



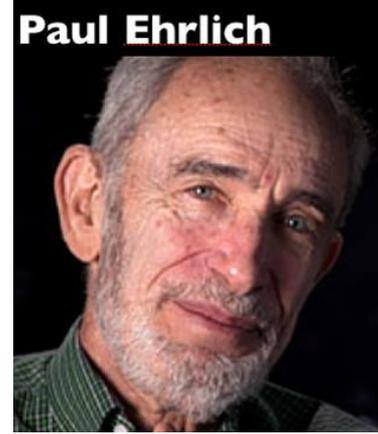
Critical Materials Institute
AN ENERGY INNOVATION HUB

Critical Materials, Past, Present and Future

Alex King



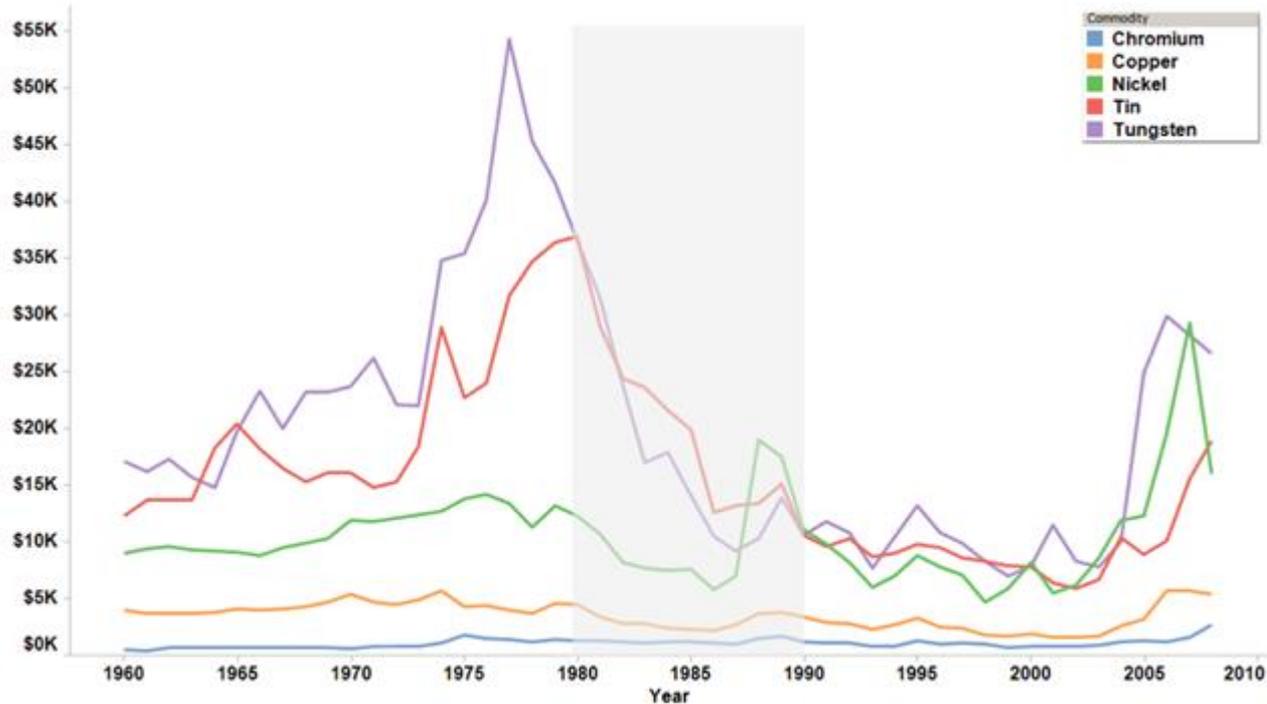
The Ehrlich-Simon Bet 1980



- Paul Ehrlich (professor of Population Studies at Stanford University)
 - Metal prices will be higher in 10 years because of ever-increasing demand driven by relentless population growth.
- Julian Simon (professor of Business Administration at the University of Maryland)
 - Prices will be lower because technology will make the extraction of the metals cheaper, or we will find alternatives for those that are really running out.

Who won?

- Ehrlich and his colleagues selected a \$1000 “market basket” comprising \$200-worth of each of five different metals, at 1980 prices.



- In 1990, Ehrlich gave Simon a check for \$576.07, representing the decline in value of the basket.

