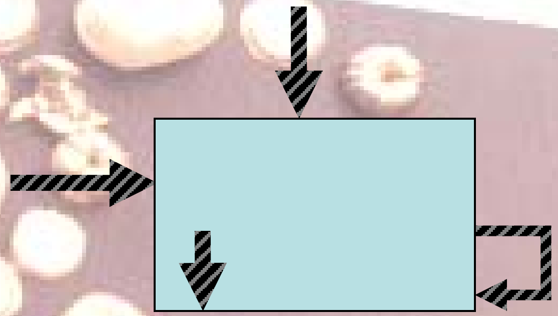
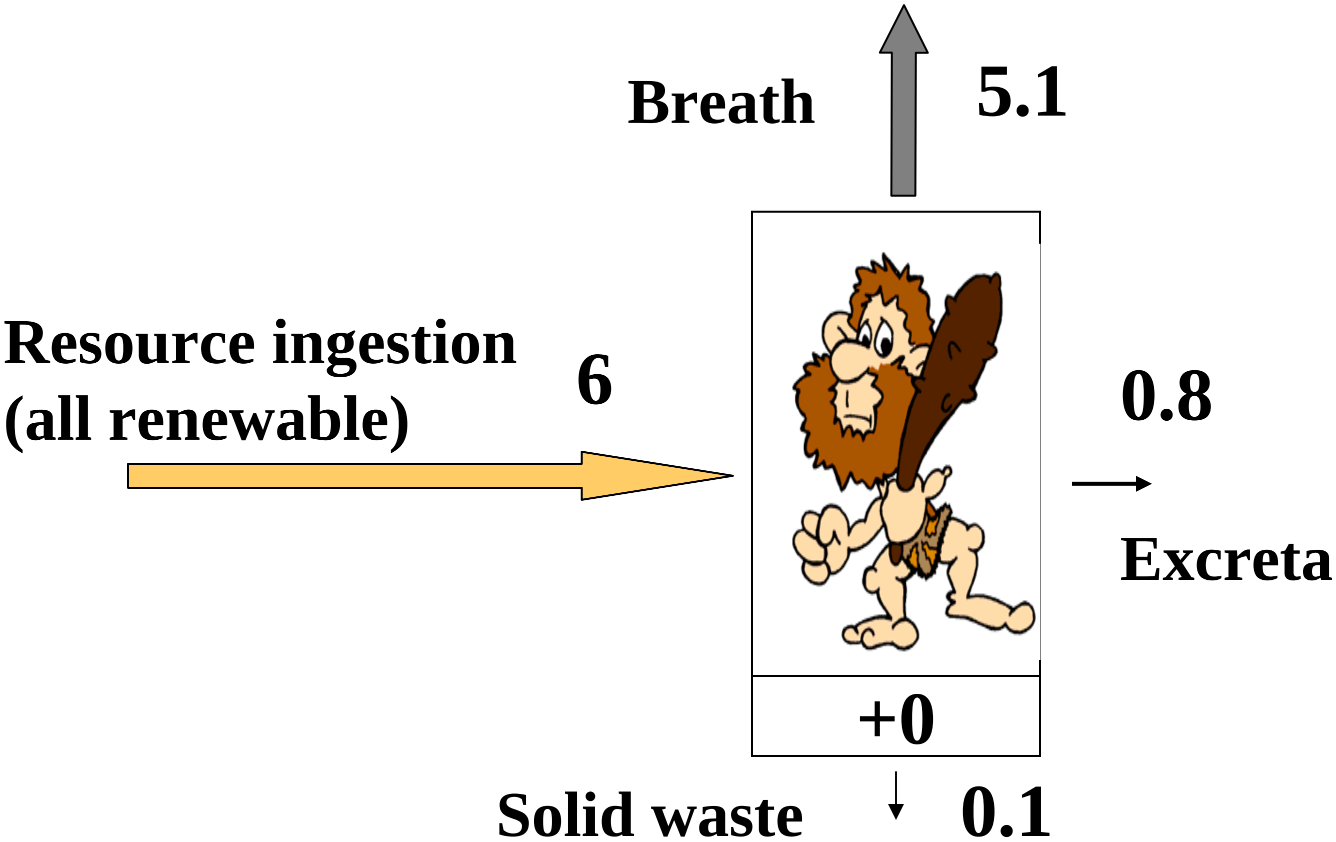
Are Non-Renewable Resources Critical?

