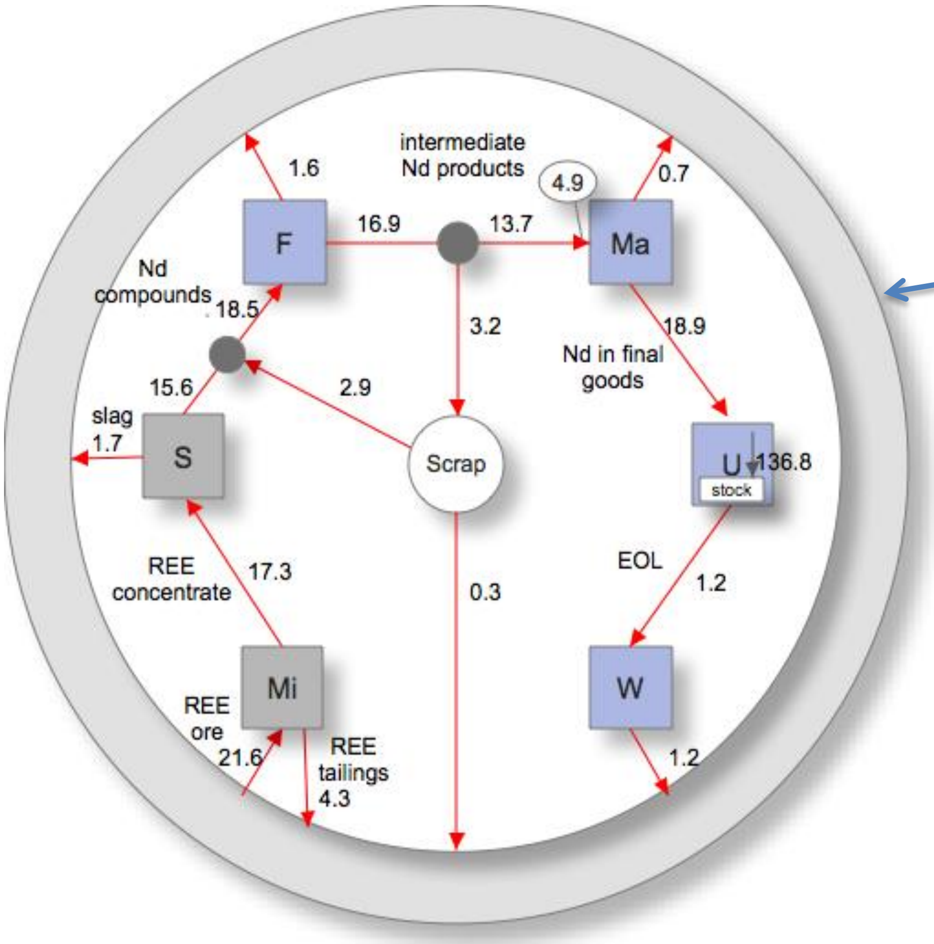
The end uses of the rare earth elements in 2007

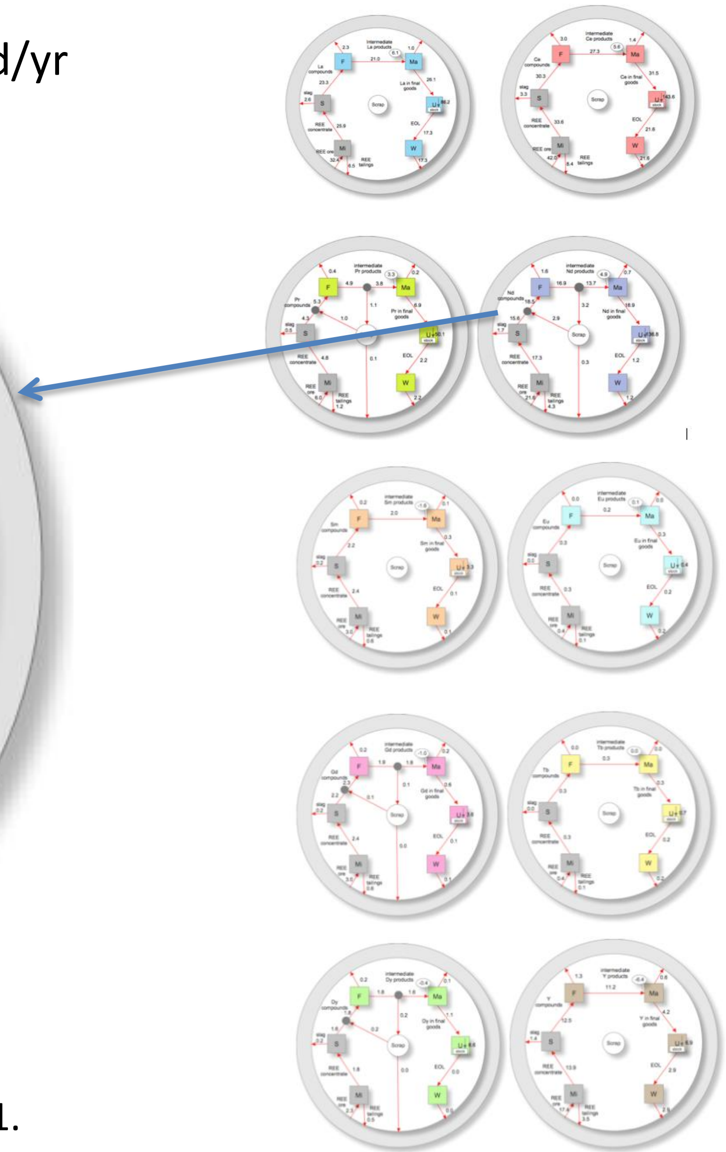


Source: X. Du and T.E. Graedel, *Sci. Total Env.,* in press, 2013.