Long-term trends

Metal detector

3

The Economist industrial commodity-price index, real* \$ terms, 1845-50=100

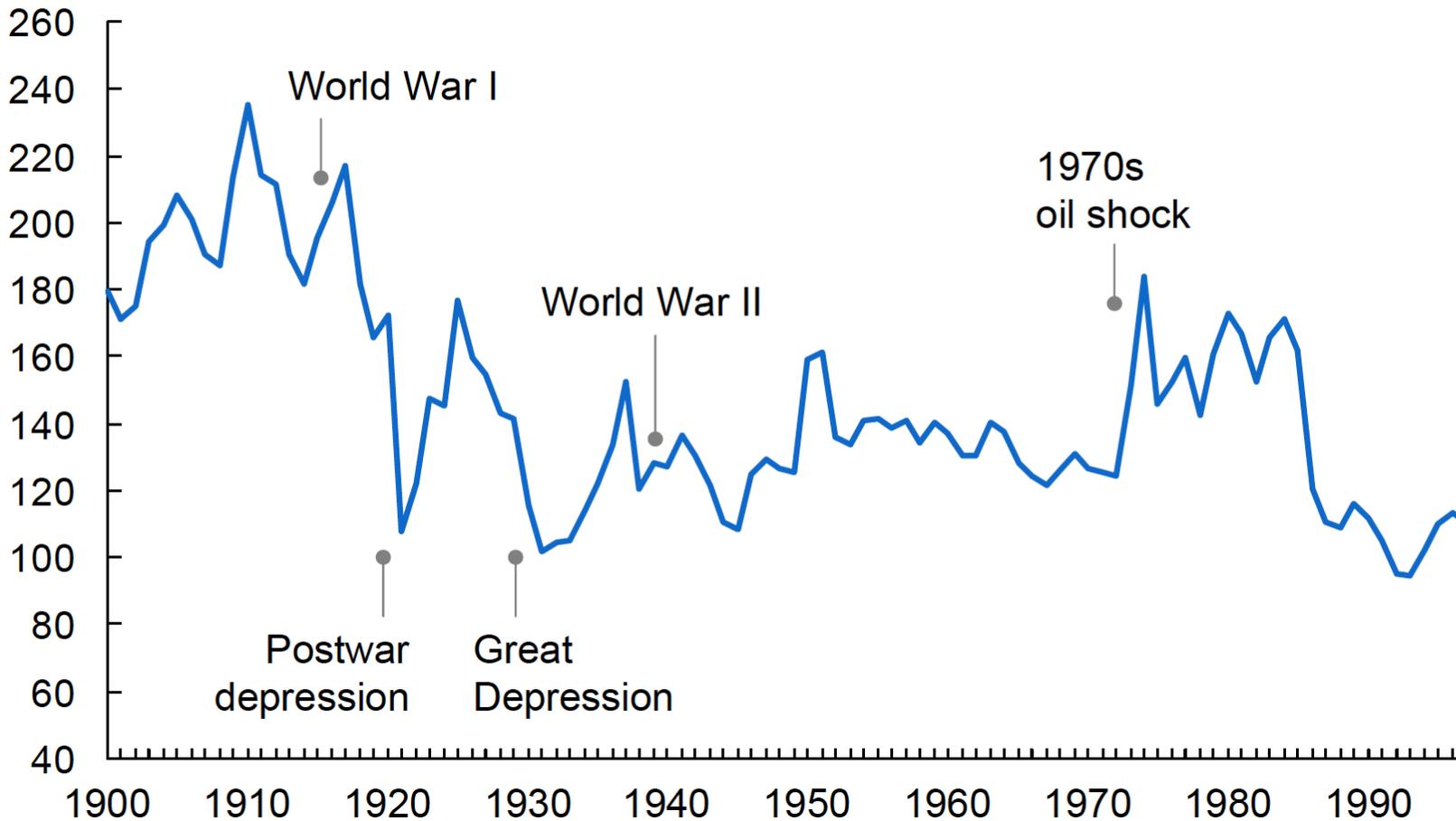


Sources: *The Economist*; Thomson Reuters

*Adjusted by US GDP deflator

Is there a “hockey-stick” effect?

MGI Commodity Price Index (years 1999–2001 = 100)¹



Source: McKinsey Global Institute



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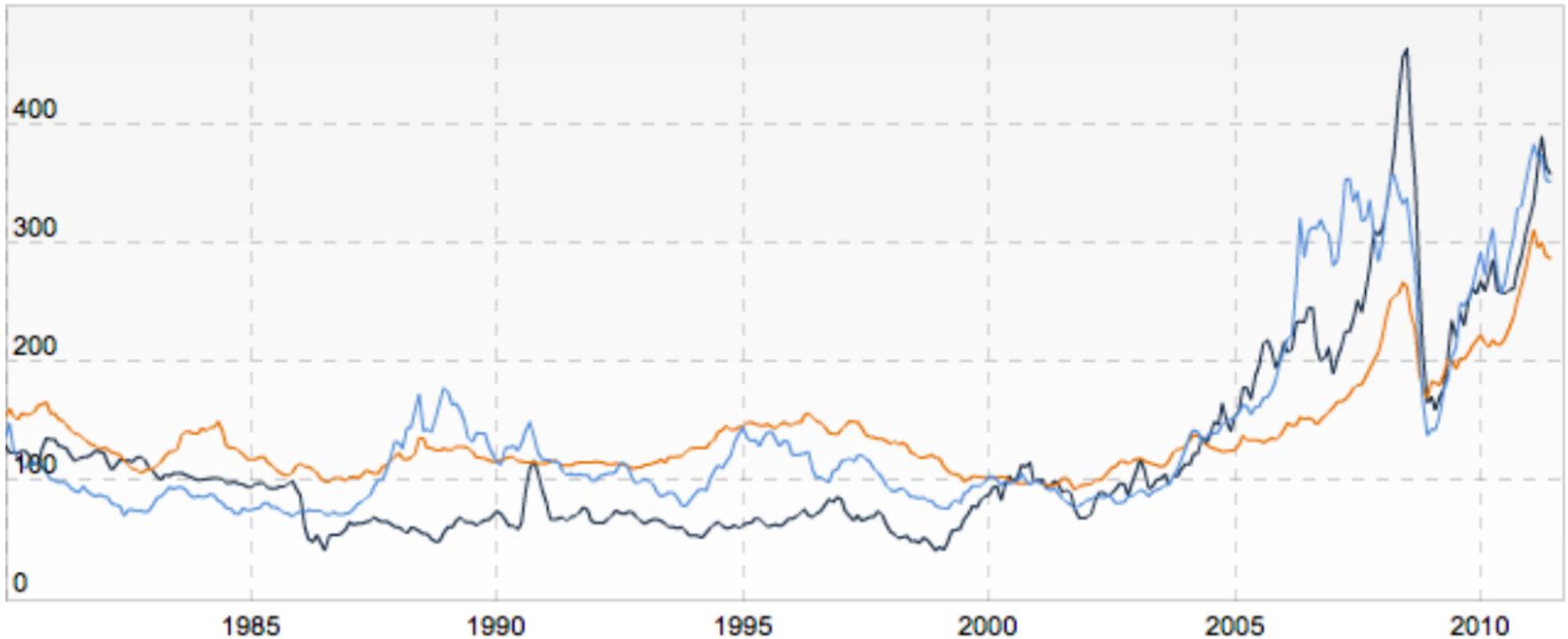
Is there a “hockey-stick” effect?

Major Price Indices

(Indices of Nominal US\$ Prices (2000=100))