Thomas E. Graedel

Yale University

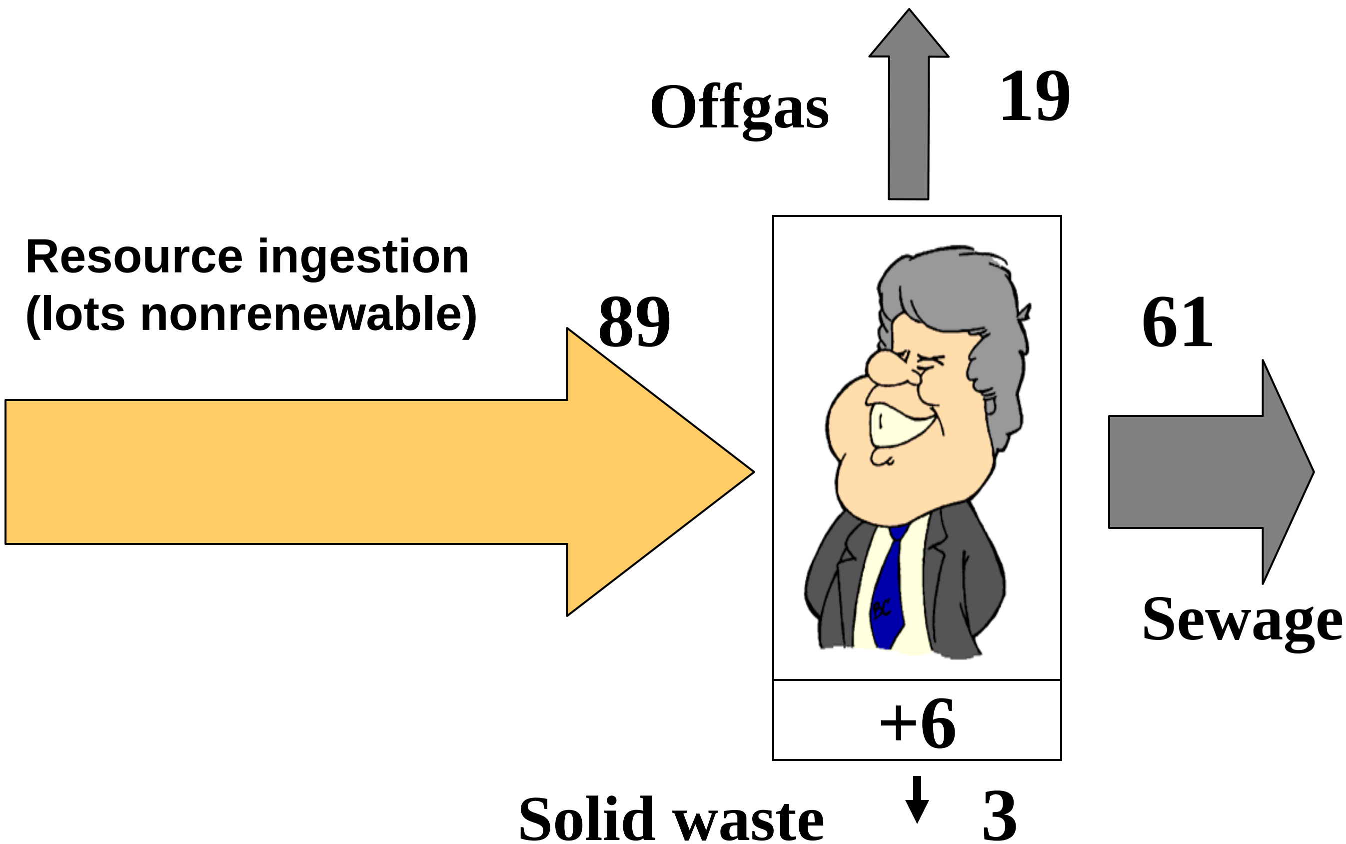


Total Material Consumption: Neolithic Human



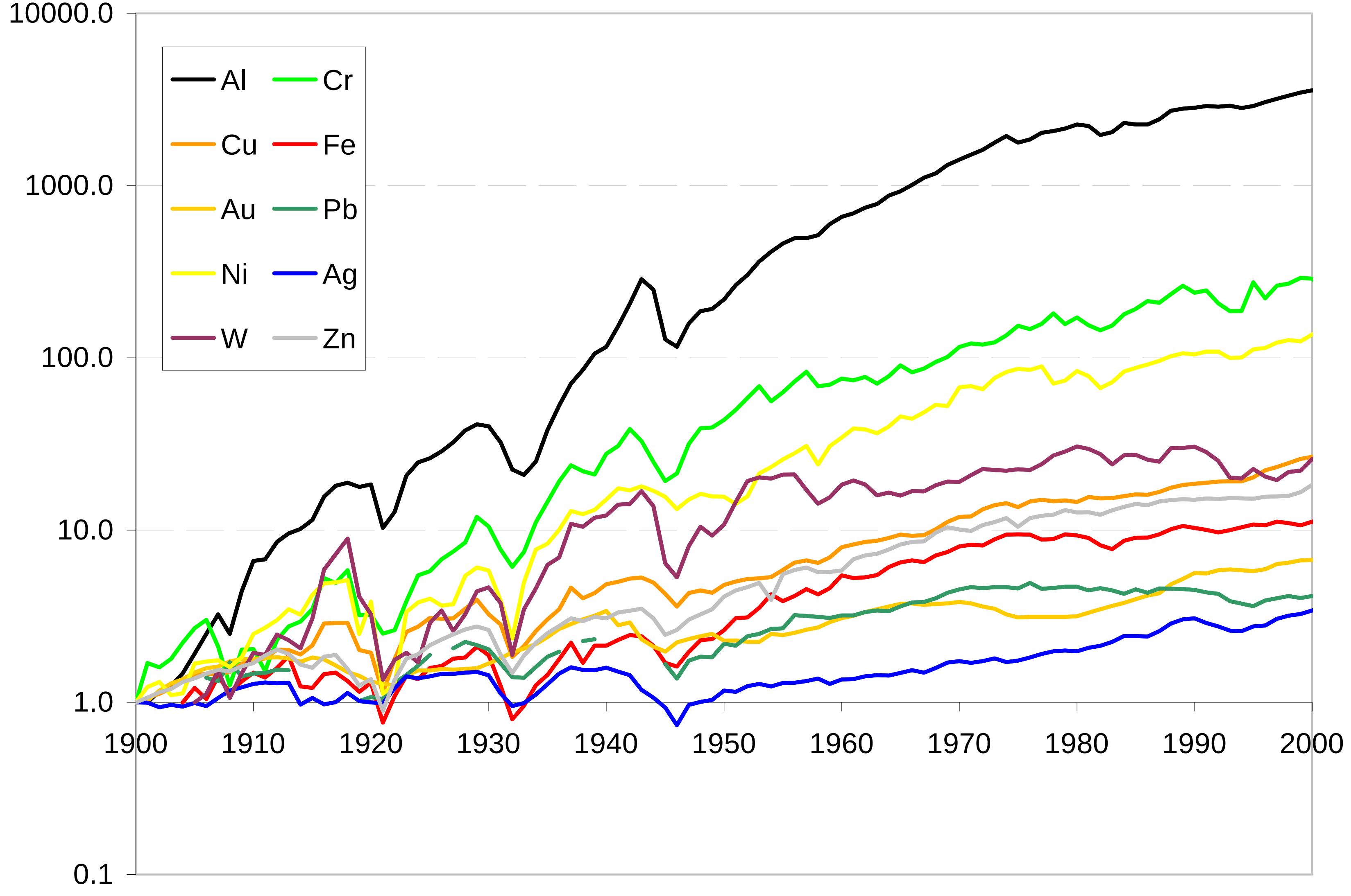
Unit: tonnes/cap-yr

Total Material Consumption: Modern Human

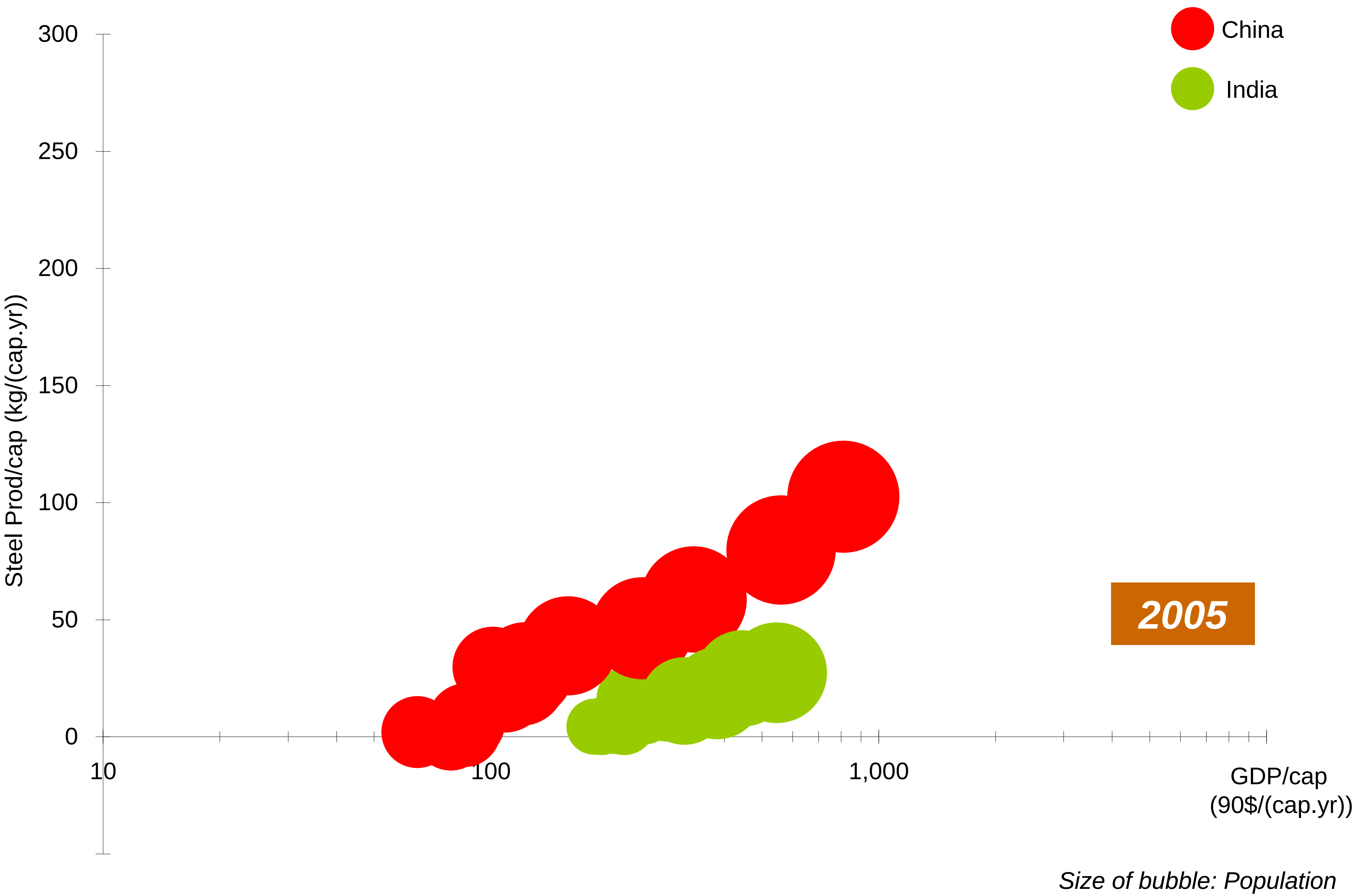


