Center for Industrial Ecology
Yale School of Forestry & Environmental Studies

Determining the Criticality of Materials

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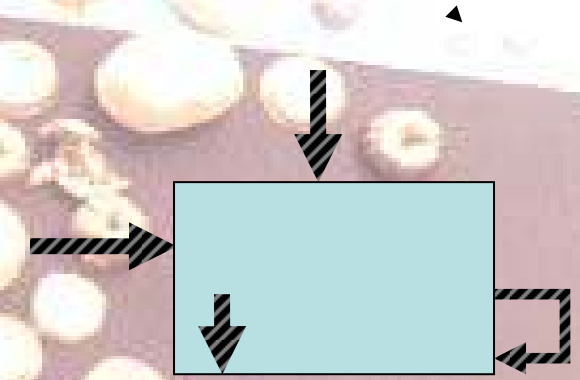
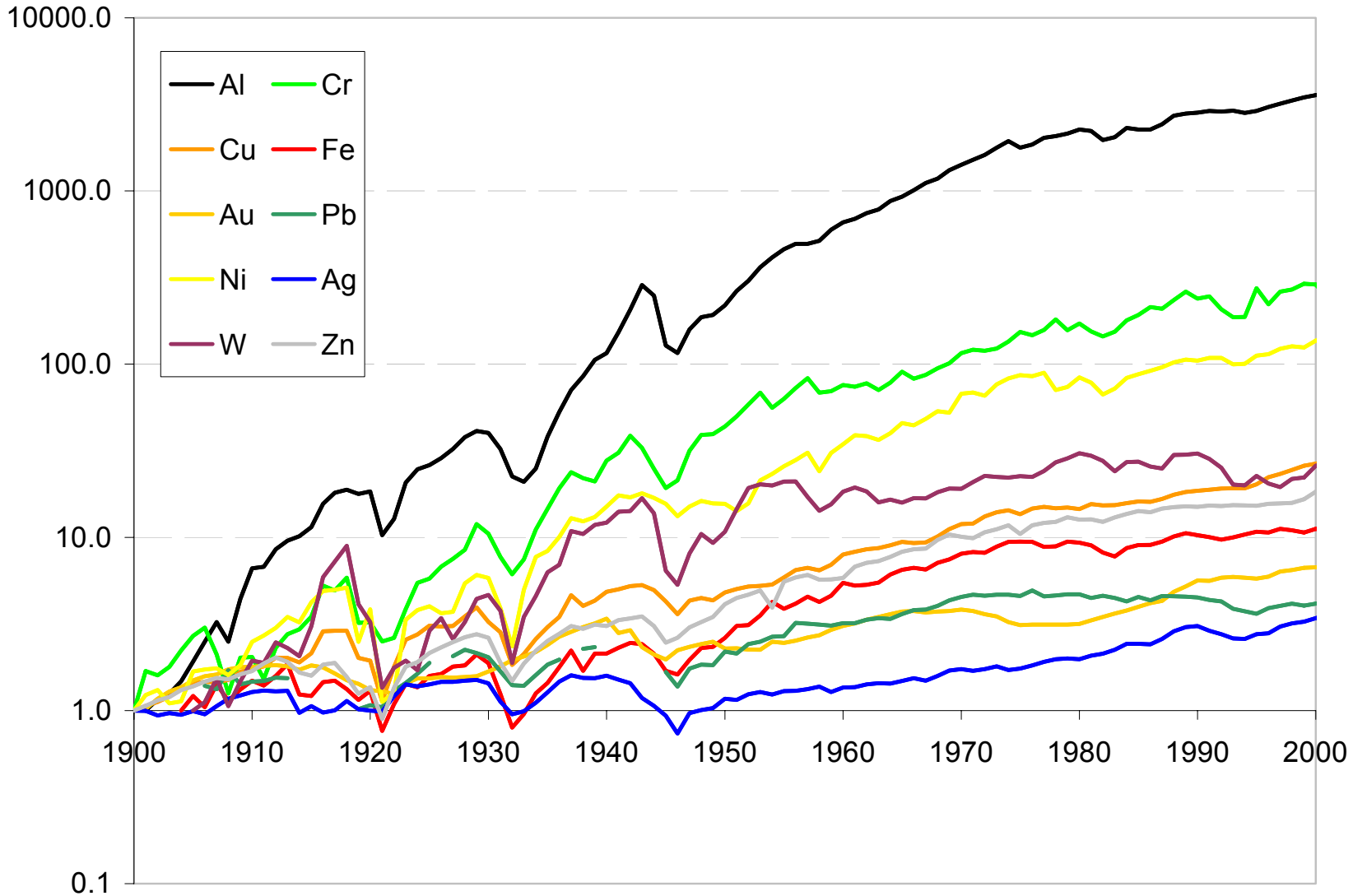
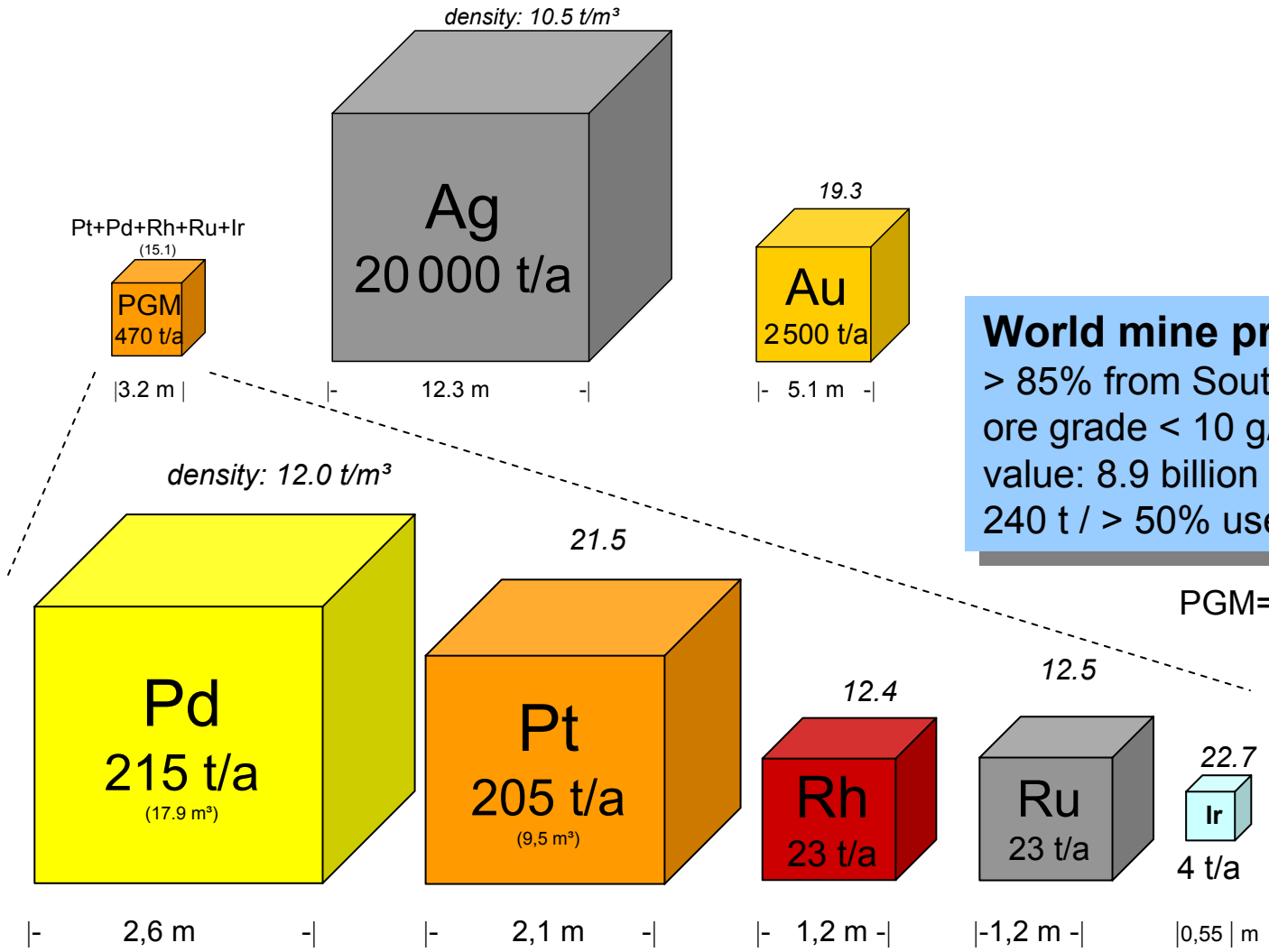