● Energy ● Metals ● Agriculture

Jan 1980 - Sep 2011

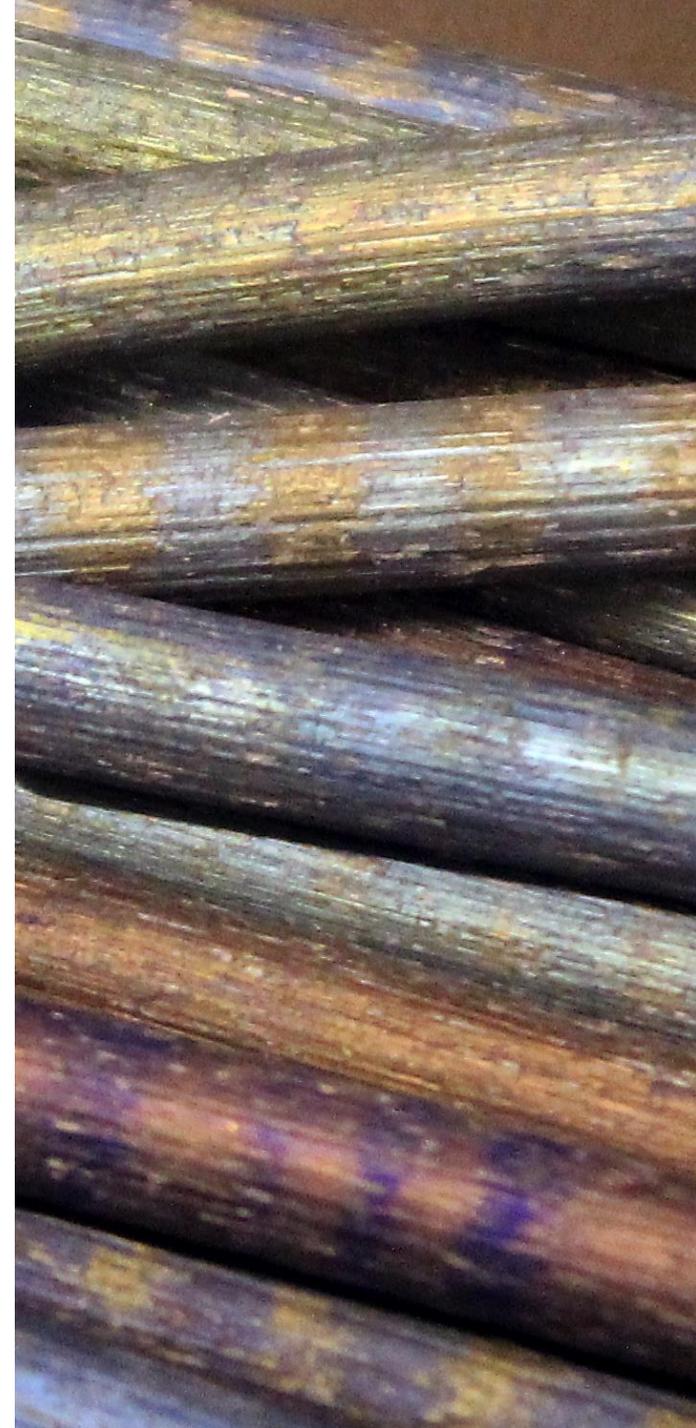


Source: World Bank

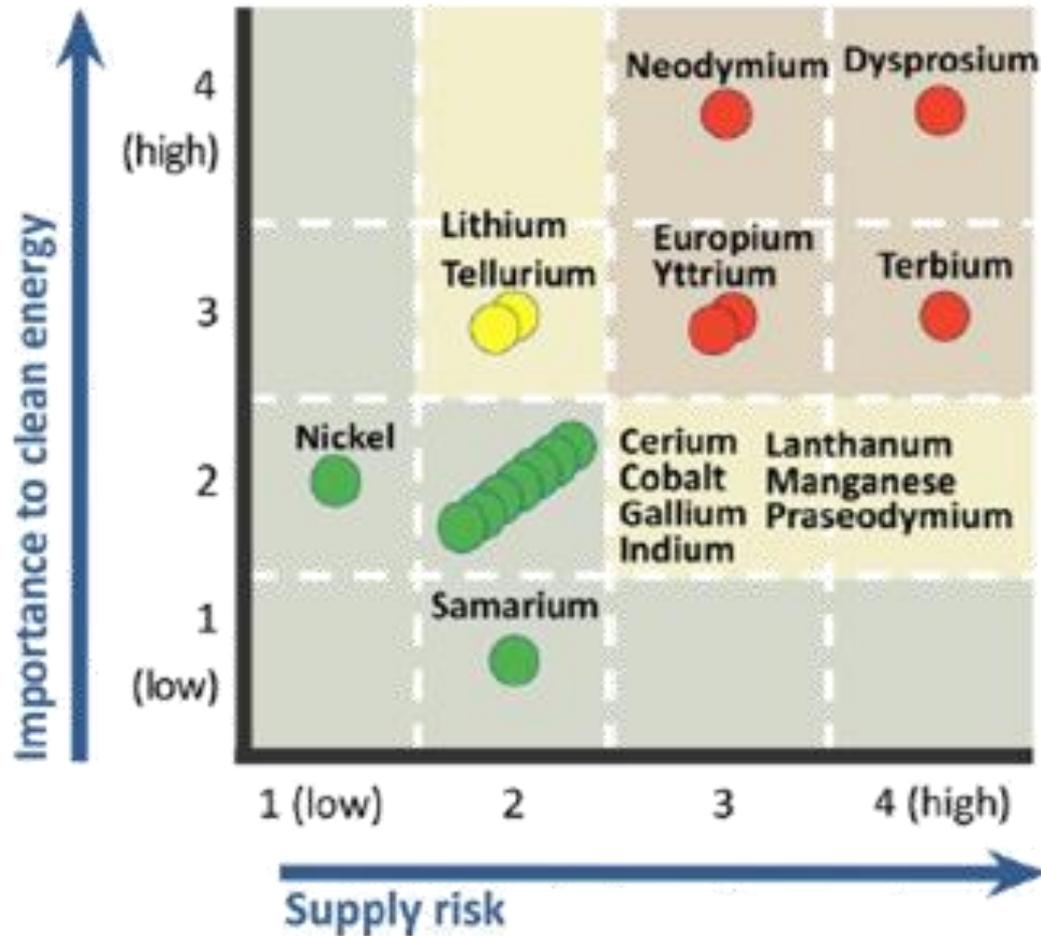


What is a “Critical Material?”

- Any substance used in technology that is subject to supply risks, and for which there are no easy substitutes.
- Or, in plain English – stuff you really need but can’t always get.
- The list of materials that are considered critical depends on who, where and when you ask.
- CMI focuses on clean energy technologies, in the US, over the next 10 to 15 years.