Unit: tonnes/cap-yr

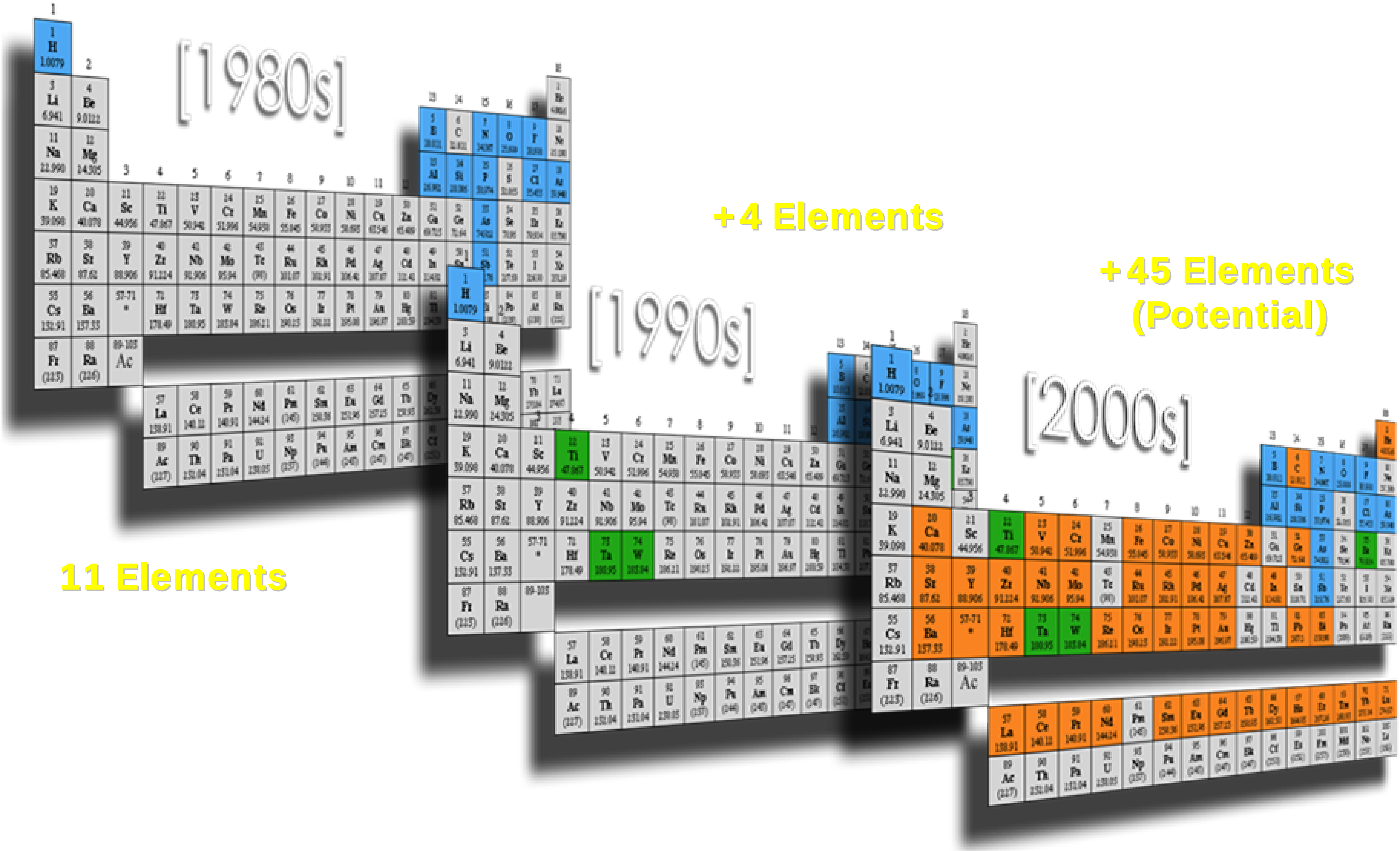
Global 20th Century Metal Use



Crude Steel Production in China and India, 1945-2005

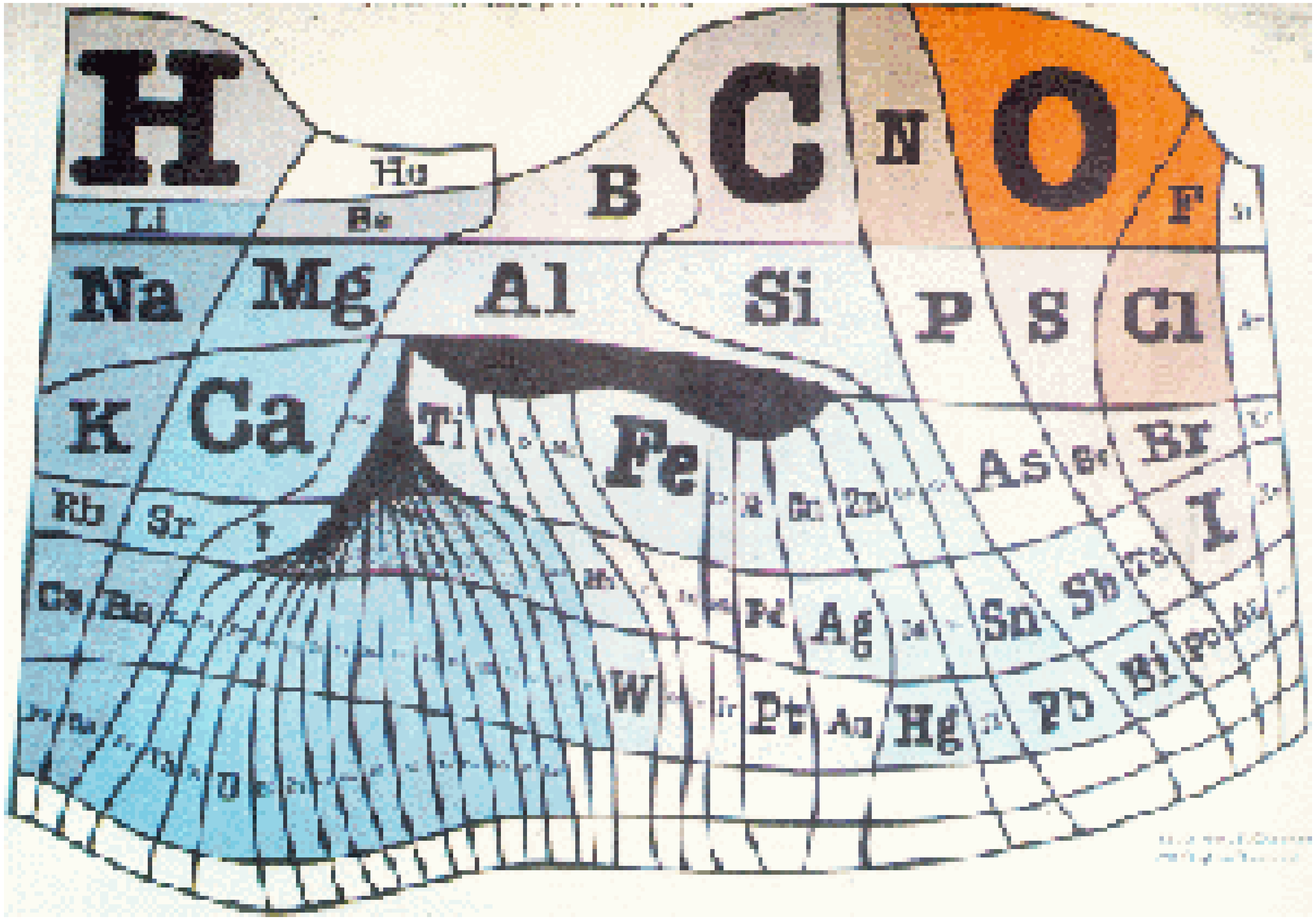


Metal Linkages in the New Mineralogy



Source: T. McManus, Intel Corp., 2006