Global 20th Century Metal Use



The global annual mine production of precious metals could fit into a small warehouse



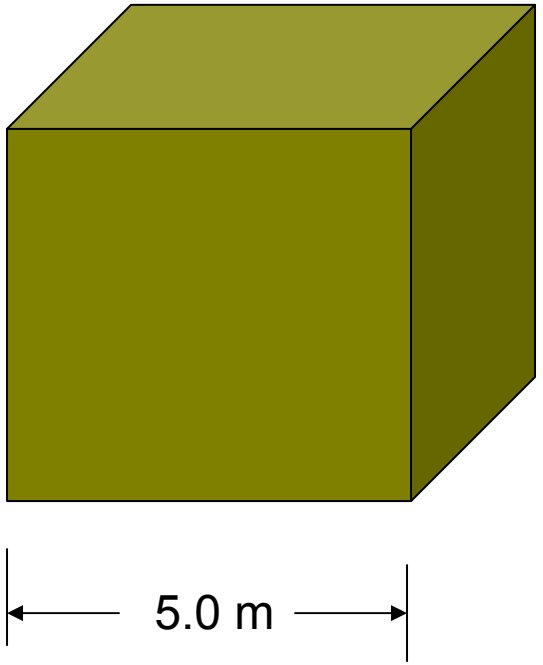
World mine production PGM:
> 85% from South Africa & Russia
ore grade < 10 g/t
value: 8.9 billion $ (at 2005 prices)
240 t / > 50% used for catalysis