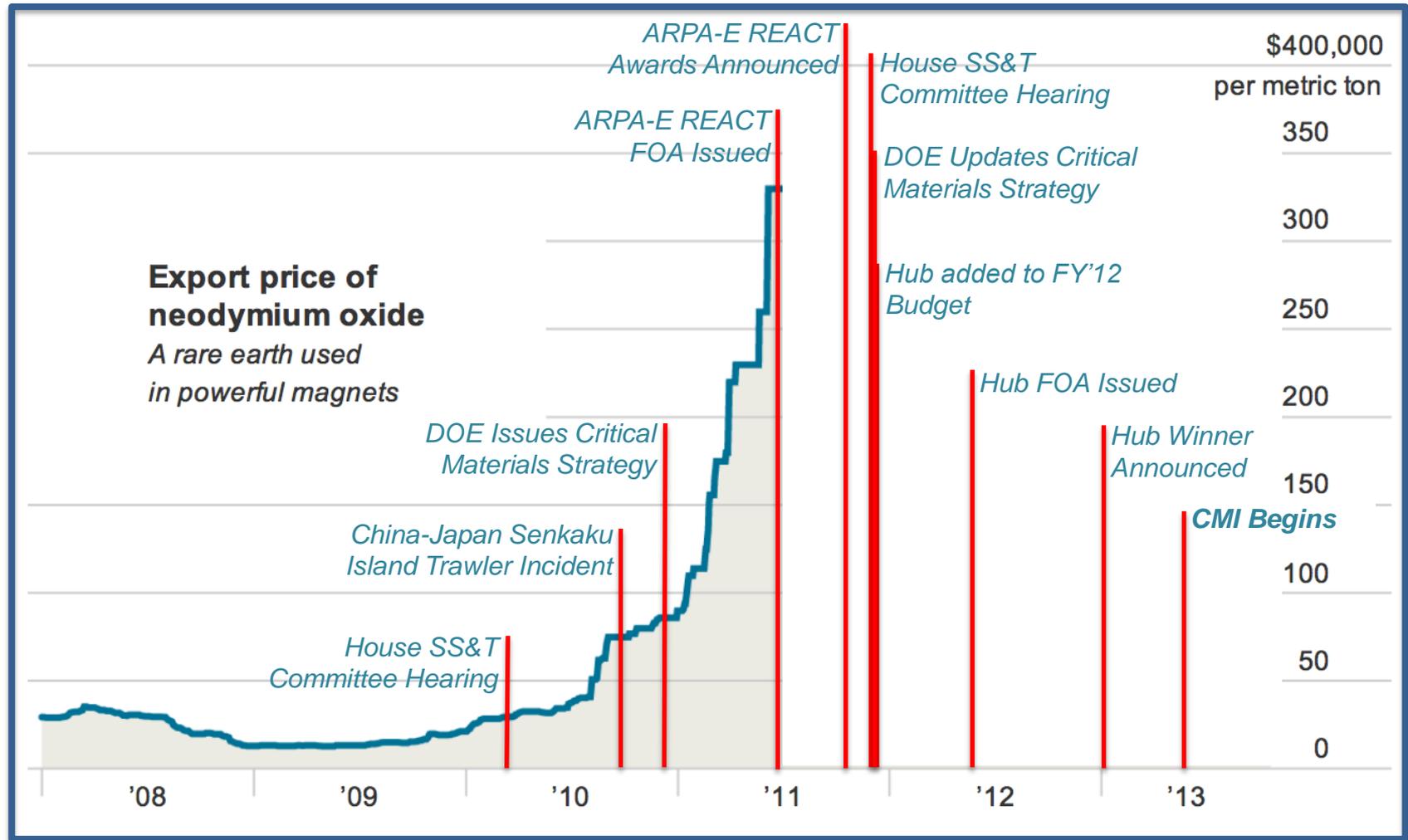


How is criticality assessed?



DOE Medium Term Outlooks: 2015 – 2025

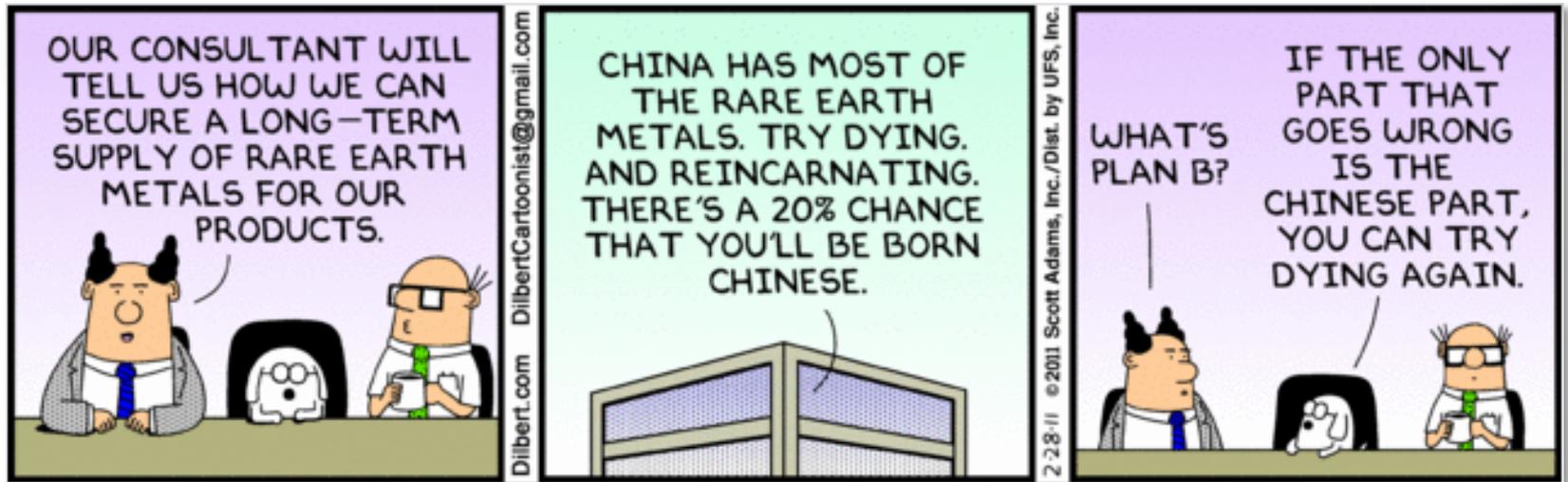
CMI was created in response to a crisis rather than an opportunity