Global Nd Cycle 2007

Gg Nd/yr





Source: X. Du & T.E. Graedel, *Sci. Rep., 1*, srep00145, 2011.

Use it once,

and then throw it away?

Brake Linings: An Example of Dissipative Use

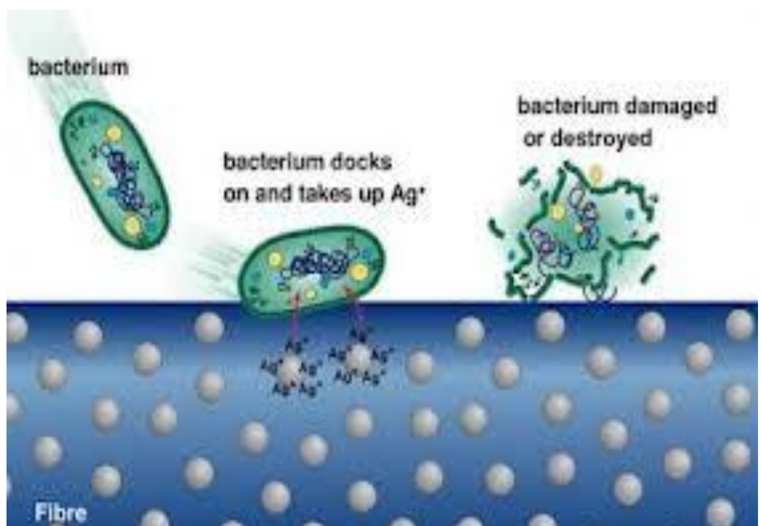
Brake linings contain phenolic resin binder, clay and powder fillers, graphite lubricants, and metallic fibers (Ba, Ca, Ti, Cu, Mg, Cr, Sb, Zn, Zr)

Image courtesy of Sansin Brake Co., etrade.daegu.go.kr/.../Brake_Lining.html

Designed dissipative uses of metals (2008)

- Titanium – 94% (pigments)
- Yttrium – 88% (phosphors)
- Arsenic – 68% (wood preservative)
- Antimony – 40% (flame retardant)
- Molybdenum – 15% (lubricant)