PGM=Platinum Group Metals

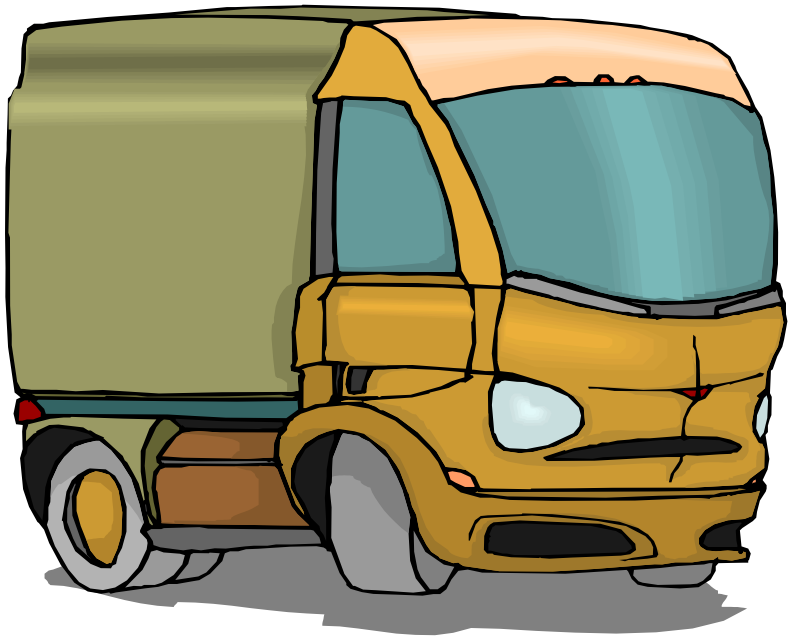
Figures for 2005

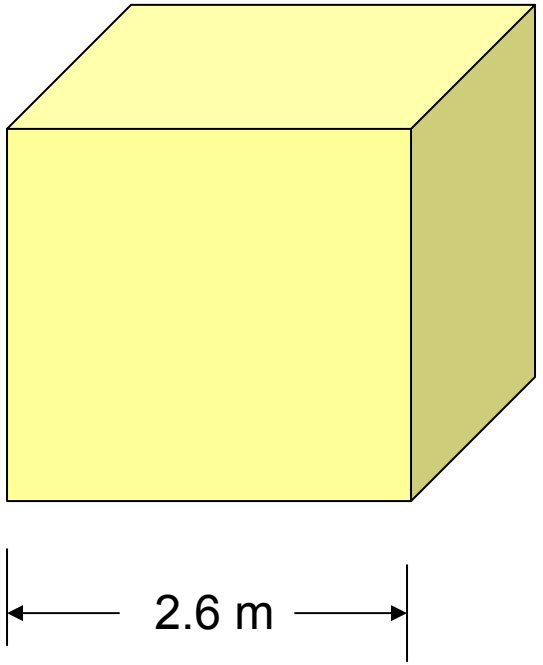
Annual average 2005*: Pd = 201 $/troz / 6.5 $/g; Pt = 897 / 28.8; Rh = 2053 / 66.0; Ru = 74 / 2.4; Ir = 169 / 5.4

The World's Annual Production of Terbium

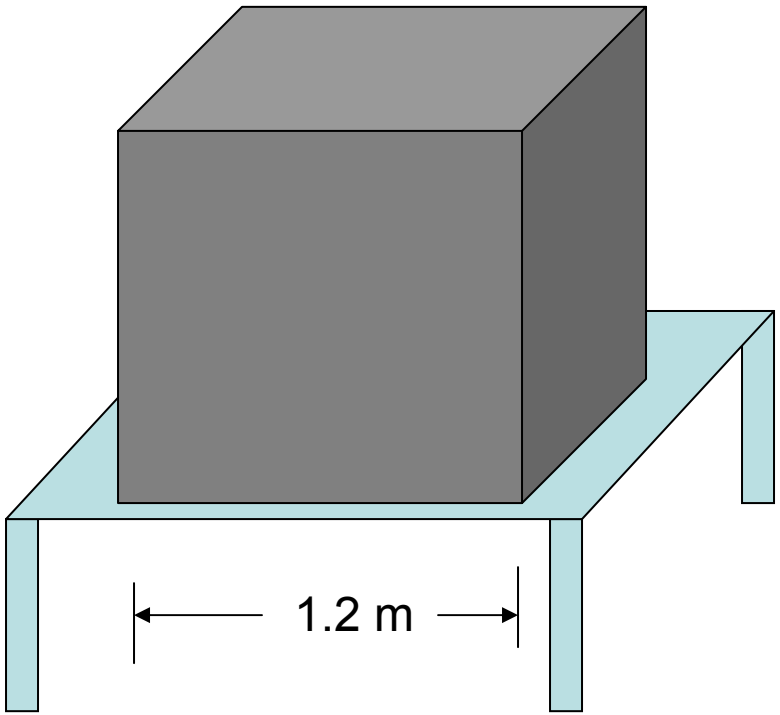


The World's Annual Production of Tellurium





The World's Annual Production of Rhenium



Research Questions Related to the Consideration of Critical Resources

- How much is known about the ways in which modern society uses metals?
- How much metal exists in the ground, in in-use stock, and in other reservoirs, and where is it located geographically?
- What factors other than absolute abundance may limit metal use?
- Should we “mine” tailings, slag, landfills?
- Are supplies of any metals of long-term concern and, if so, which ones?

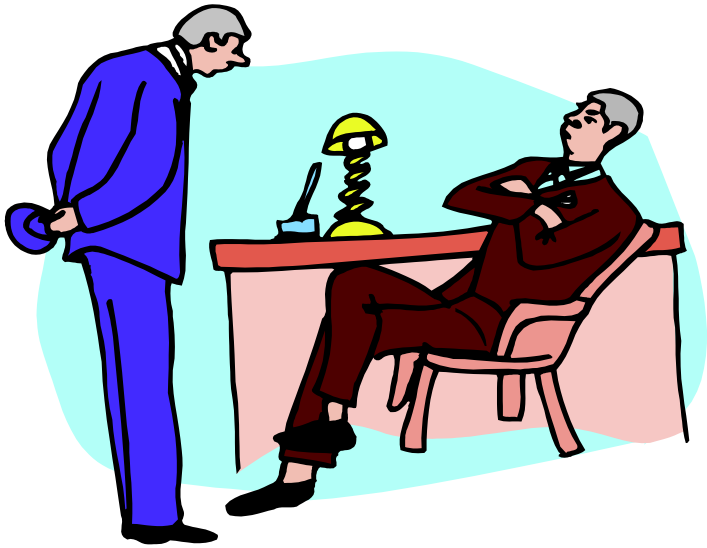
Important Questions for Corporations Related to the Consideration of Critical Resources

- Are supplies of any of the materials used in major products of possible long-term concern?
- Could resource constraints place major products in a “no-build” situation?
- Can innovative approaches to product design and recycling avoid resource availability problems?