Price Graphic: New York Times, 10-22-2013

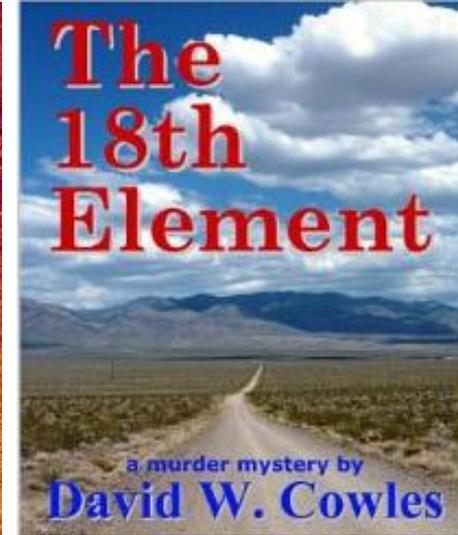
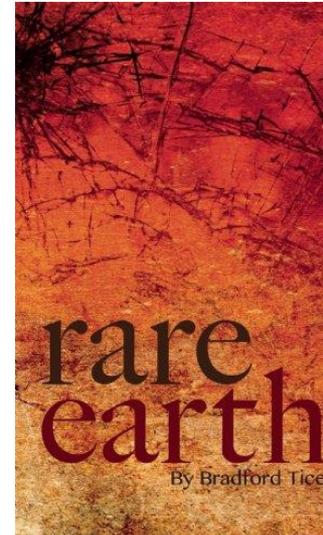
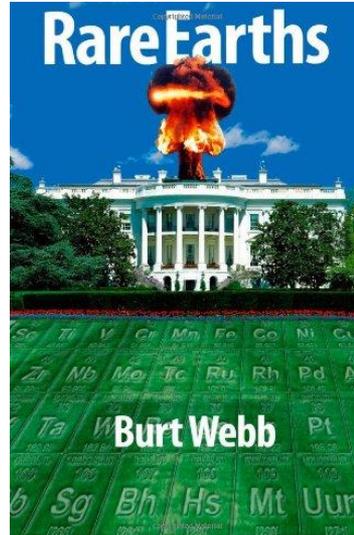
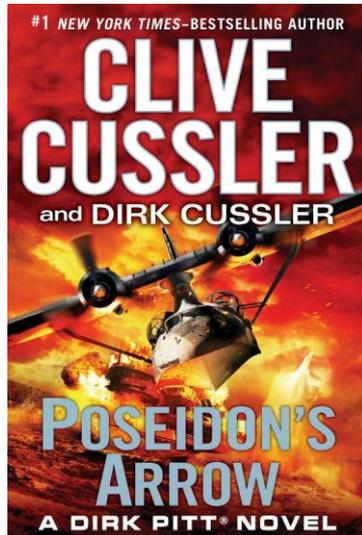
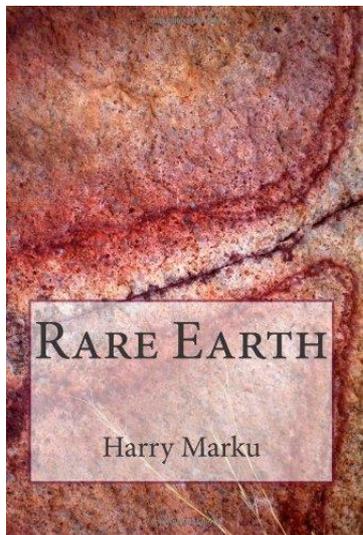
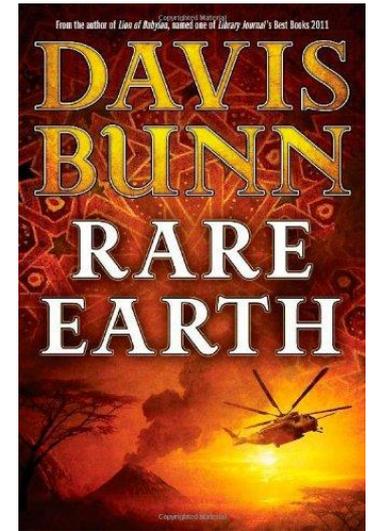
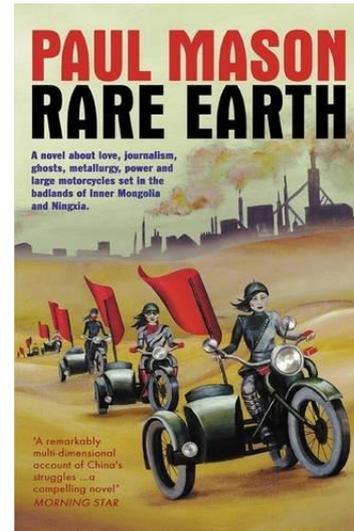
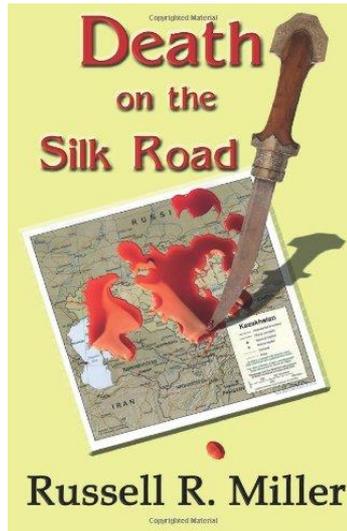
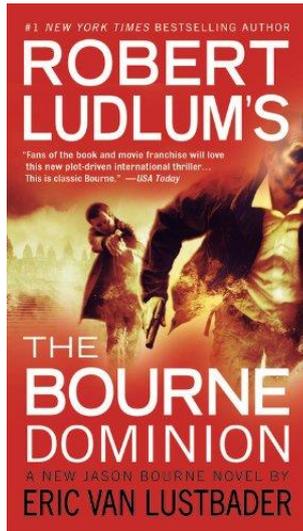
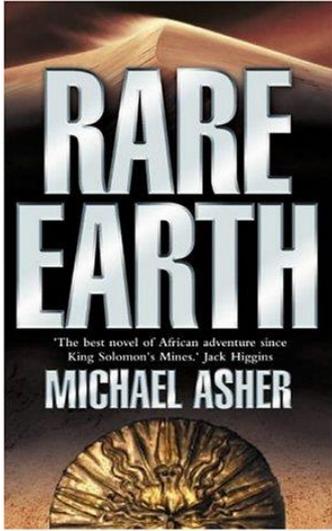


Cul de Sac, August 7, 2010



Dilbert, February 28, 2011

The hottest new literary sub-genre?