Silver Nanoparticles

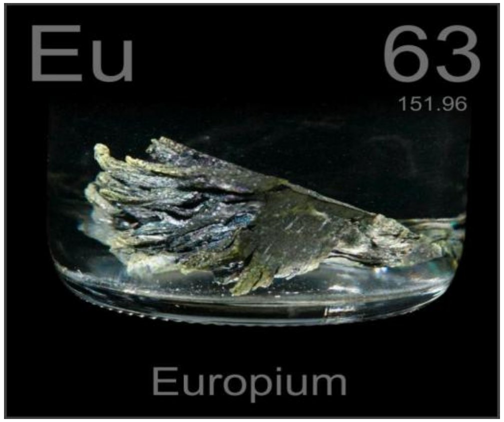


Silver Nanoparticle Consumer Goods

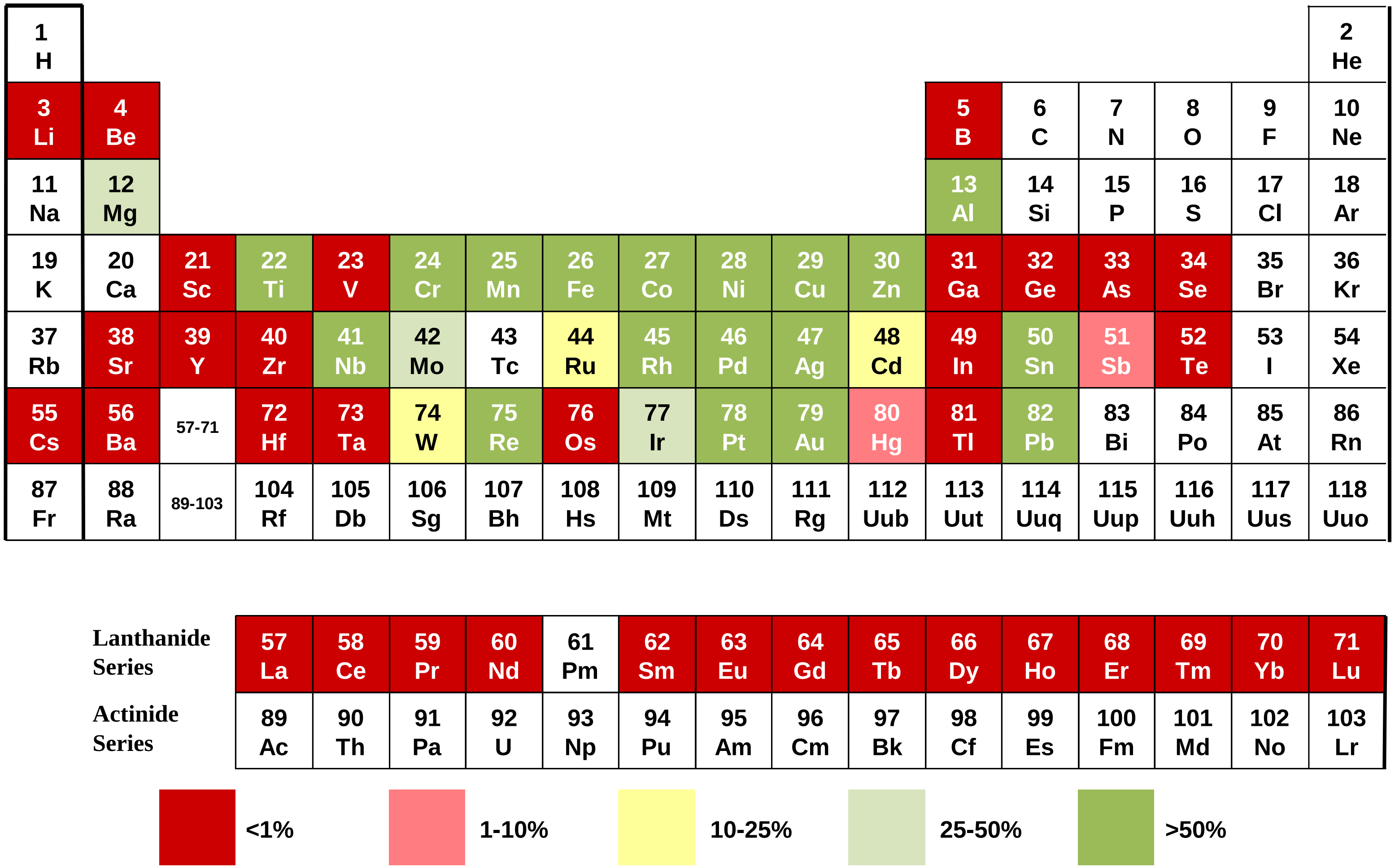
- Creams and cosmetics – 32%
- Textiles and clothing – 18%
- Household items – 16%
- Air and water filters – 12%
- Detergents – 8%
- Other – 14%