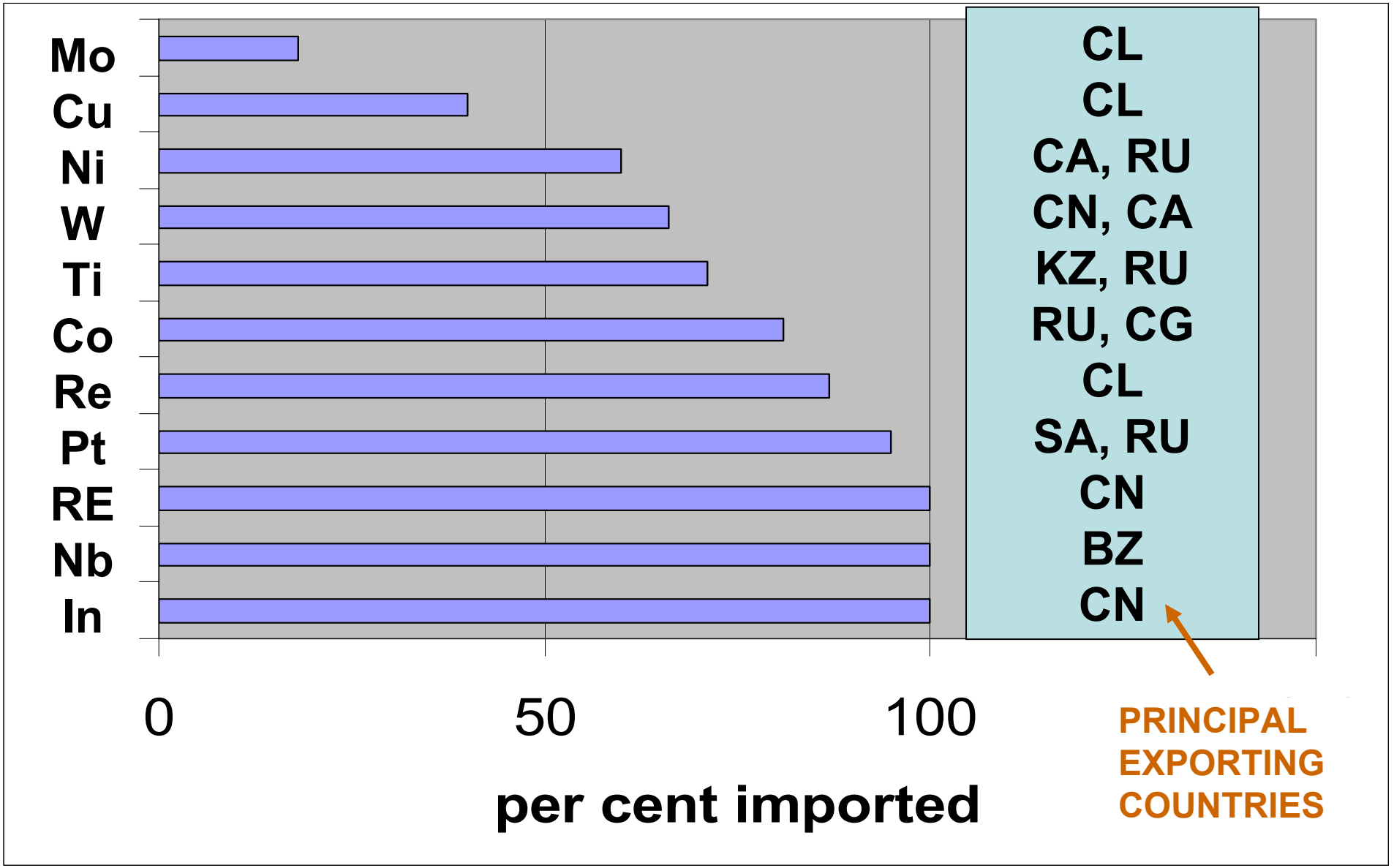
Evaluating the Criticality of Materials

The First Dimension of Criticality

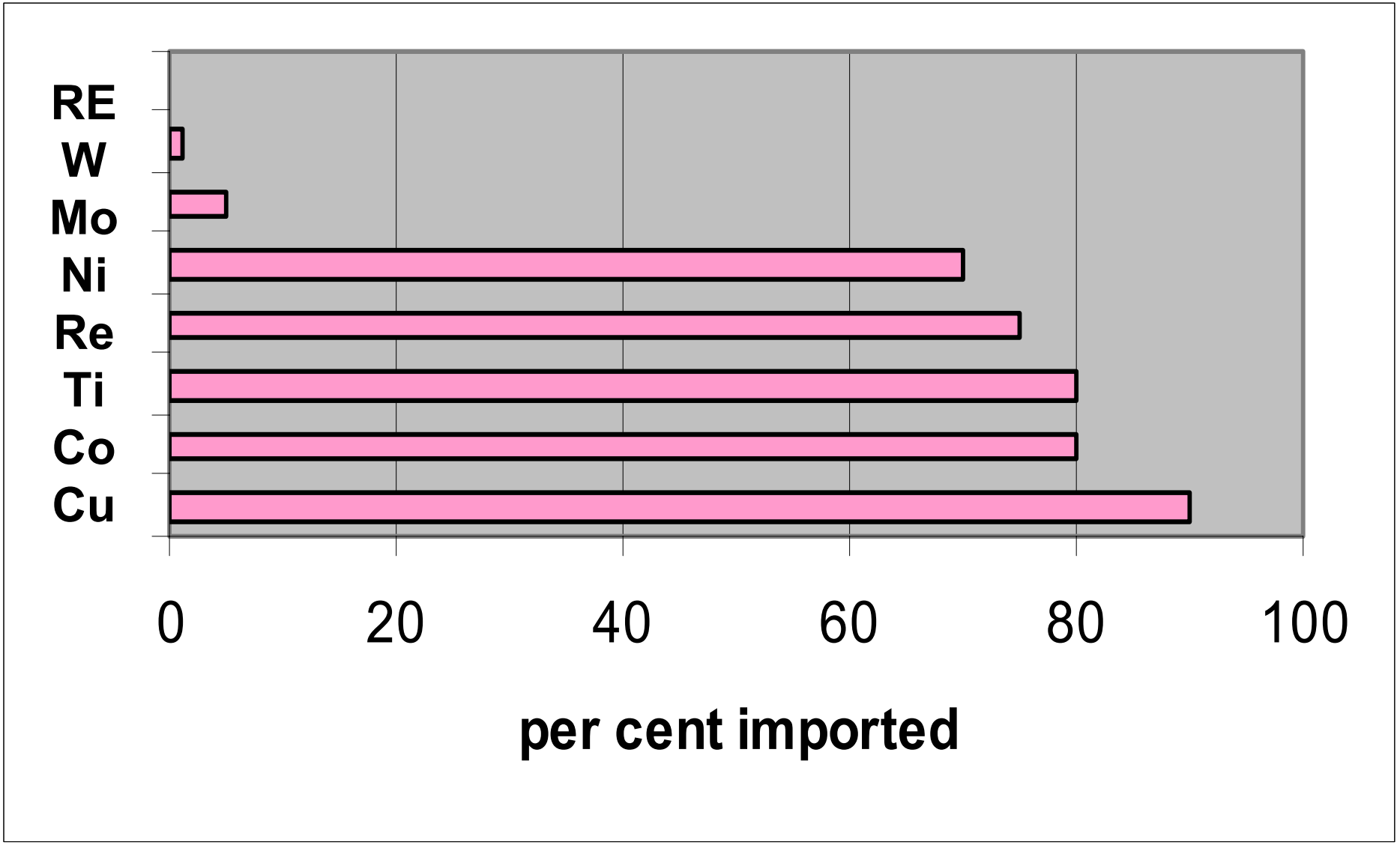
- The Supply Risk
  - **Geologic availability -- Technical availability**
  - **Regulatory availability -- Geopolitical availability**
  - **Social availability -- Market availability**