Periodic Table According to Atomic Abundance in Earth's Crust



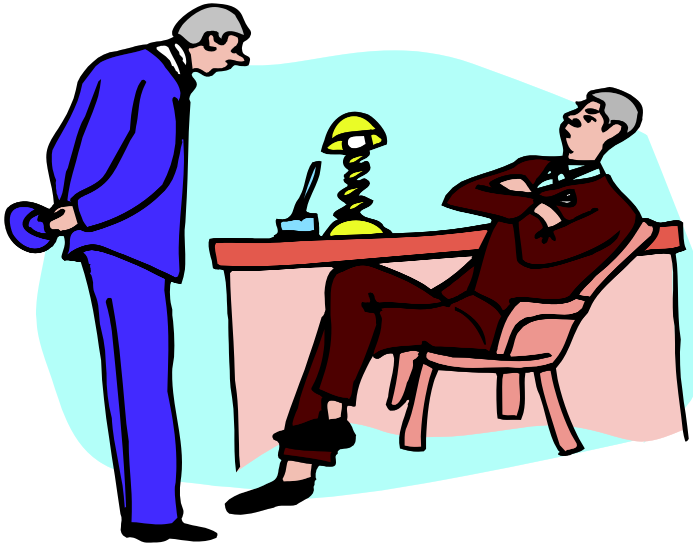
The Central Question

People agree we are getting close to "peak oil" – the year in which oil production will hit a peak and then decline. Should we expect "peak metals" in our future?