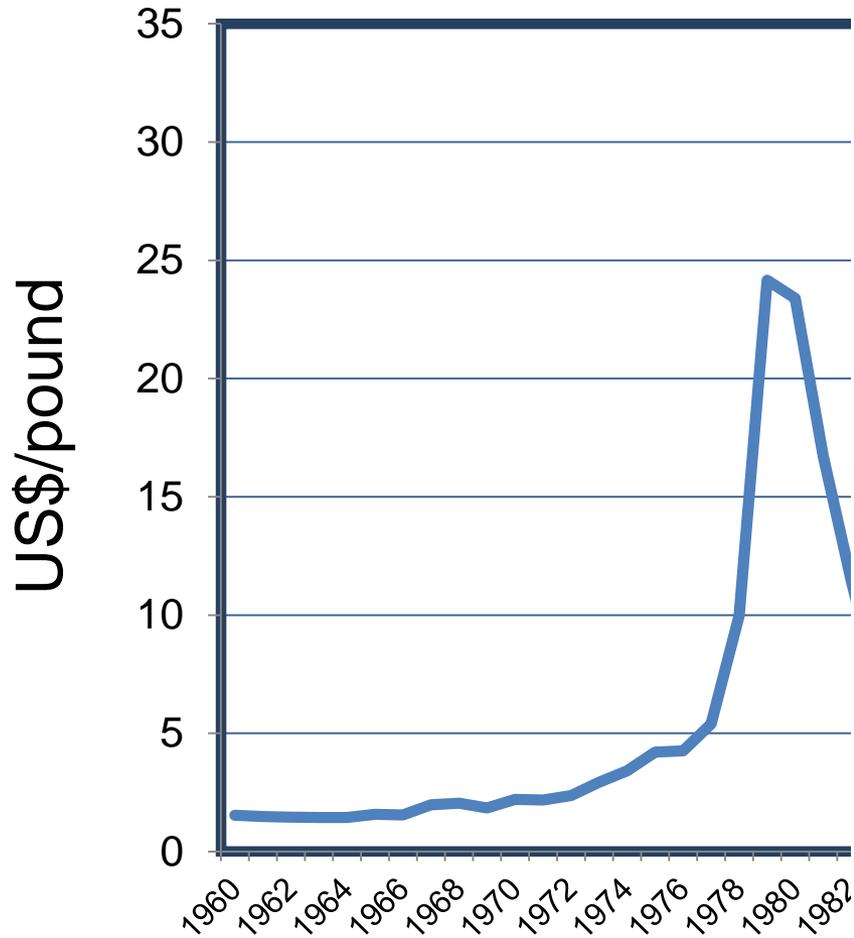


Corruption and Intrigue in Washington...

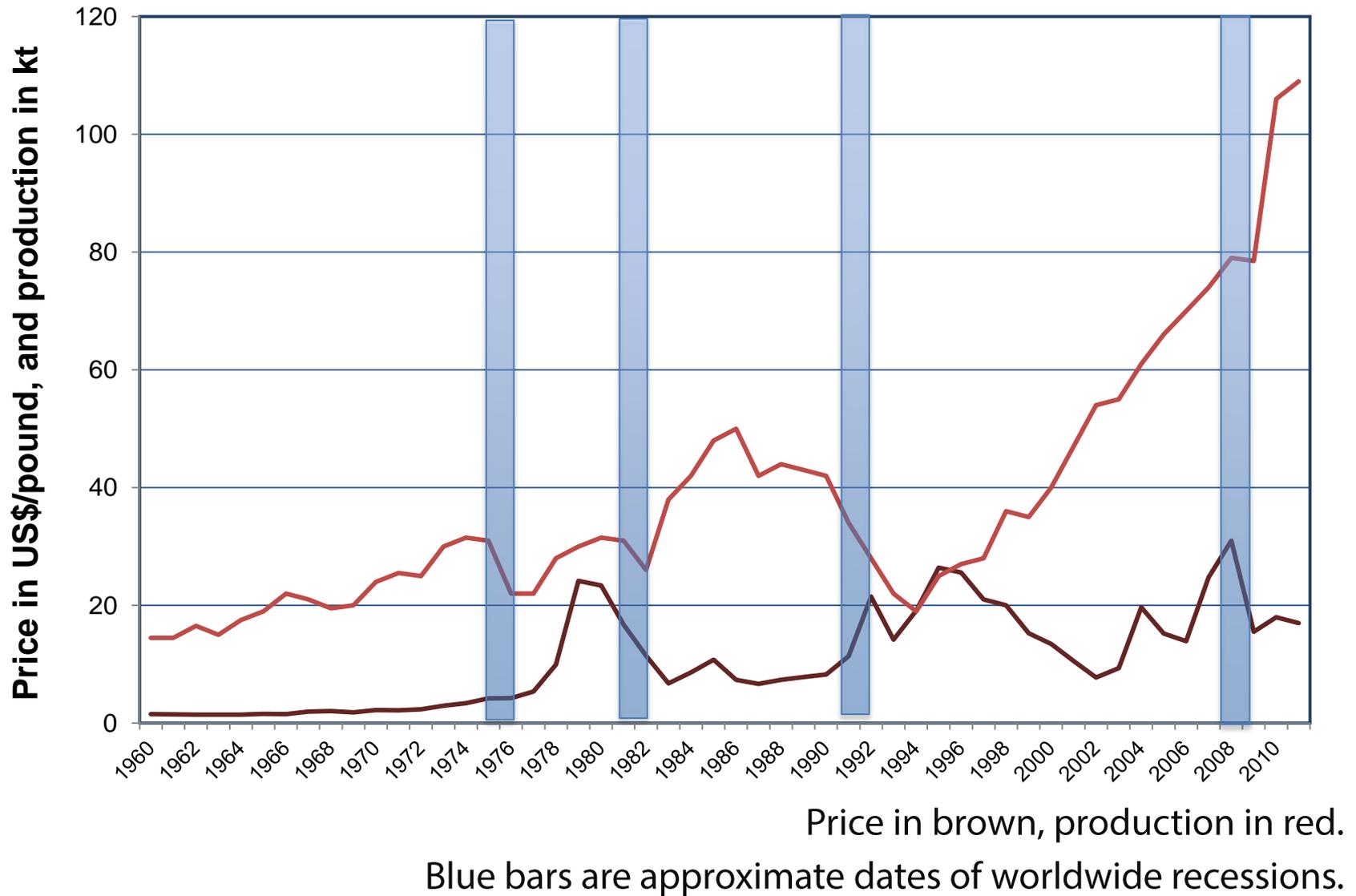
In one of many subplots, Chinese billionaire Xander Feng, is in a joint-venture, rare-earths mining operation with U.S. power plant billionaire Raymond Tusk.



Annual Average Cobalt Prices



Cobalt price and production



Critical Materials are Not New



- “The stone age did not end because we ran out of stones” – Steven Chu.



- The copper age replaced the stone age because copper was better for some things.



- The bronze age replaced the copper age because bronze was better than copper.



- But the bronze age was not replaced by the iron age. It ended because copper became unavailable.