US Resource Dependencies

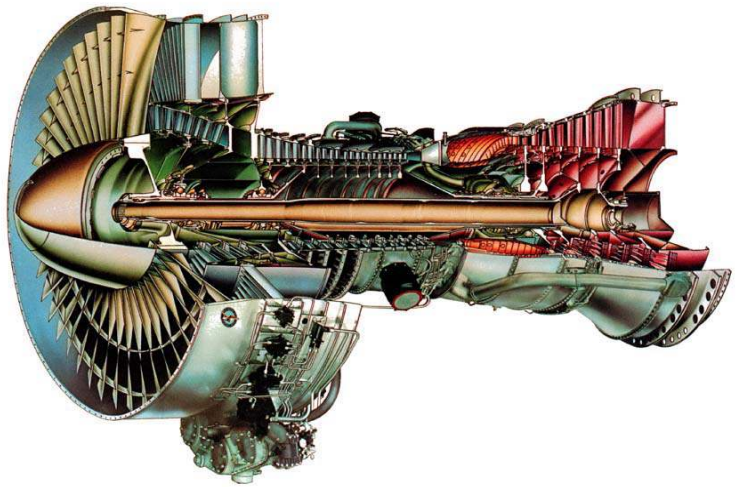


China Resource Dependencies



The Second Dimension of Criticality

- The Impact of Supply Restriction
  - **Prevents manufacture**
  - **Impedes product development**
  - **Influences profitability**