2009 accounting of products containing silver nanoparticles - 1027

Rare Earths and Modern Lighting



End-of-life recycling rates remain very low for many metals

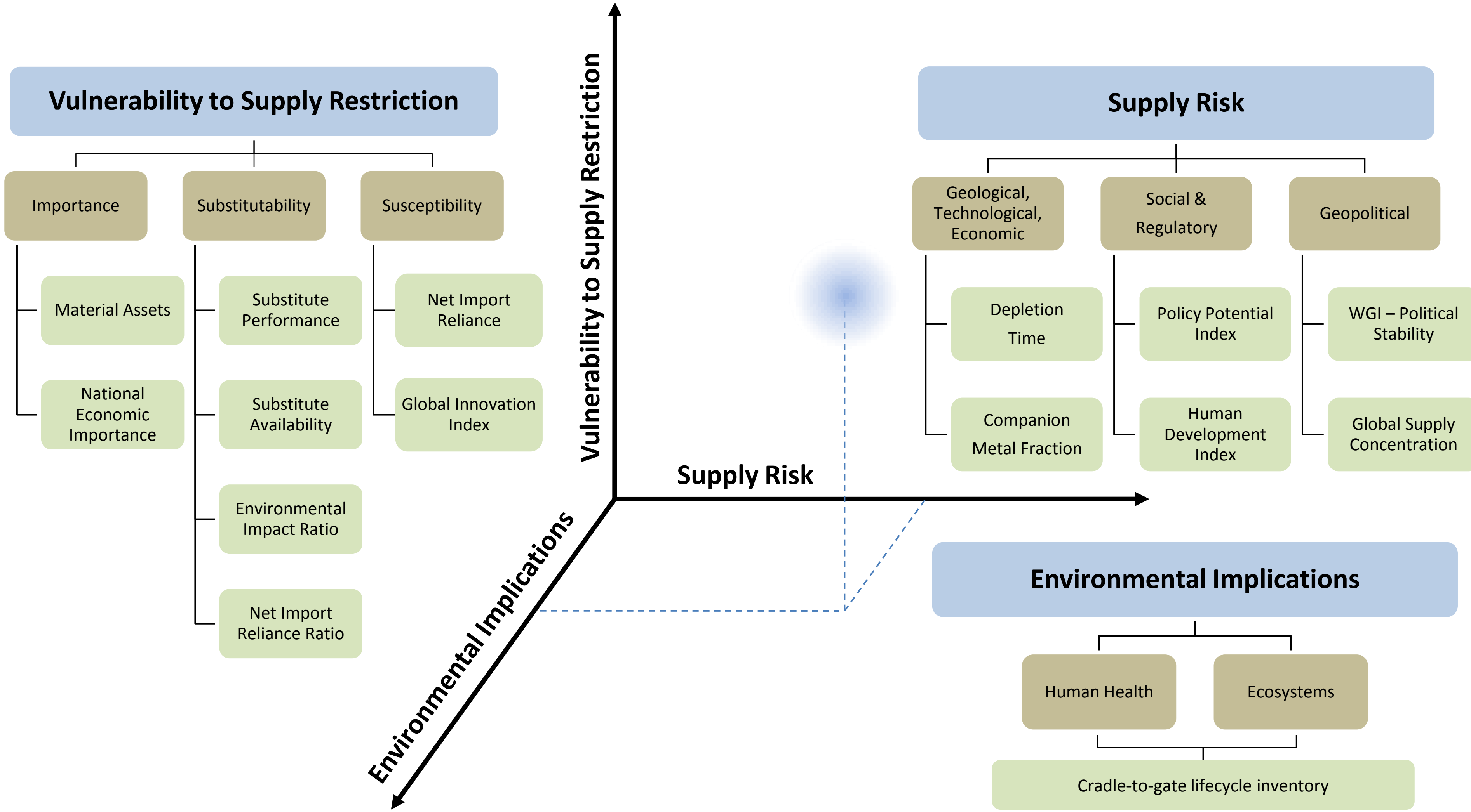


Source: Graedel T.E. et al, *Journal of Industrial Ecology*, *15*:355-66, 2011.

The Yale Criticality Project

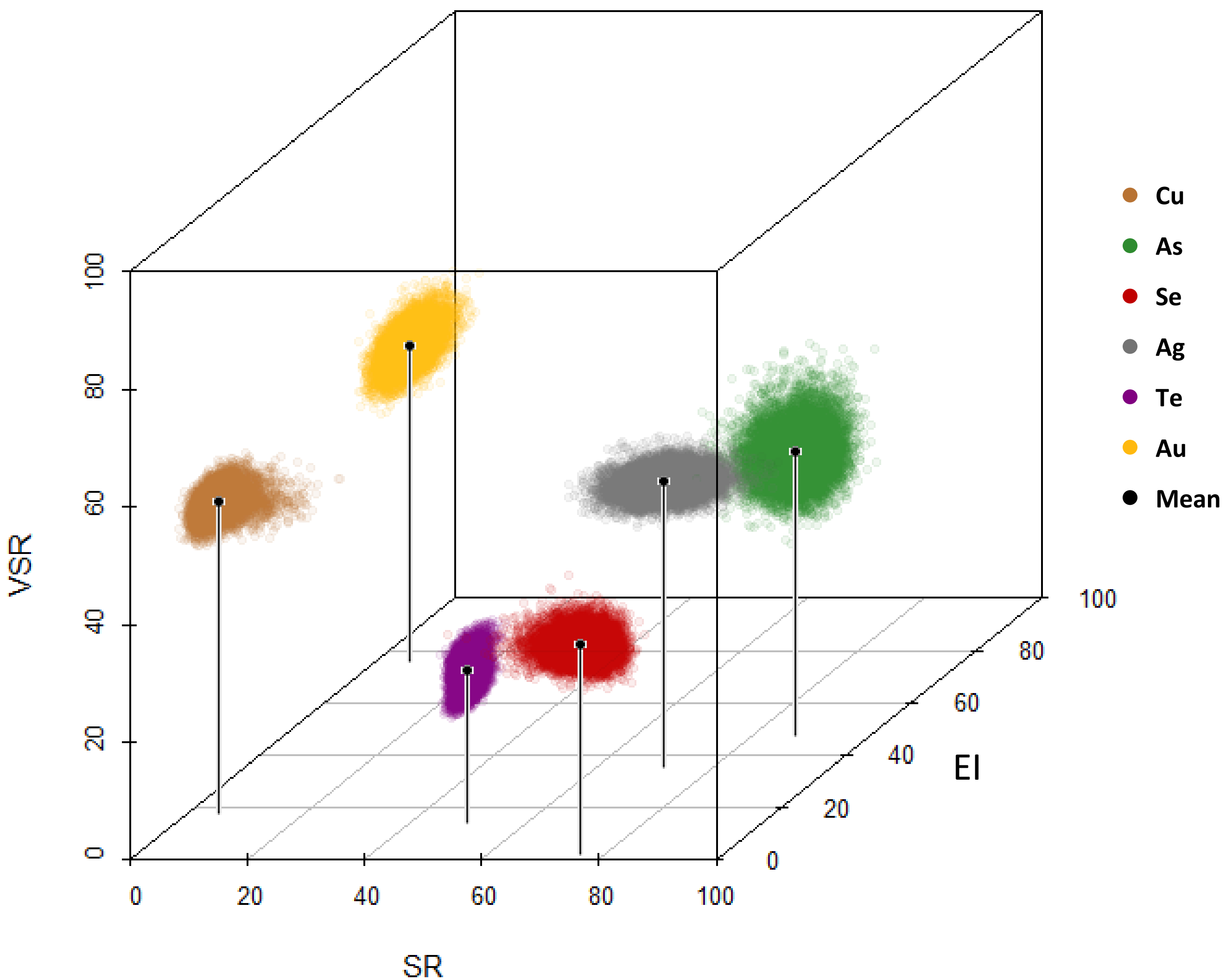
New methodology evaluates metal Criticality on three complementary dimensions.