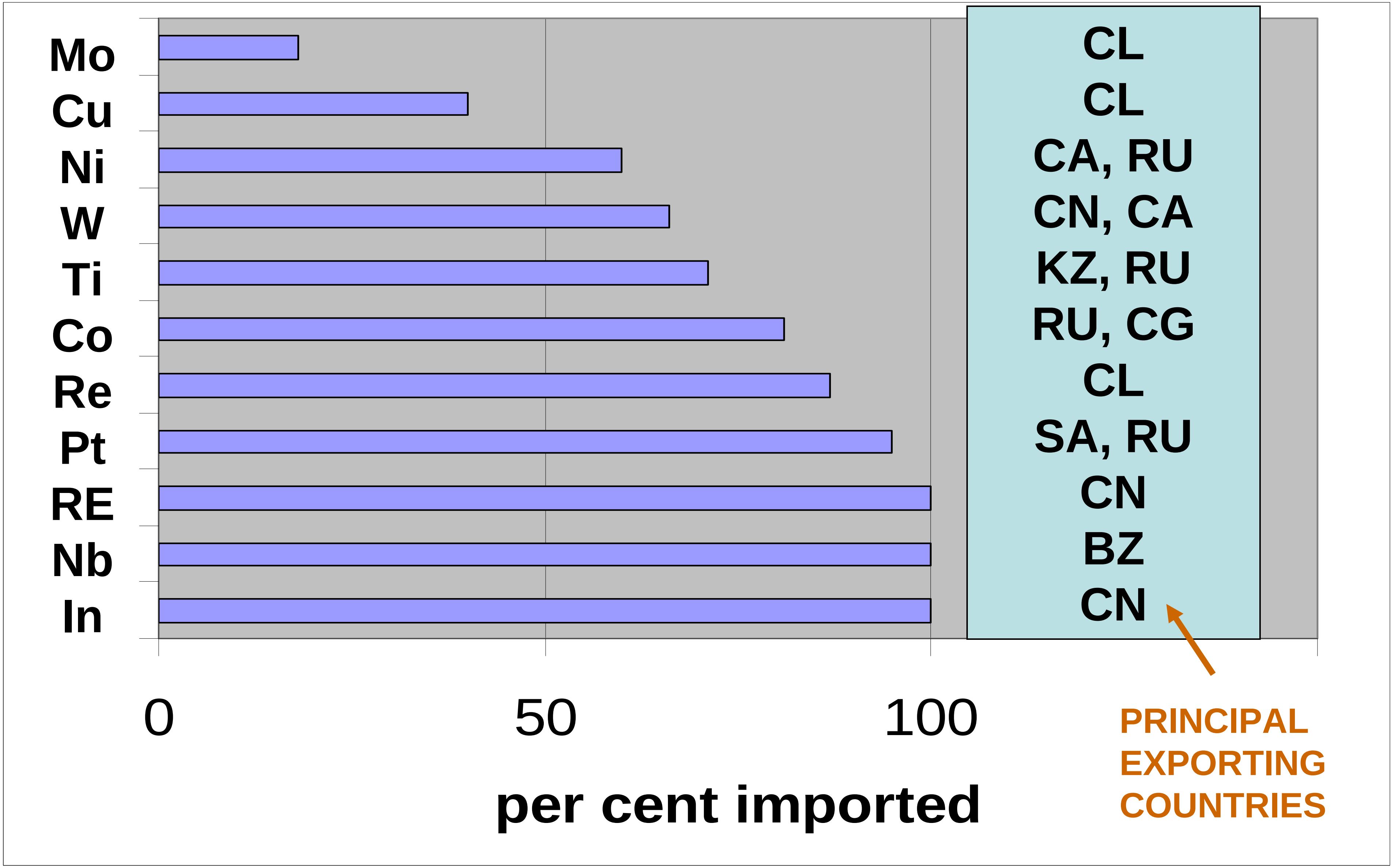
Evaluating the Criticality of Materials

The First Dimension of Criticality
Supply risk

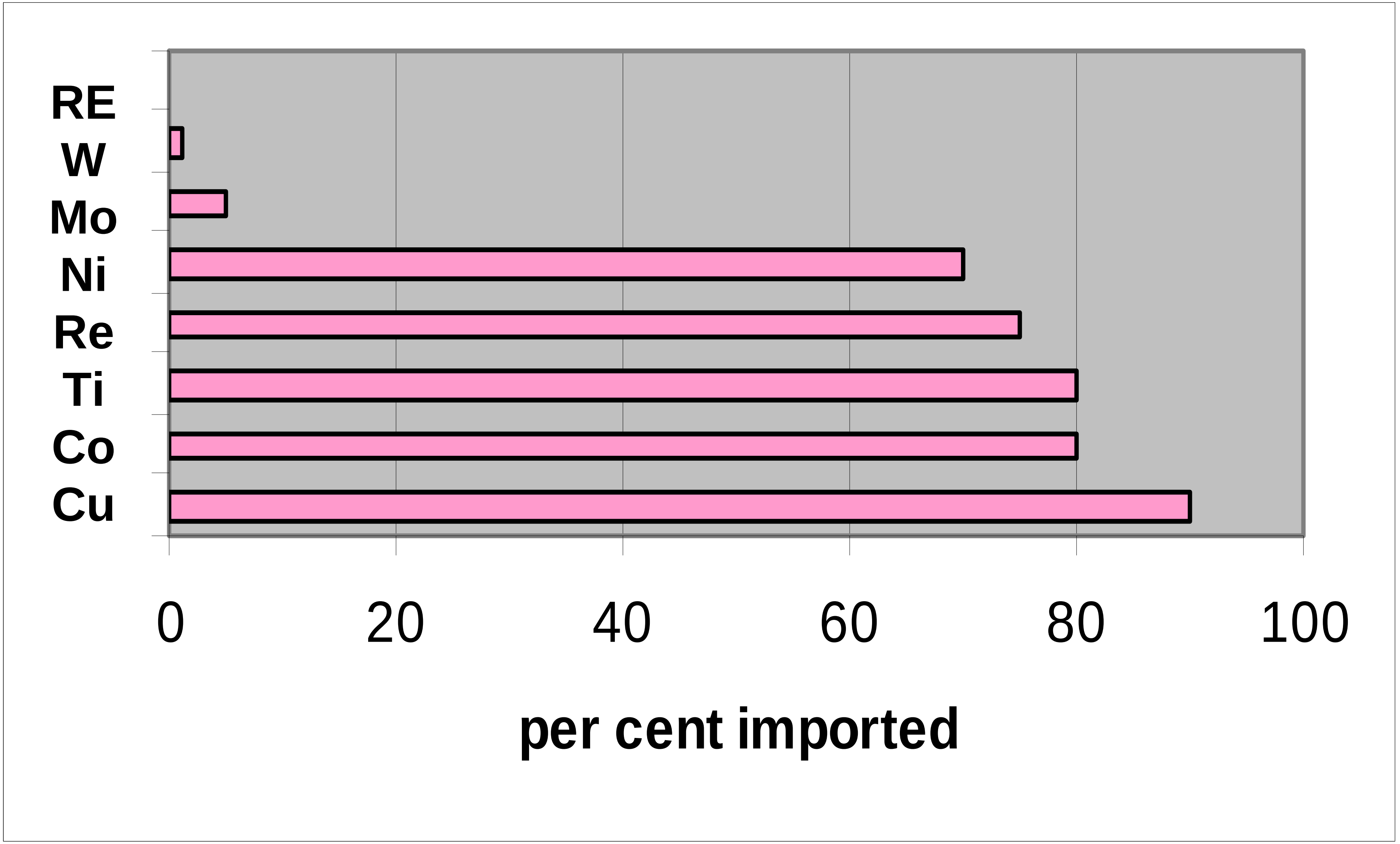
– **Geologic availability** **-- Technical availability**
– **Regulatory availability** **-- Geopolitical availability**
– **Social availability** **-- Market availability**