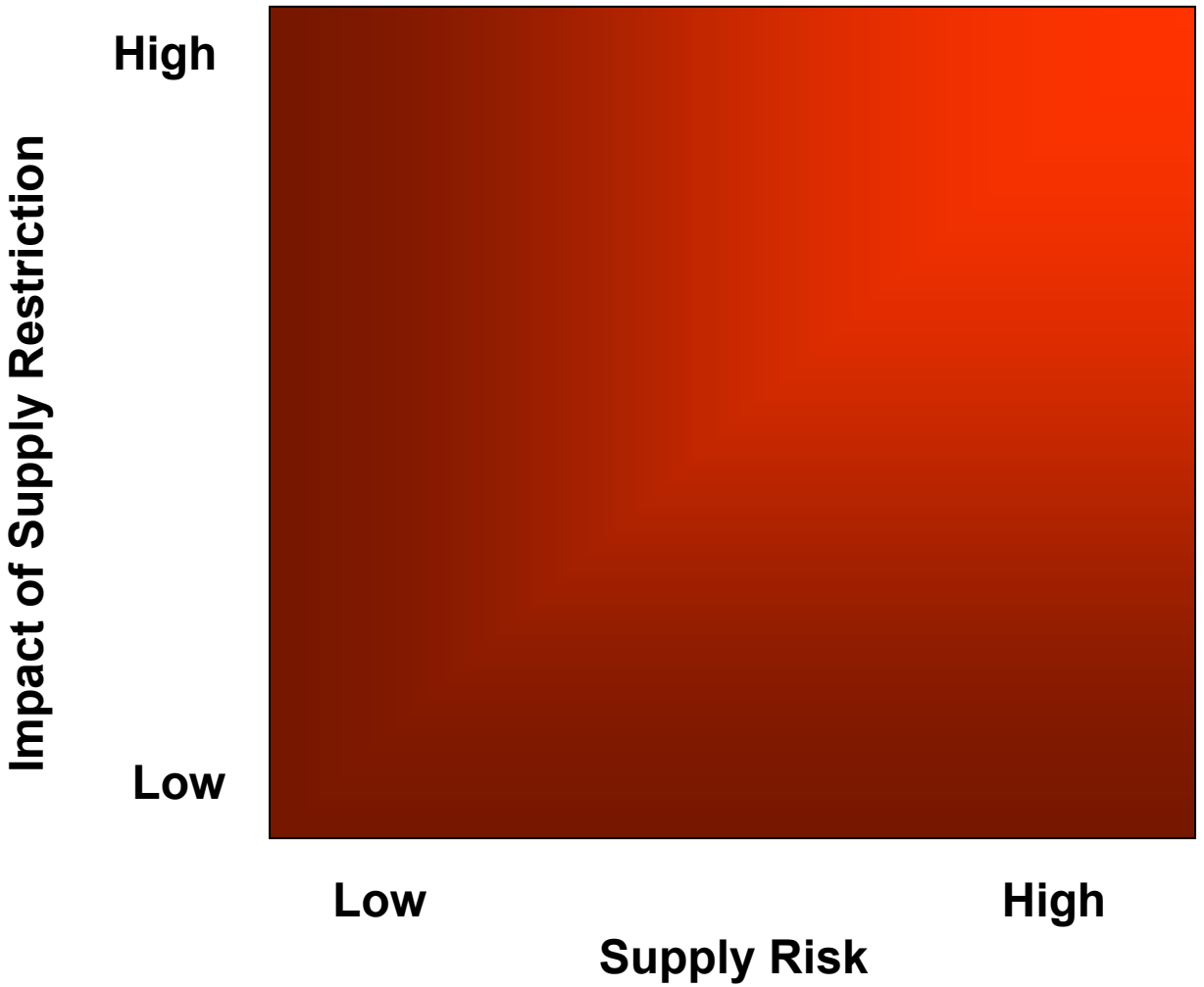


The Two Dimensions of Criticality

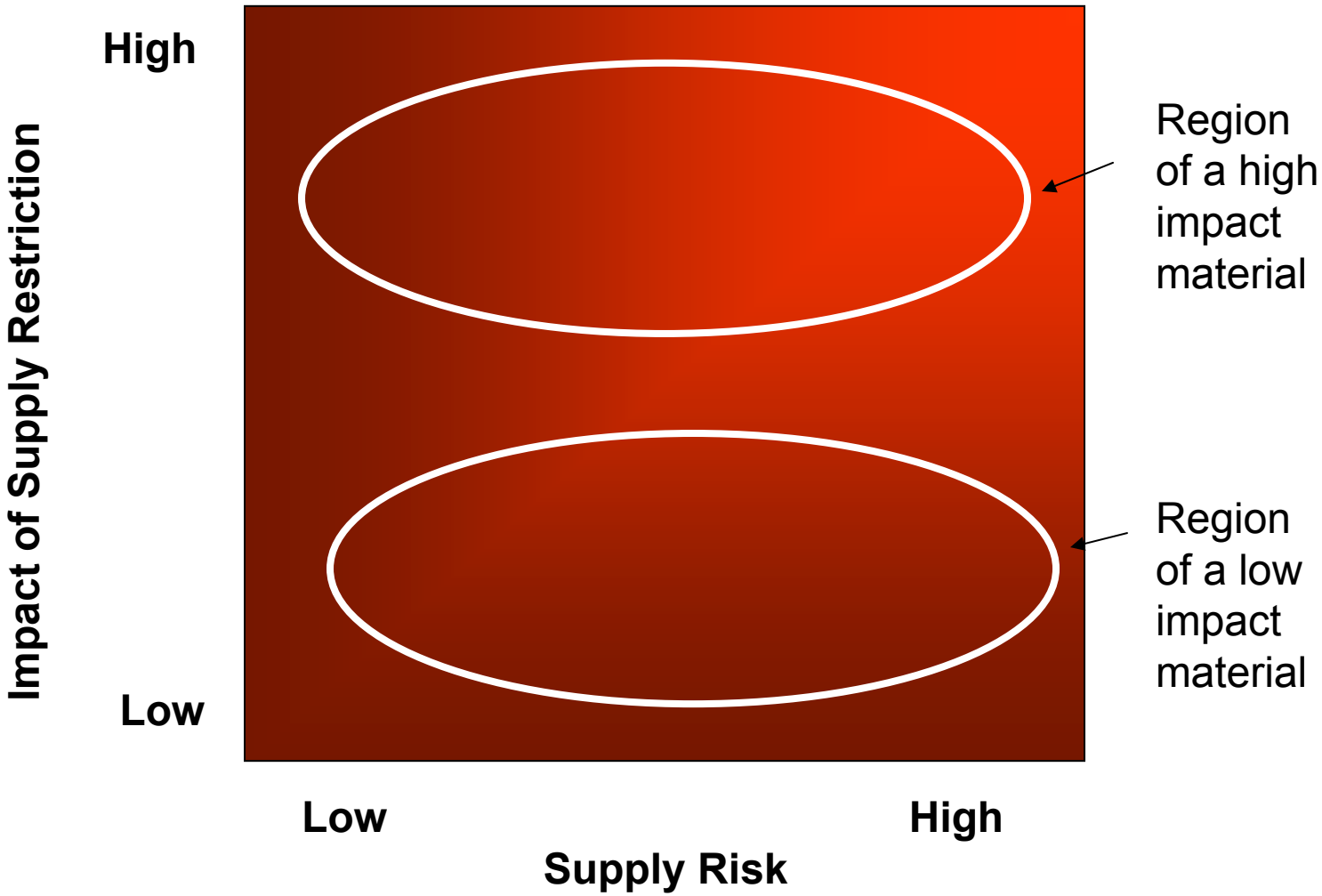
- The Impact of Supply Restriction
  - **Prevents manufacture**
  - **Impedes manufacture**
  - **Little effect on manufacture**

- The Supply Risk
  - **Geologic availability -- Technical availability**
  - **Regulatory availability -- Geopolitical availability**
  - **Social availability -- Market availability**