National-level assessment

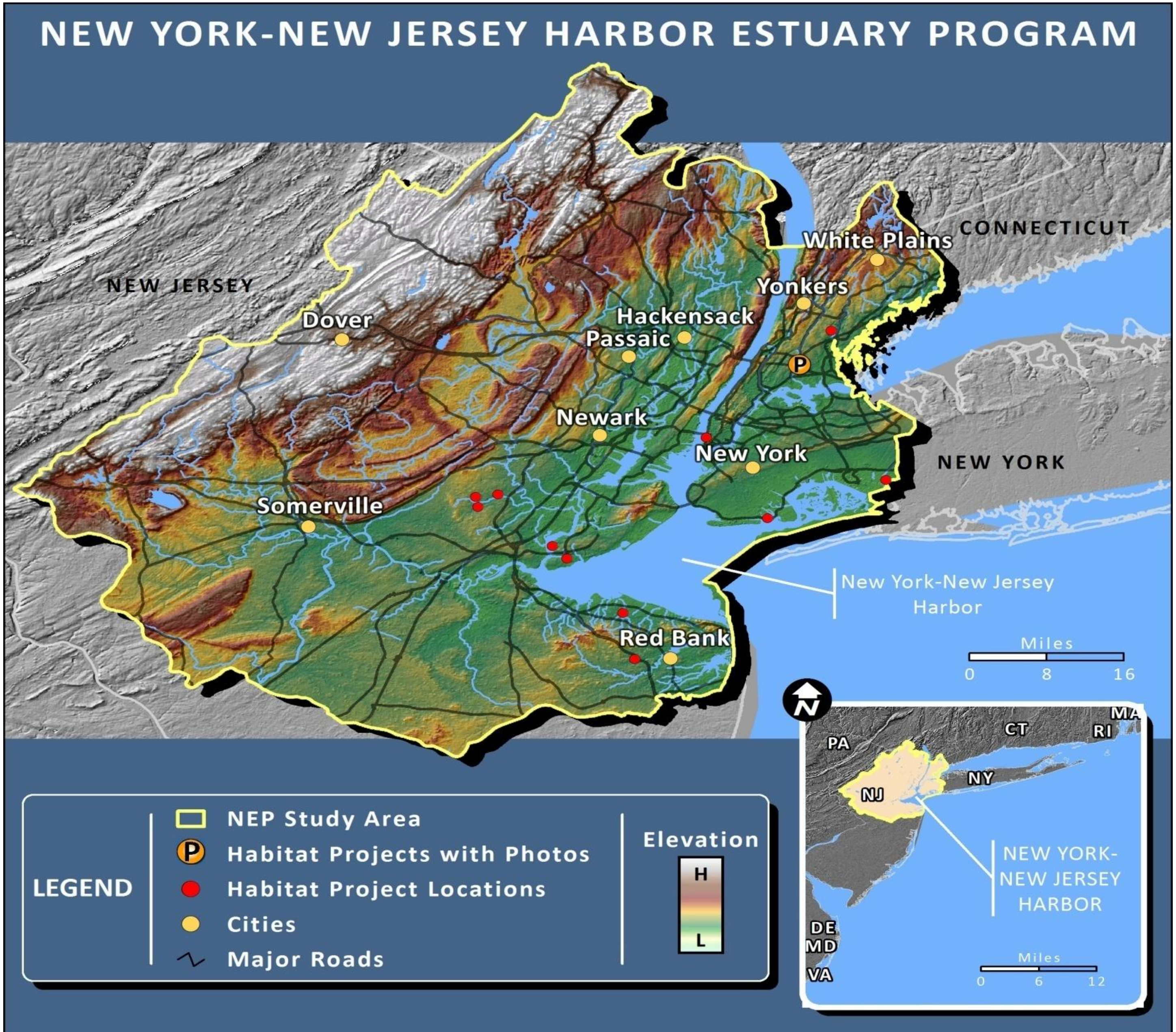


Source: T.E. Graedel, et al. *Environ. Sci. Technol.*, *46*, 1063–1070, 2012.

Copper geological family – global level



A success story: Limiting harmful emissions as a result of material flow analysis