US Resource Dependencies

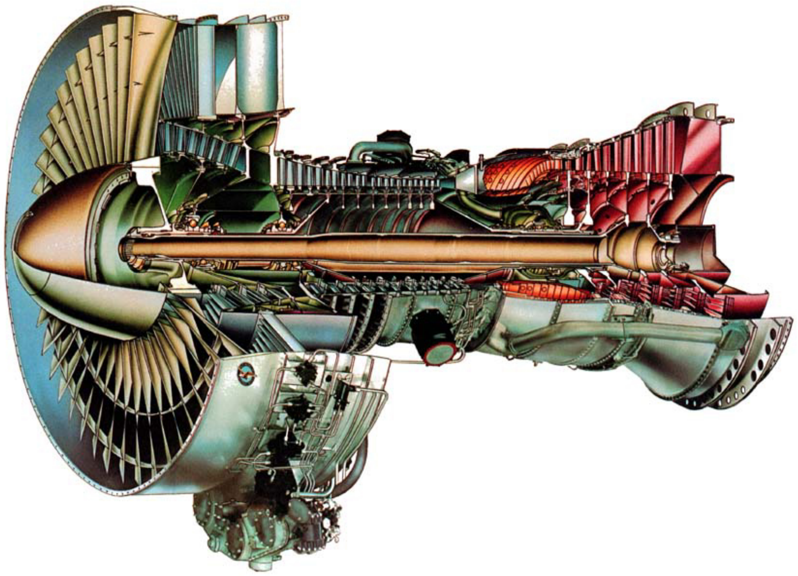


China Resource Dependencies

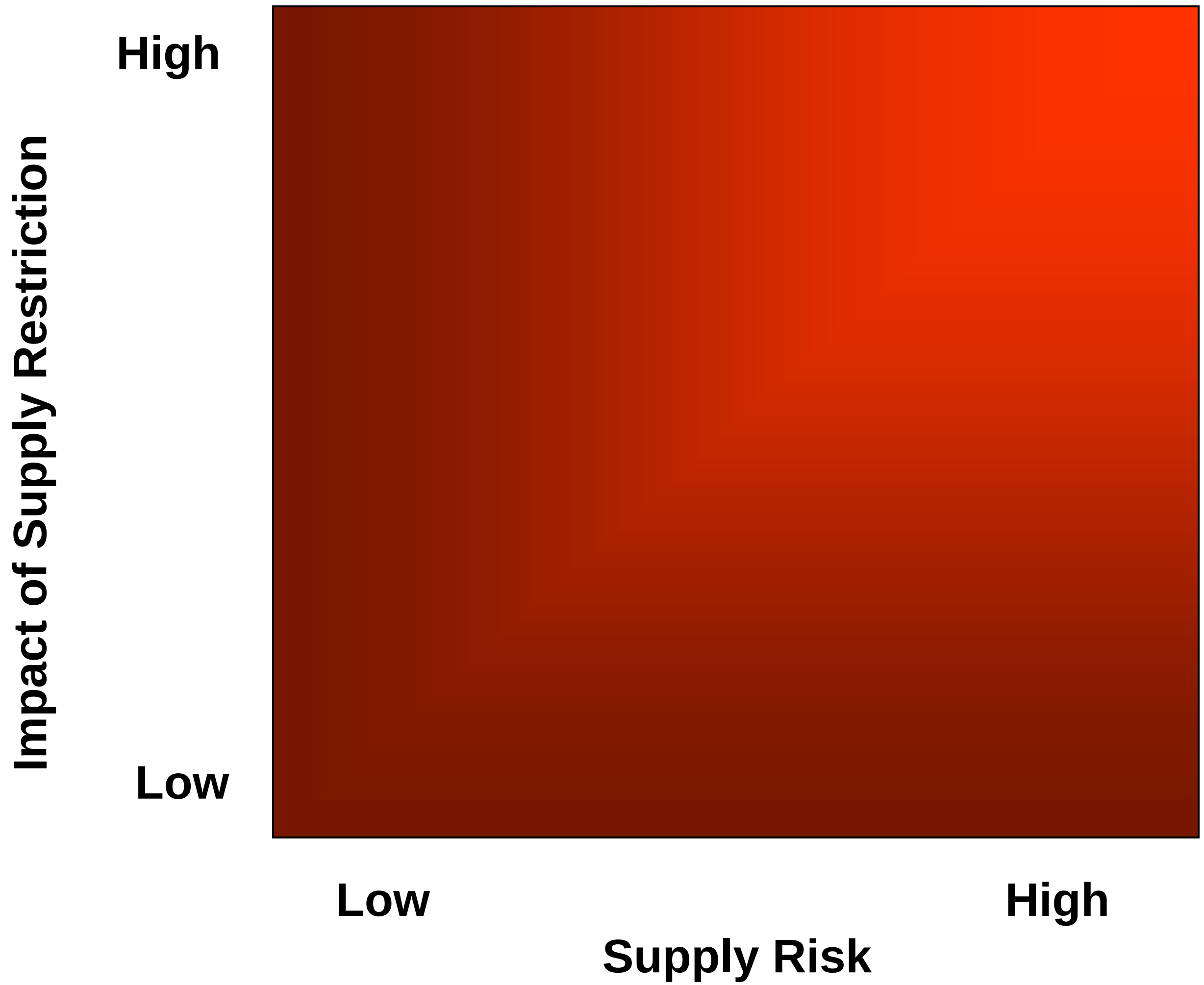


The Second Dimension of Criticality: Impacts of Supply Restriction

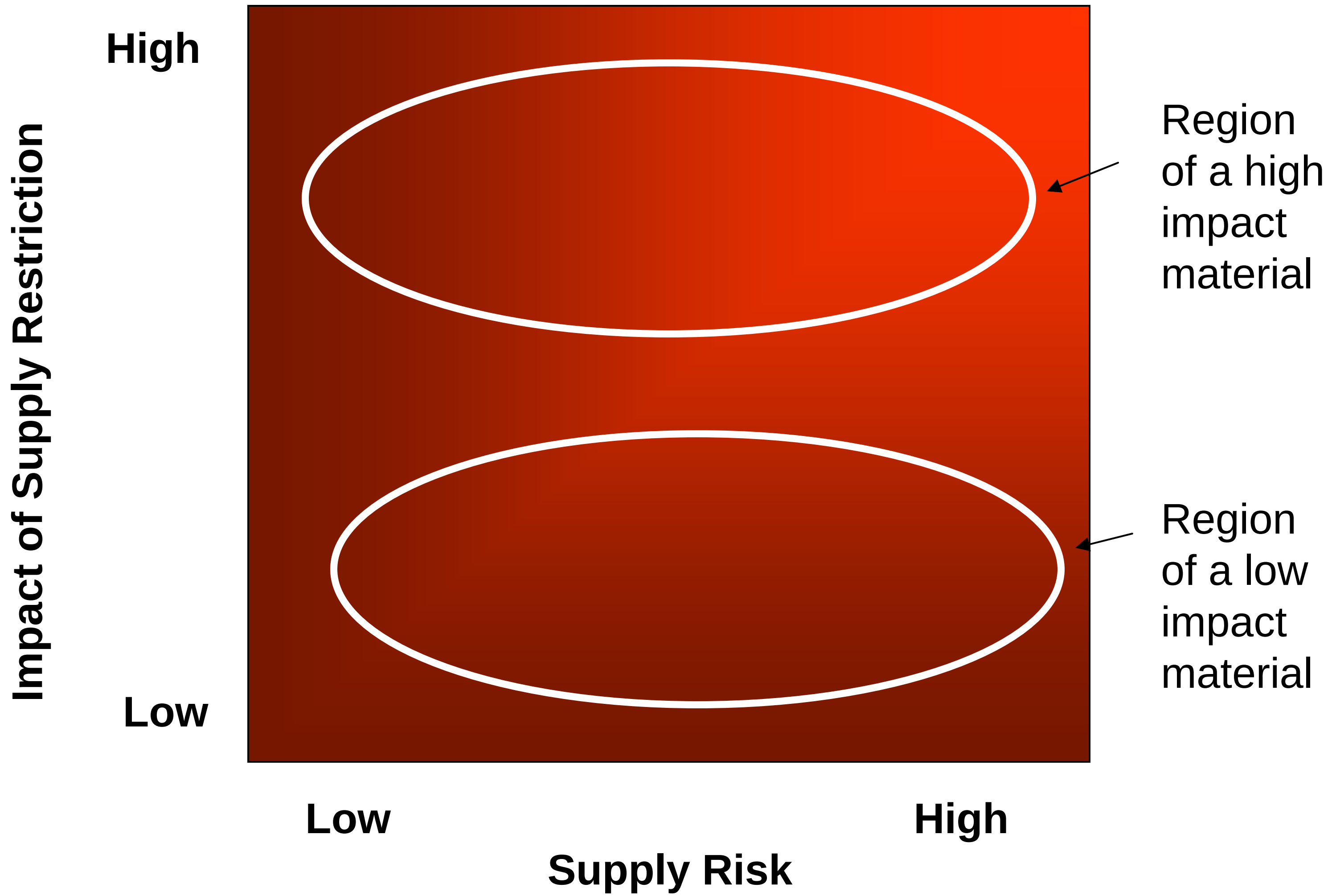
- **Prevents manufacture**
- **Impedes product development**
- **Influences profitability**