Iron vs. Bronze, 1200 BC

- **Processing**
 - Bronze requires lower temperatures
- **Hardness**
 - Bronze is better, because no effective hardening mechanisms are yet available for iron.
- **Corrosion**
 - Bronze is better
- **Cost**
 - Iron is nine times more expensive than gold



The Bronze Age Collapse

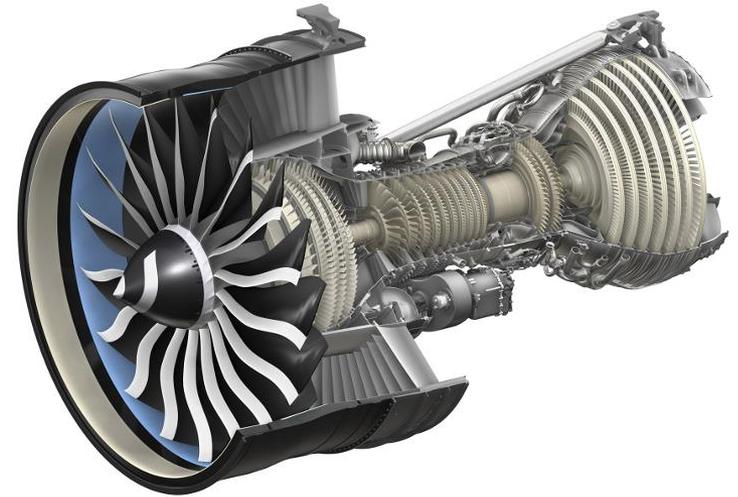
~1200 BC

- **Bronze becomes unavailable**
 - Possibly because Cyprus is overtaken by war, making copper inaccessible.
- **Results**
 - Collapse of trade; collapse of civilization
 - Strengthening of Egypt, which found alternative sources in Africa
 - Eventual emergence of the iron age
- **Responses include**
 - Recycling
 - Source Diversification
 - Materials Substitution



Materials criticality is affecting us *today*

- Jet engine manufacturers, including CMI partner GE, have had to deal with shortages of rhenium.
 - <http://www.gereports.com/engineering-ways-to-reduce-the-rare-metal-rhenium-in-jets/>
- A major disk-drive manufacturer came within one week of shutting down production for lack of Nd-Fe-B magnets.



Materials criticality is affecting us *today*



- Loudspeaker manufacturers have been severely impacted by magnet price increases.



- Tesla Motors may be forced to reduce production because of short supplies of Li-ion batteries.

– http://wheels.blogs.nytimes.com/2013/09/06/as-it-increases-production-tesla-worries-about-battery-supply/?_r=0

Materials criticality is affecting us *today*

- The target date for transition to high-output T5 fluorescent lamps has been delayed by two years because manufacturers claim that there is a shortage of Eu and Tb for the phosphors.
- Utility-scale wind turbine installations are overwhelmingly gearbox-driven units, despite the high failure-rate of the gearboxes, because of the cost and unavailability of Nd and Dy required for direct-drive units.



Materials criticality is affecting us *today*

- Even military hardware is occasionally being sourced from China, because of the lack of a domestic supply-chain for certain key materials.

<http://www.reuters.com/article/2014/01/03/us-lockheed-f-idUSBREA020VA20140103>



The screenshot shows a Reuters news article. At the top is the Reuters logo and navigation menu. The article title is "Exclusive: U.S. waived laws to keep F-35 on track with China-made parts". Below the title is the byline "BY JOHN SHIFFMAN AND ANDREA SHALAL-ESA" and the location "WASHINGTON | Fri Jan 3, 2014 3:45pm EST". There are social media sharing buttons for Twitter (371), LinkedIn (51), Facebook, and Email. Below the text is a photograph of an F-35 fighter jet on the deck of an amphibious assault ship, with crew members visible around it. The caption reads: "The flight deck crew secures an F-35B Lightning II aircraft aboard the amphibious assault ship USS Wasp following testing in this handout photo taken off the coast of North Carolina August 24, 2013. CREDIT: REUTERS/U.S. NAVY/HANDOUT". At the bottom of the screenshot, there is a paragraph of text: "(Reuters) - The Pentagon repeatedly waived laws banning Chinese-built components on U.S. weapons in order to keep the \$392 billion Lockheed Martin Corp F-35 fighter program on track in 2012 and 2013, even as U.S. officials were voicing concern about China's espionage and military buildup."

Most solutions take effect “*tomorrow*”

- Mine development, *where there is a known resource*, takes at least 10 years.
- Deployment of substitute materials, *when there is an existing option*, takes an average of 4 years.
- Development and deployment of *new* substitute materials takes an average of 18 years.
 - Nd-Fe-B is a notable counterexample: four years from need to deployment.

Two Universal Grand Challenges

- **Starting sooner**
 - We need to anticipate criticality, not just respond to it.
- **Working faster, faster**
 - 200 years at ~1000 BC
 - 20 years at ~ 2000 AD
 - **2 years by ~ 5000 AD?**

Three Rare Earth Grand Challenges

- **Separations**

- We shouldn't feel so bad about this. Nature does it badly, too.



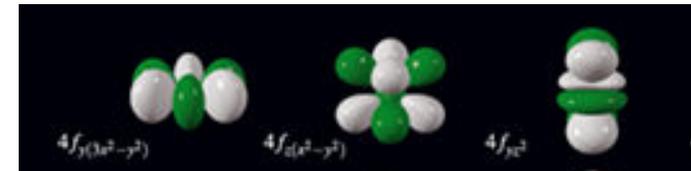
- **Smelting**

- So polluting that it is only done in China.



- **Understanding the f-electron**

- Your theories are no good here.