NEW YORK-NEW JERSEY HARBOR ESTUARY PROGRAM
CONNECTICUT
White Plains
NEW JERSEY
Yonkers
Hackensack
Dover
Passaic
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Newark
New York
NEW YORK
Somerville
New York-New Jersey
Harbor
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Miles
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12
LEGEND
NEP Study Area
Habitat Projects with Photos
Habitat Project Locations
Cities
Major Roads
Elevation
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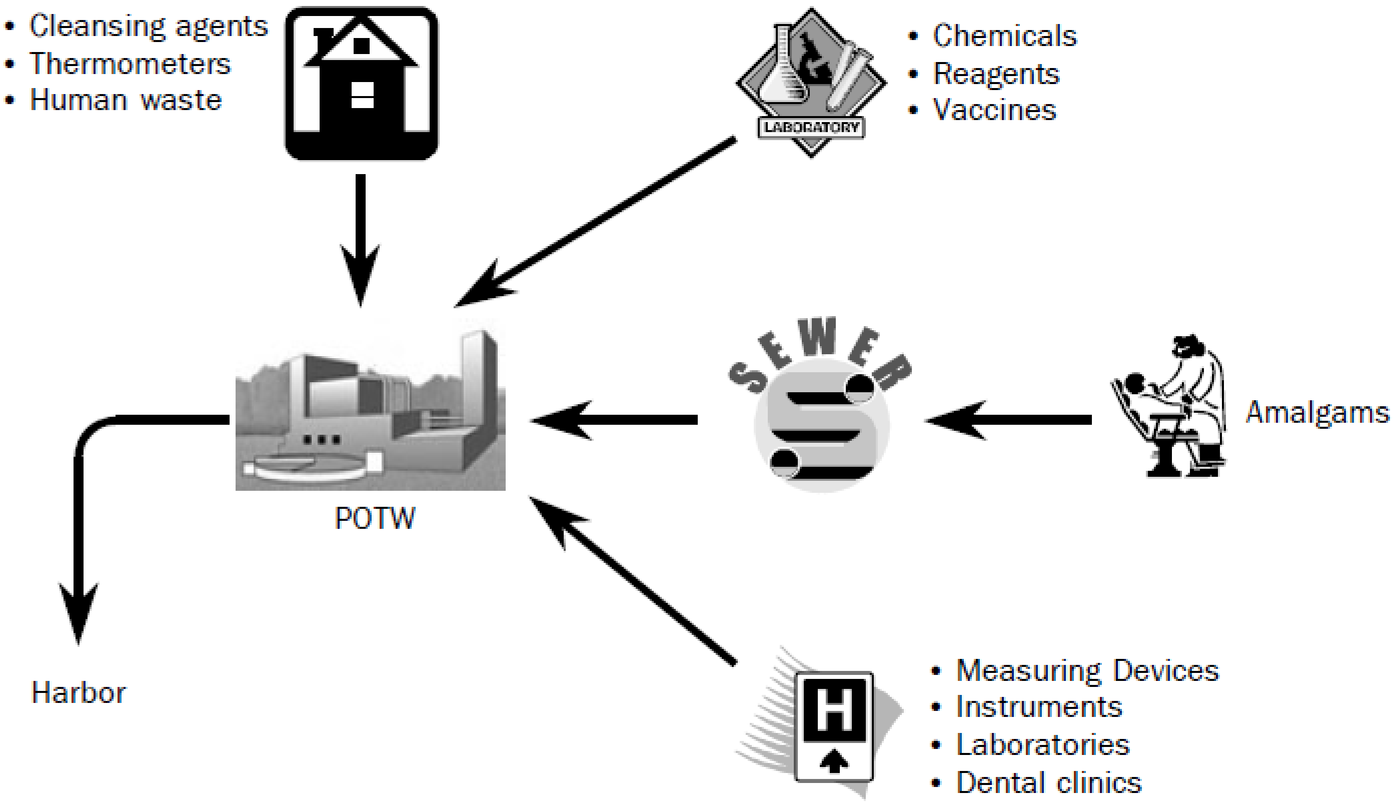
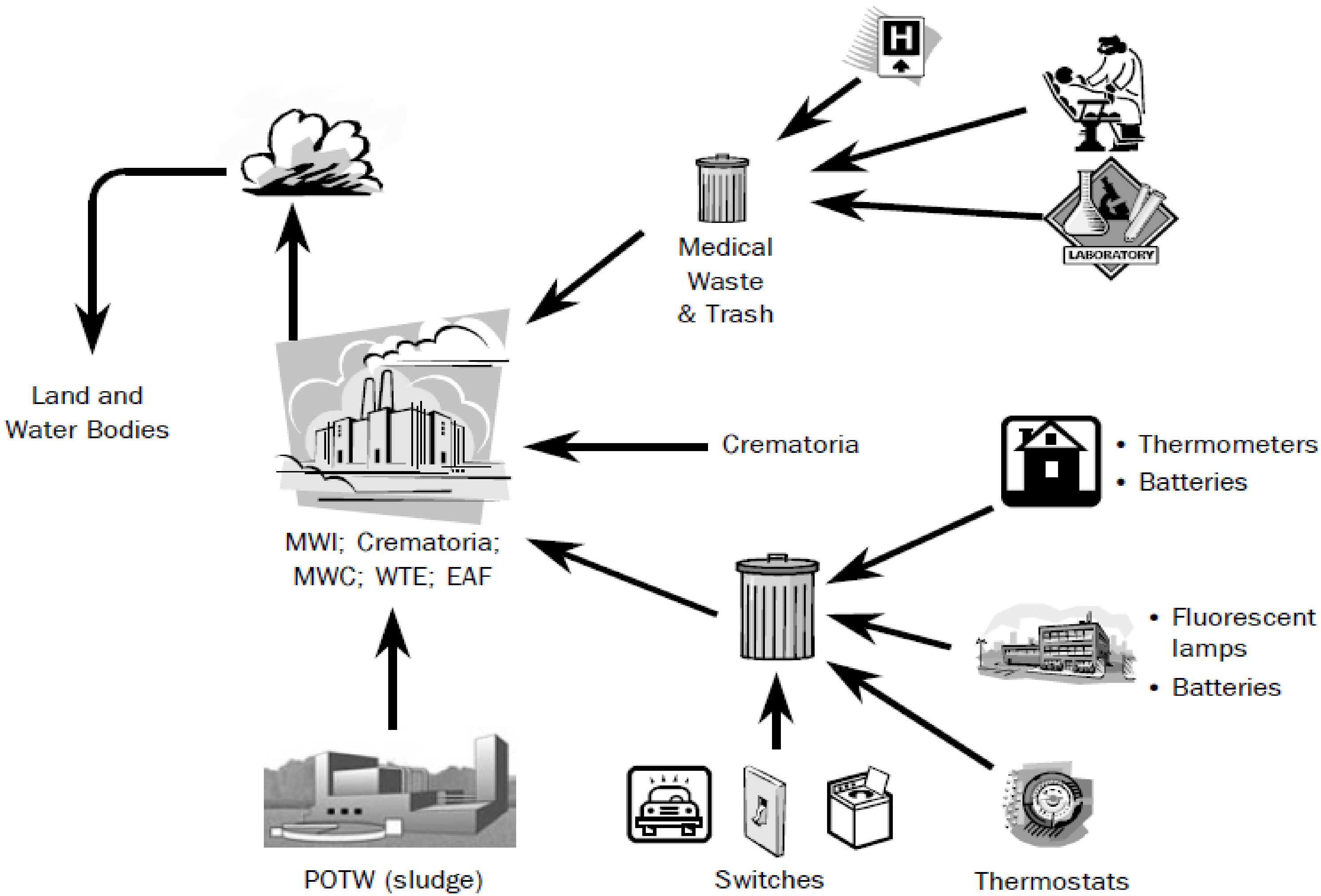
Pathway of Mercury through Water Treatment and Into the Harbor