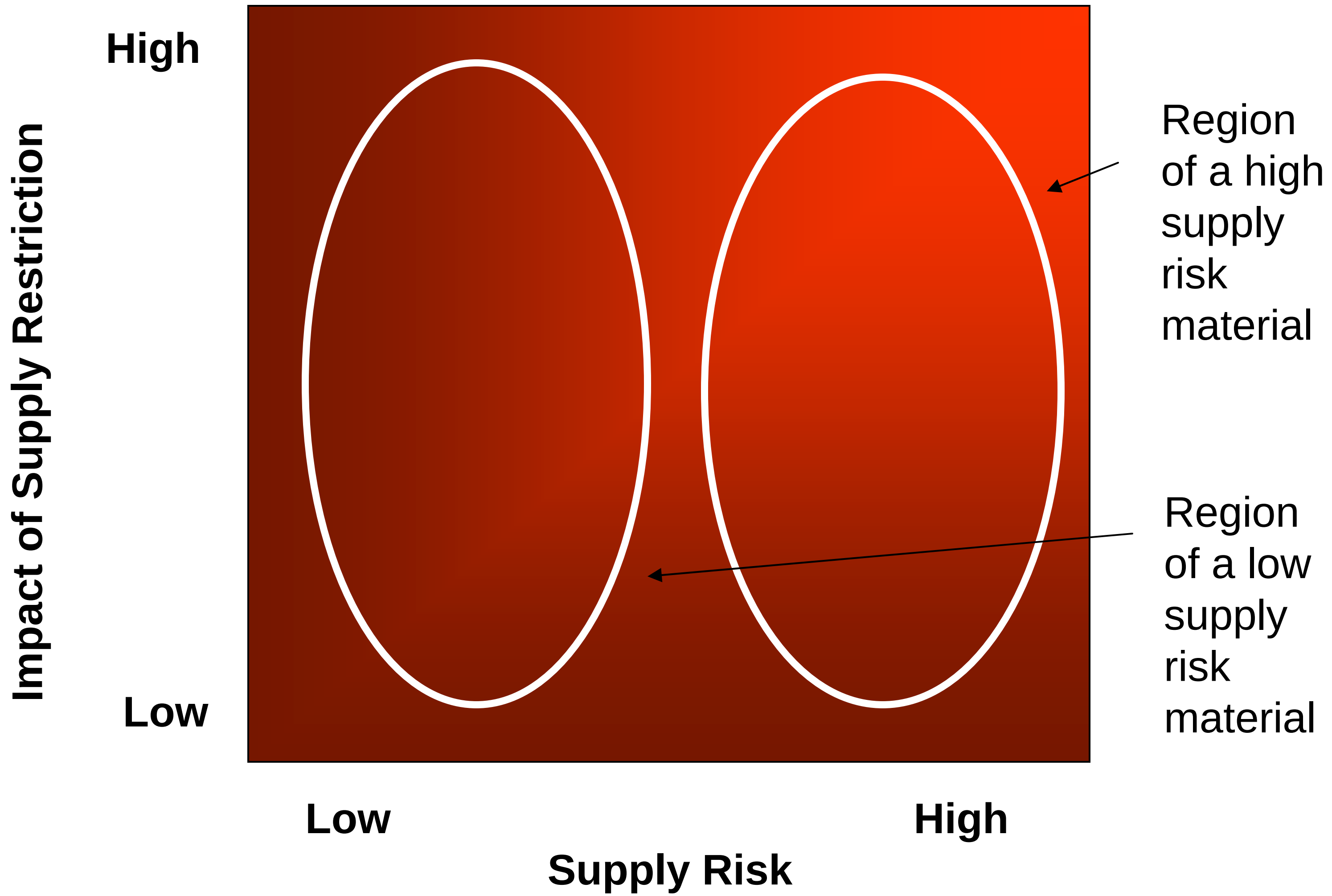
Two-Dimensional Criticality



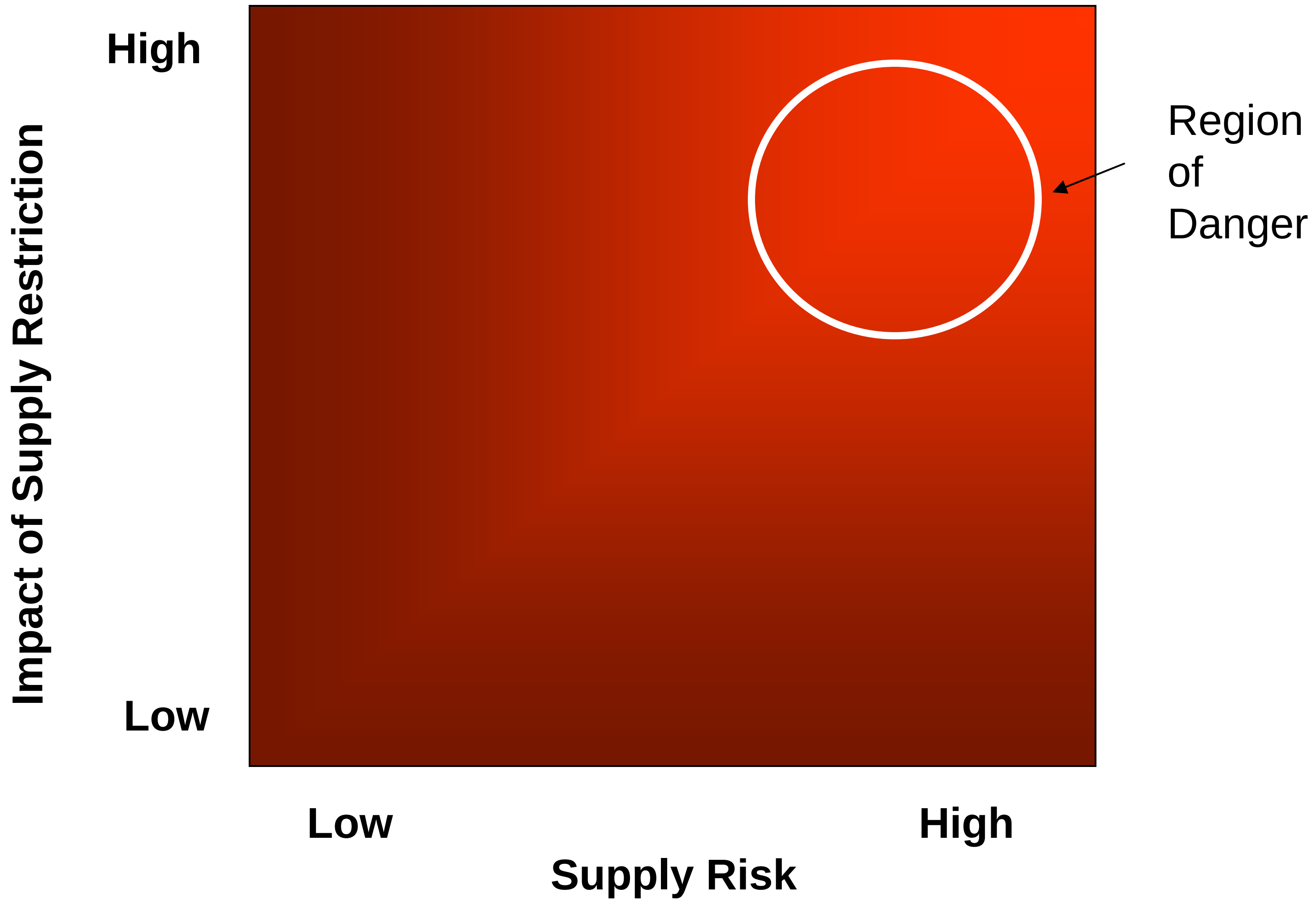
Locating a Product Material on the "Impact of Restriction" Axis