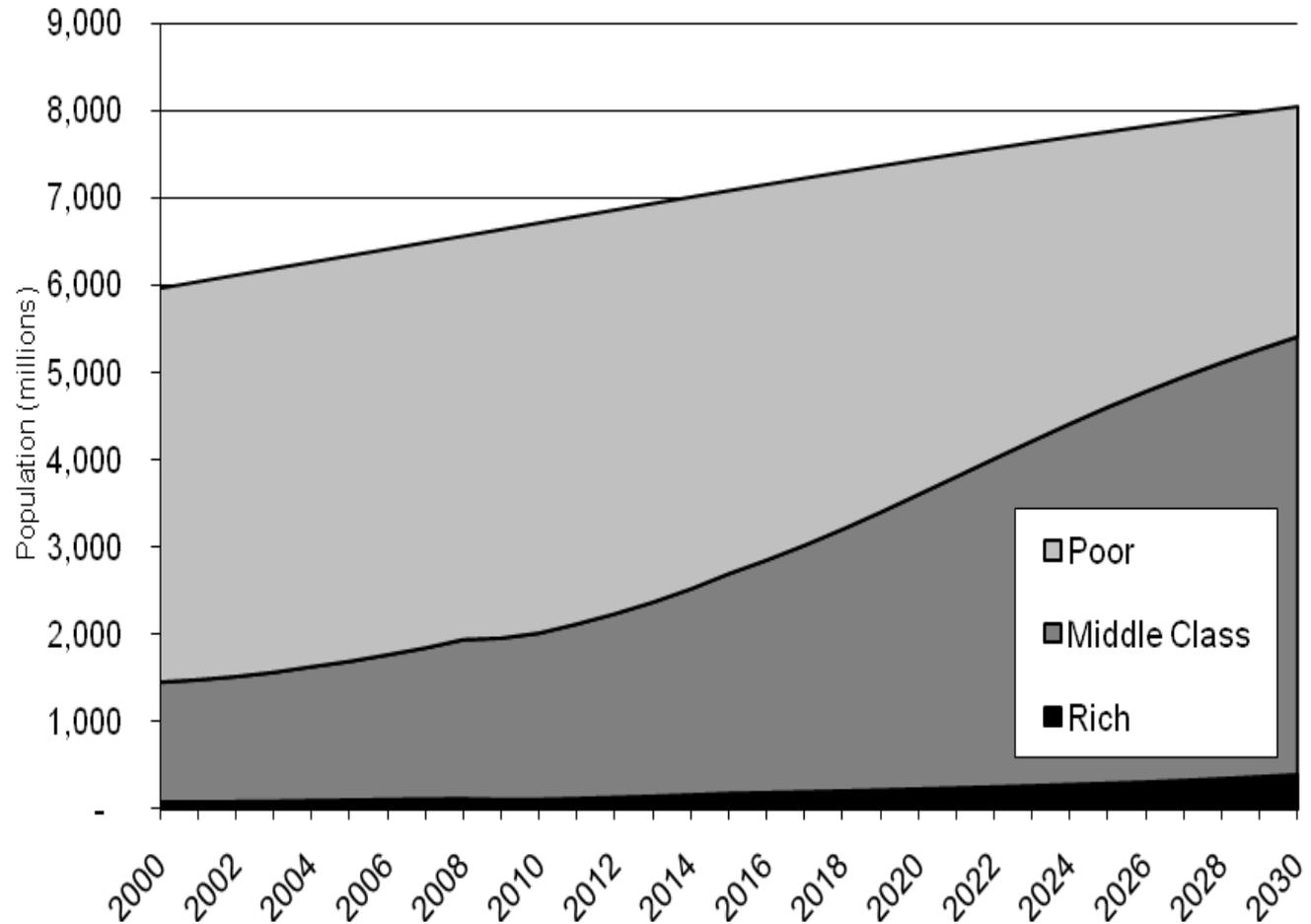
Looking Ahead

- Middle class population growth
 - Ehrlich was *nearly* right!
- Technological complexity
 - More things we can't do without
 - More difficult recycling
- Increasing co-production
 - Production balance issues
- Declining ore grades

 More risk of criticality

Middle class growth

OECD expects the world's middle class to grow -
from 1.8 billion people, in 2012,
to 4.9 billion in 2030.



Source: Wolfensohn Center for Development, at Brookings

- Complexity begets vulnerability -



~30 elements

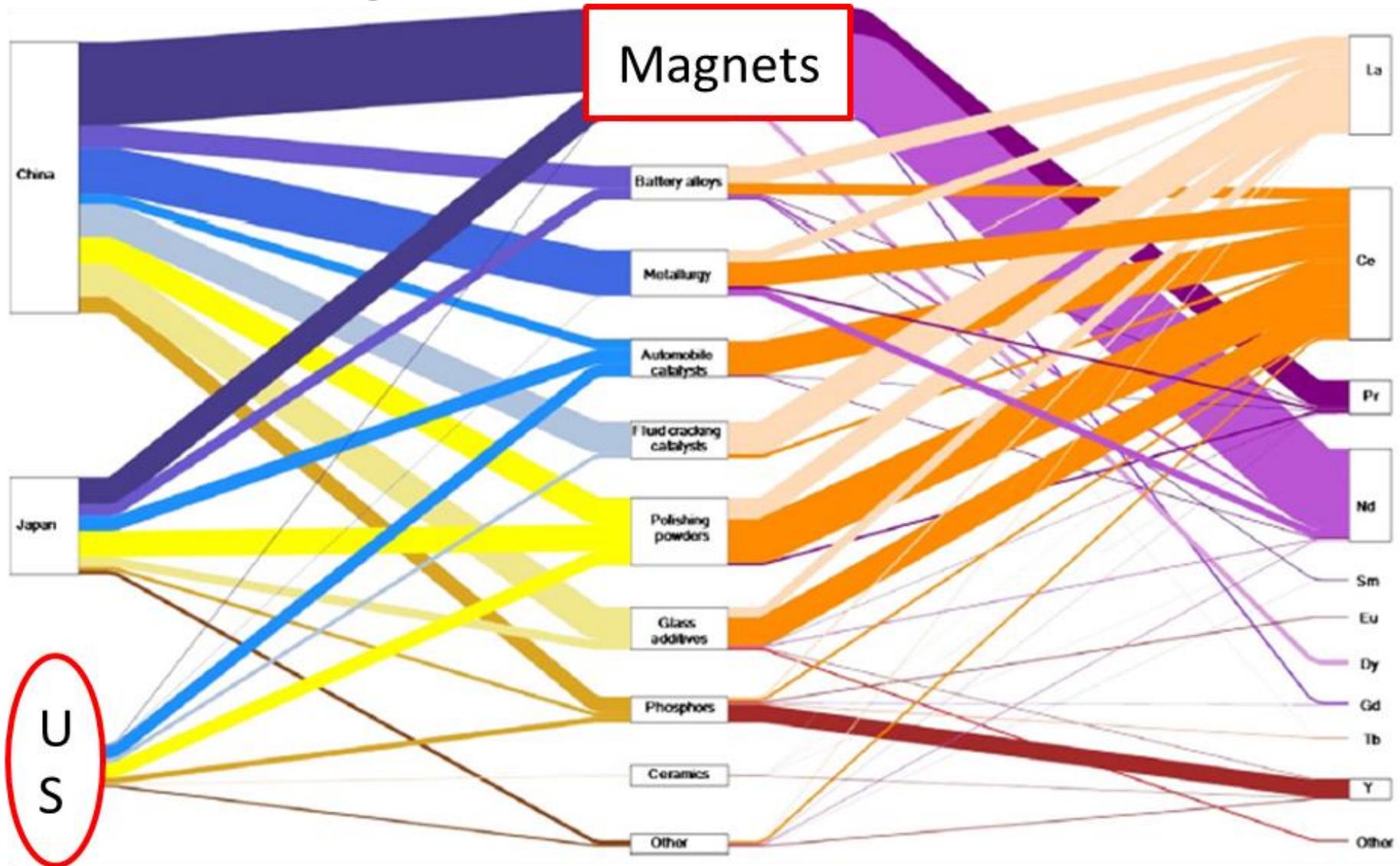


~65 elements

Thank You!

Questions?

Where it all goes



Du, X., & Graedel, T. E. Uncovering the end uses of the rare earth elements. *Science of The Total Environment*, 461–462 (2013) 781–784.