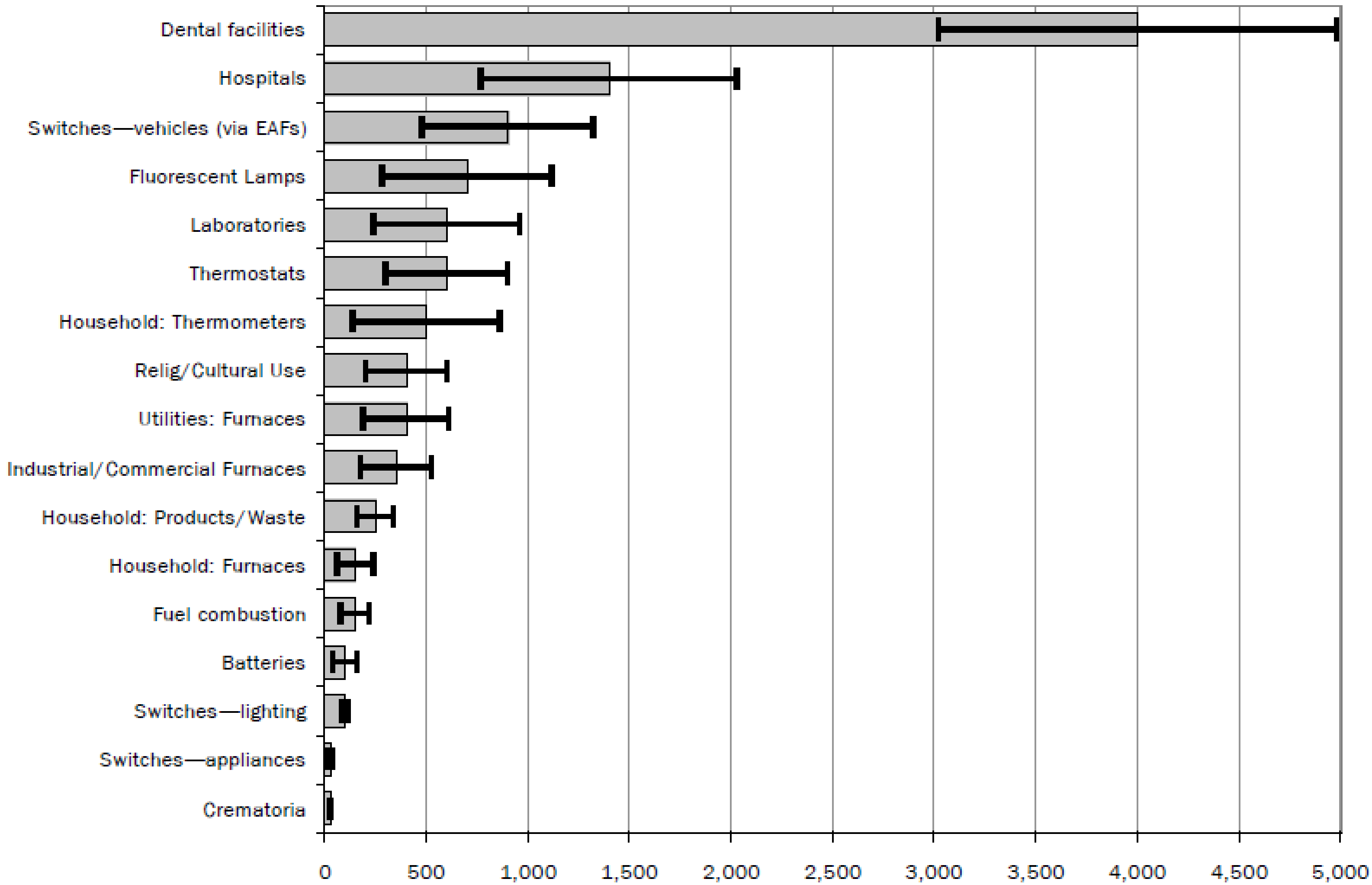
Source: A.L.C. de Cerrano et al., *Pollution Prevention for Mercury in the NY/NJ Harbor*, NYAS, 2002