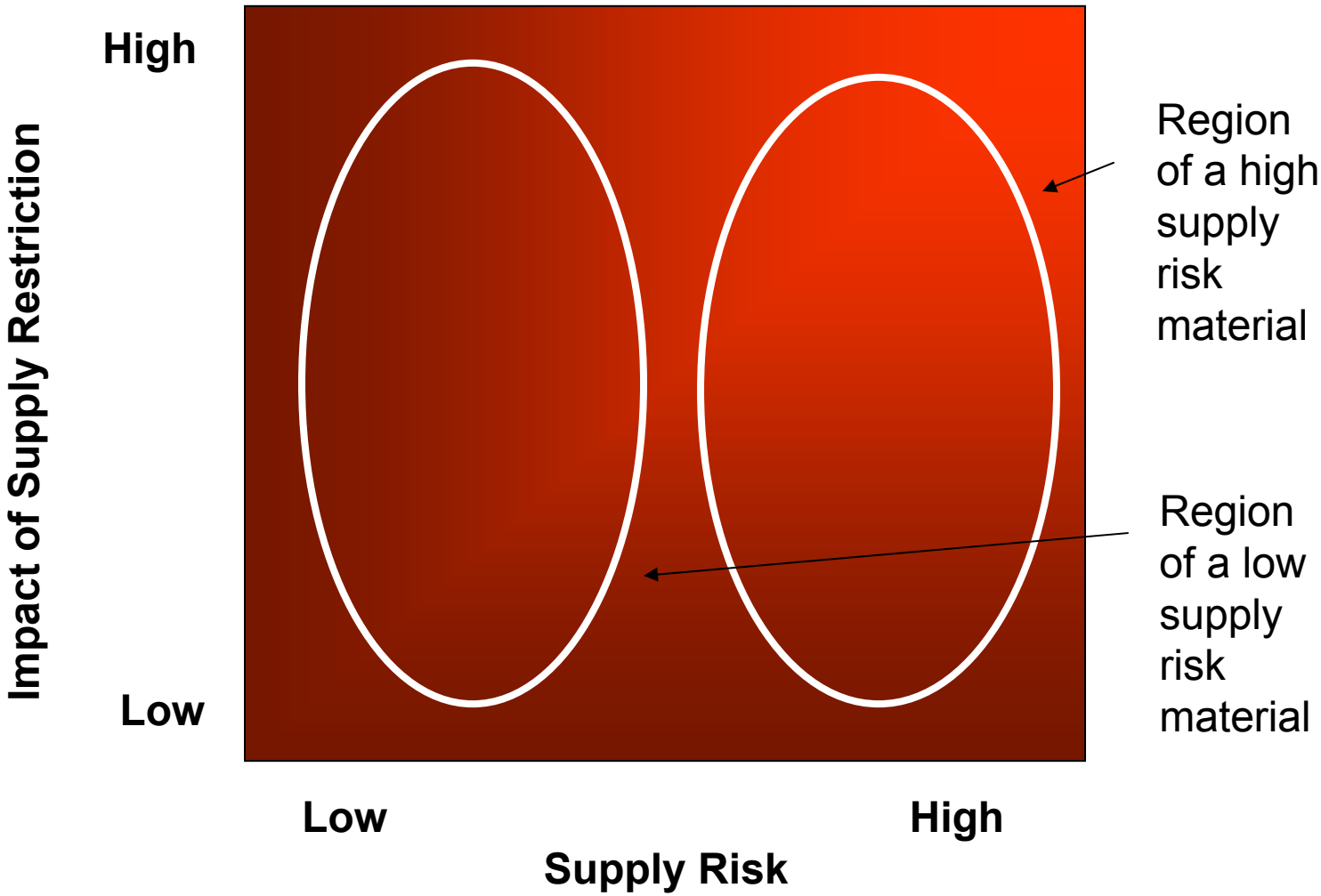
Determining a Material's Criticality



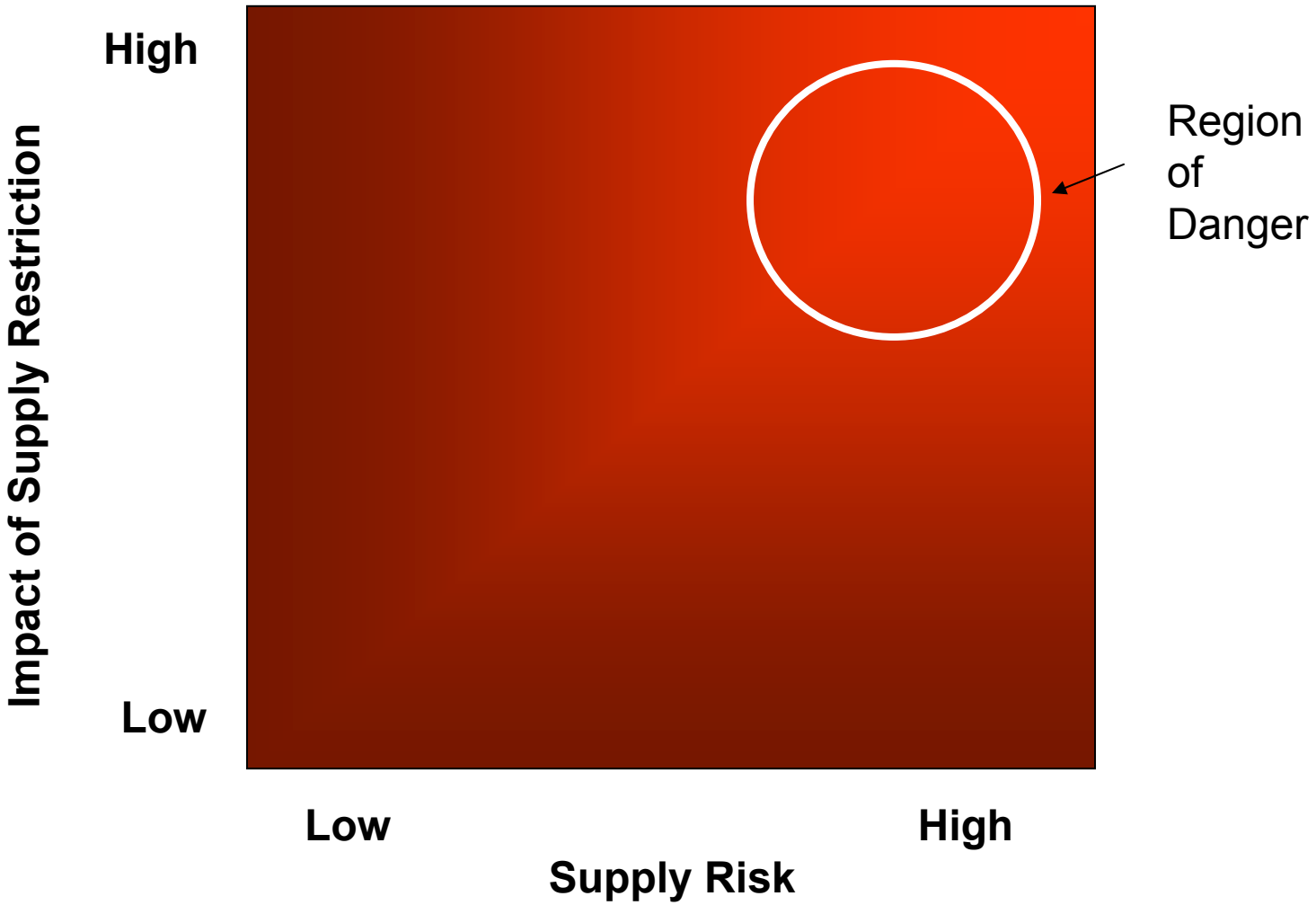
Locating a Product Material on the "Impact of Restriction" Axis