Locating a Product Material on the "Supply Risk" Axis



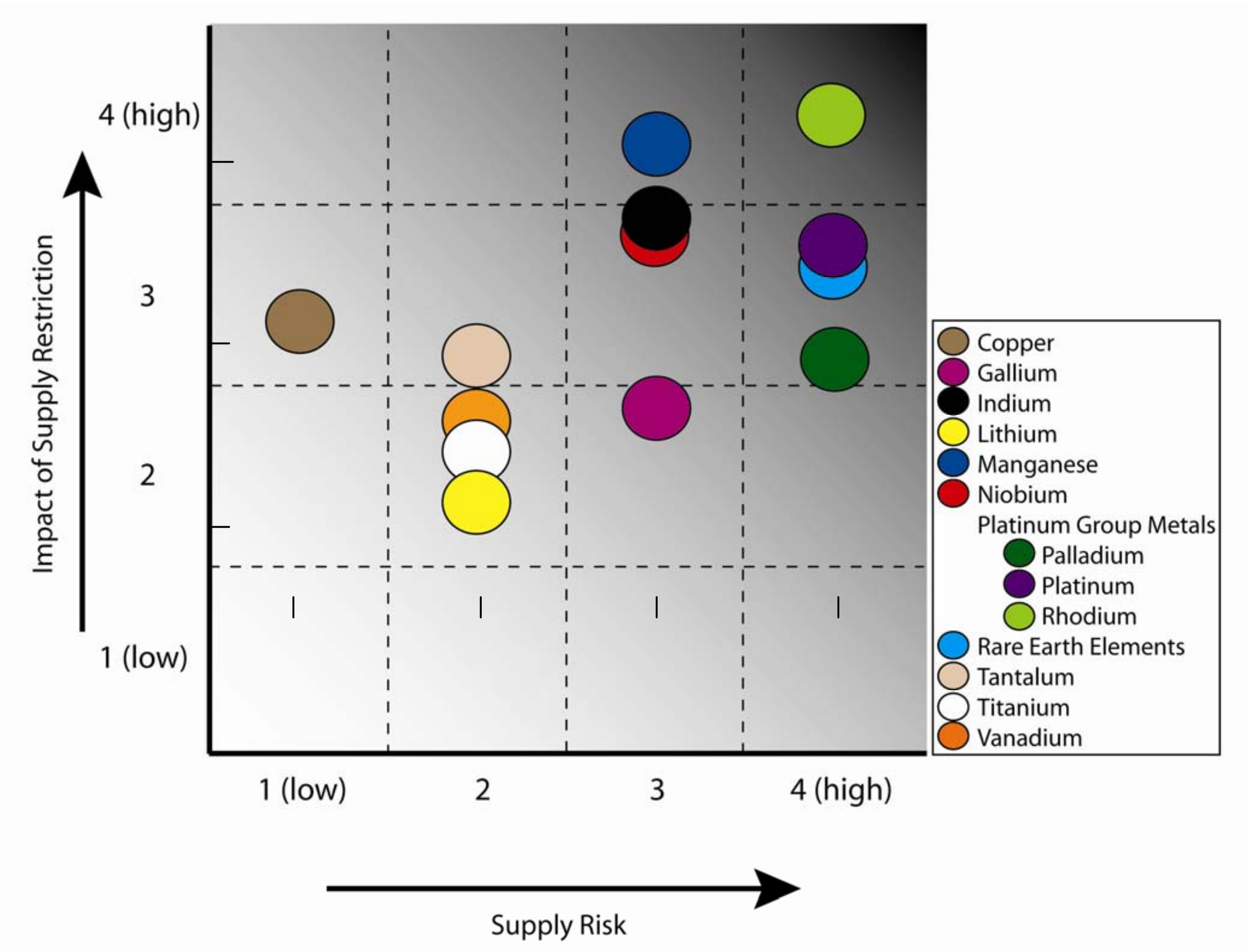
Identifying the "Region of Danger"



Criticality Example: Platinum

- Application in the auto industry: CO and HC reduction in catalytic converters
- Substitutes
  - Gasoline catalytic converters: Palladium
  - Diesel catalytic converters - None
- Nature of criticality
  - Primary concern: “No build” condition
  - Secondary concern: Price ($1200/troy oz on 2/20/07, $2095/troy oz on 5/9/08)

Criticality of 11 Minerals Evaluated by the U.S. National Research Council



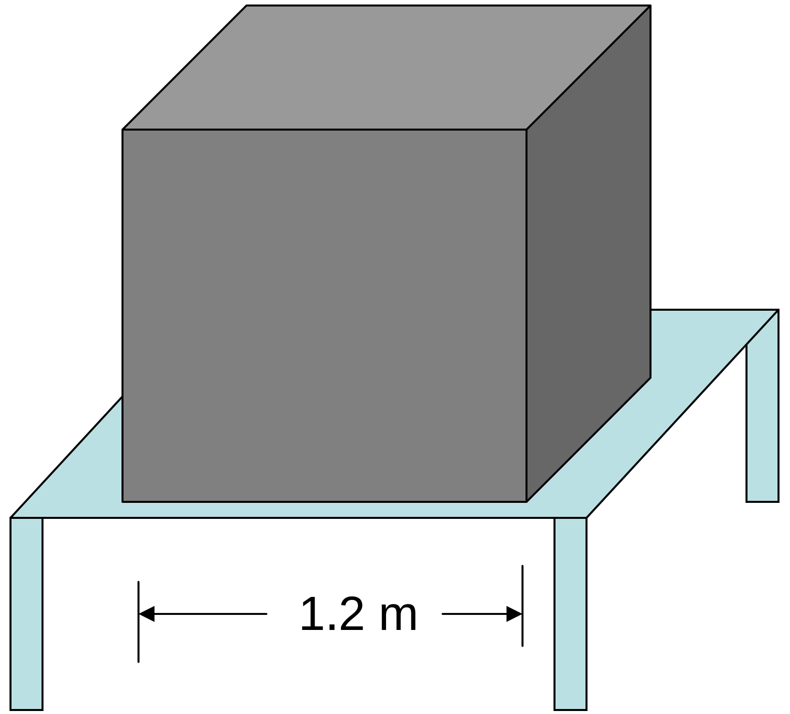
Substitution as a solution for resource depletion – Is this a reasonable option?

Aircraft Engine Combustors

Aircraft Engine Combustors

Rhenium: Only element whose alloys can withstand modern combustor temperatures

The World’s Annual Production of Rhenium

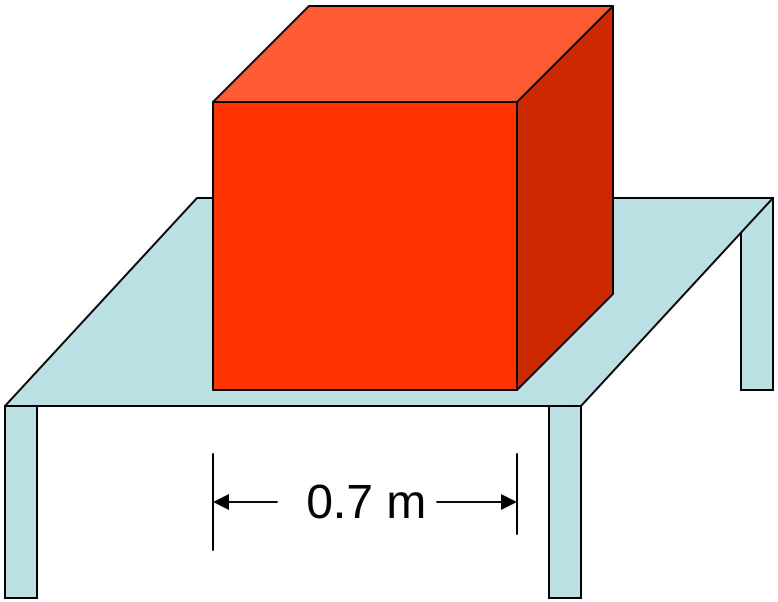


Liquid Crystal Display

Liquid Crystal Display Phosphors

Europium: Only element known suitable as LCD red phosphor activator

The World's Annual Production of Europium



POTENTIALLY LIMITED RESOURCES

- Resource appears small relative to annual extraction: Au, Cu, Zn, PGMs (Pt, Pd, Rh)
- Resource appears small and most uses are non-substitutable: In, Re, Eu, Hf, Er
- Principal source countries are politically problematic: Co, Ta
- Very large energy requirements: Al, Ti
- Toxicity limited: Pb, Hg, As, Cd

A Mine of the Past:
(Bingham Canyon, AZ Copper Mine)

A Mine of the Future

Summary

- Non-renewable resource availability requires a balance between supply and demand
- Modern technology employs most of the periodic table of resources
- We lack sufficient data, but limits to non-renewable resources are quite possible in the next decade or two
- As we deplete ore in the ground, our cities are becoming the mines of the future. We need to learn how to be better urban miners

Crude Steel Production in China and India, 1945-2005