Pathway of Mercury through Incineration and Into the Air, Land, and Water



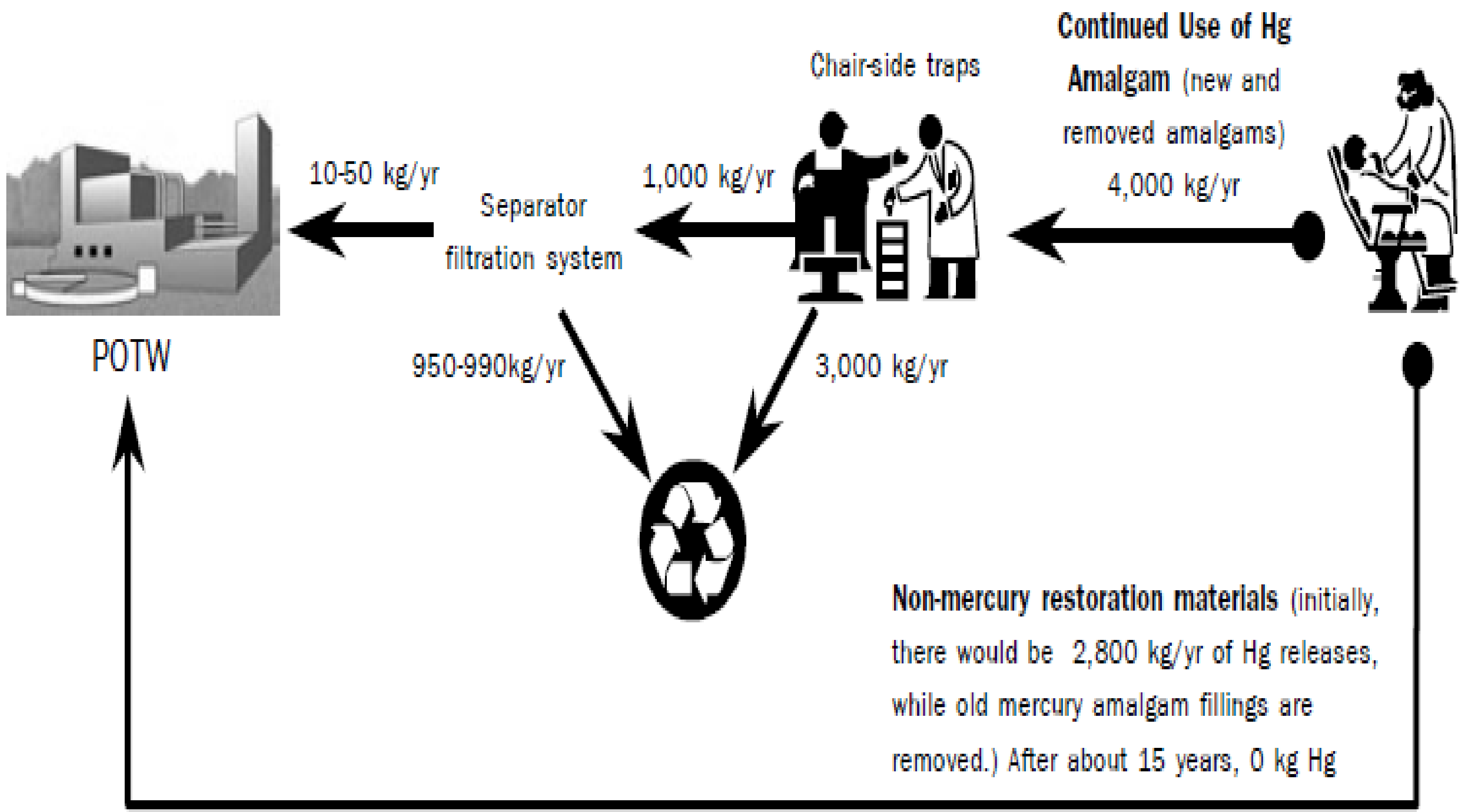
Source: A.L.C. de Cerrano et al., *Pollution Prevention for Mercury in the NY/NJ Harbor*, NYAS, 2002

Mercury Inputs (kg/yr) to NY/NJ Harbor



Source: A.L.C. de Cerrano et al., *Pollution Prevention for Mercury in the NY/NJ Harbor*, NYAS, 2002

Intervention Options for Dental Office Mercury



Source: A.L.C. de Cerrano et al., *Pollution Prevention for Mercury in the NY/NJ Harbor*, NYAS, 2002

Closing messages

- Many elements are used once and then lost, often by design
- Quantified metal cycles reveal paths of use and loss, from birth to death or reuse
- Life-cycle quantification presents the opportunities that are available to help change our ways