Locating a Product Material on the "Supply Risk" Axis



Identifying the “Region of Danger”



Data Challenges

- Ultimate sizes of resources (as opposed to the sizes of what is now or will soon be mined, i.e., the reserves) are quite poorly known
- The proportions of metals entering specific uses are rough estimates at best, because of data limitations
- Product designers are typically unaware of the criticality of a material, because no reputable published assessments are available

Final Messages

- For large or vital uses of materials, corporations and governments have the duty to evaluate materials criticality
- The criticality of a material depends on two factors: the impact of supply disruption and the supply risk
- Product designers should be well informed about the upper right corner of the criticality diagram, and should avoid it if possible
- Comprehensive recovery and reuse of materials and components minimizes criticality

Critical Mineral/Element - Platinum

Application: CO & Hydrocarbon Reduction in Catalytic Converters

Future: Fuel Cell Proton Exchange Medium

Substitutes: Gasoline Catalytic Converters – Palladium

Diesel Catalytic Converters – None

Fuel Cells - None

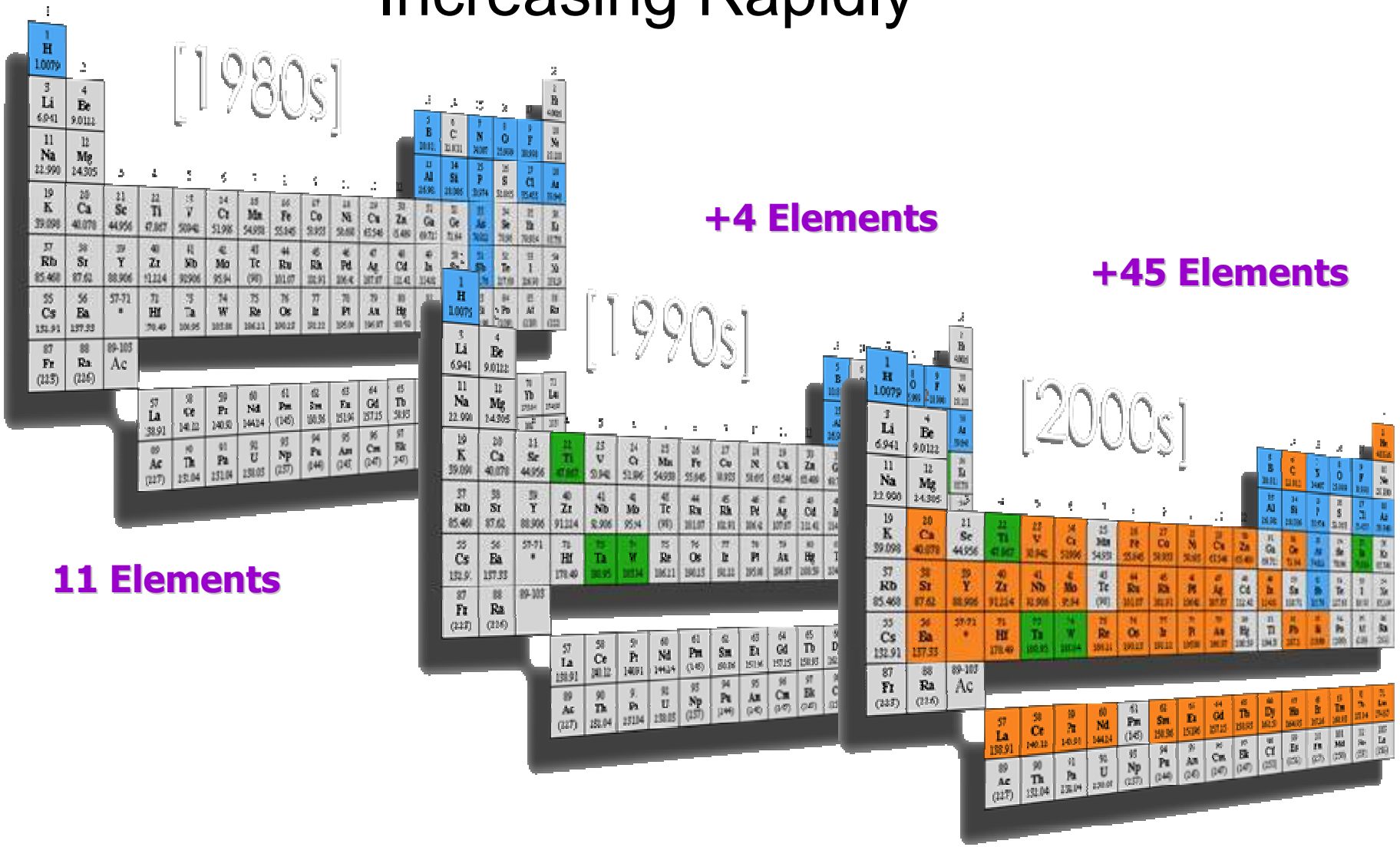
Nature of Criticality:

Primary Concern: "No Build Condition"

Secondary Concern: Price ($1,200/Troy oz. 2/20/07)

Ivan Herring, General Motors Corp., March 7, 2007

Si Technology: The Complexity is Increasing Rapidly



Source: T. McManus, Intel Corp., 2006