
Critical Materials Institute

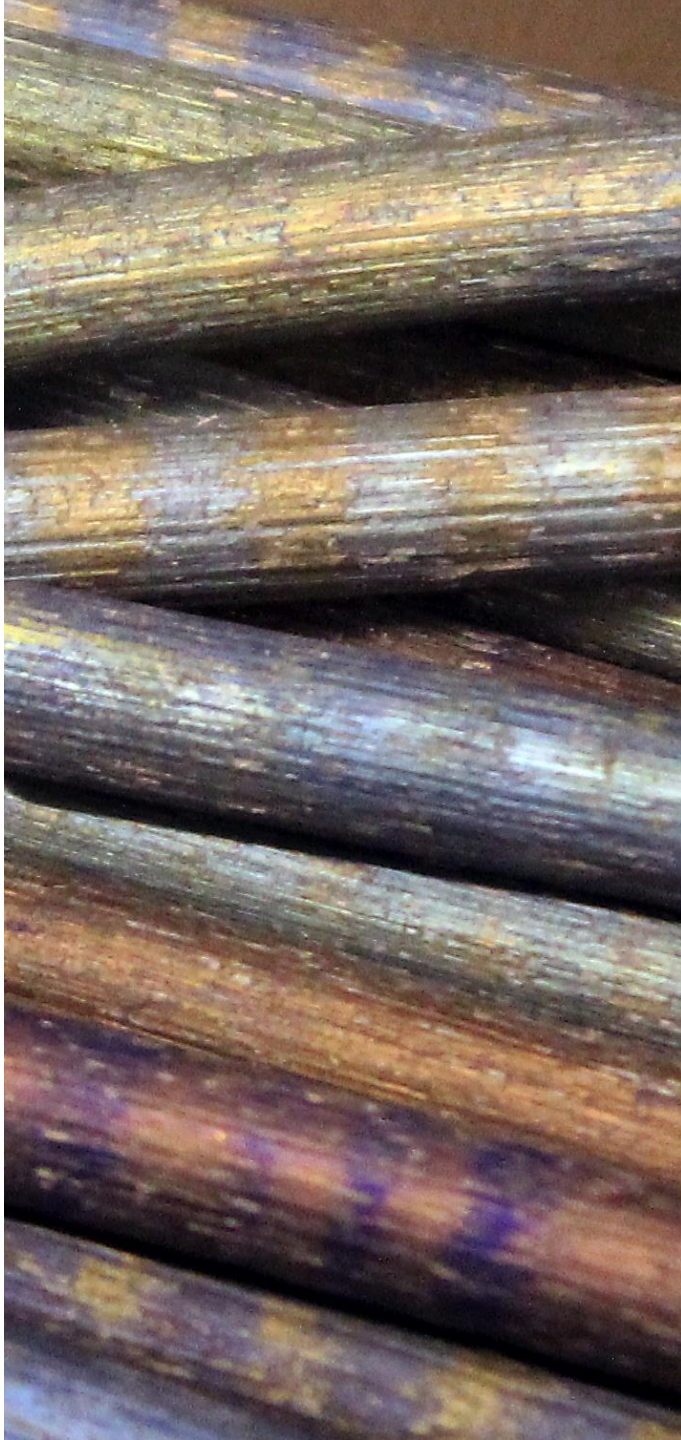
AN ENERGY INNOVATION HUB

# Critical Materials and Their Impact on Technology

Alex King


# 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.



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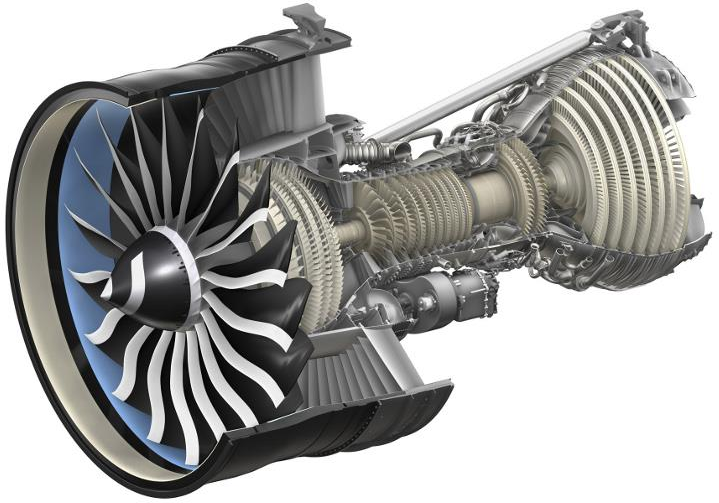
# Materials criticality is affecting us *today*

- 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 feared being 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*

- 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

REUTERS EDITION: U.S.

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## Exclusive: U.S. waived laws to keep F-35 on track with China-made parts

BY JOHN SHIFFMAN AND ANDREA SHALAL-ESA

WASHINGTON | Fri Jan 3, 2014 3:45pm EST

69 COMMENTS | Tweet 371 | Share 51 | Share this | 73 | Email | Print

The flight deck crew secures an F-35B Lighting 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

(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.

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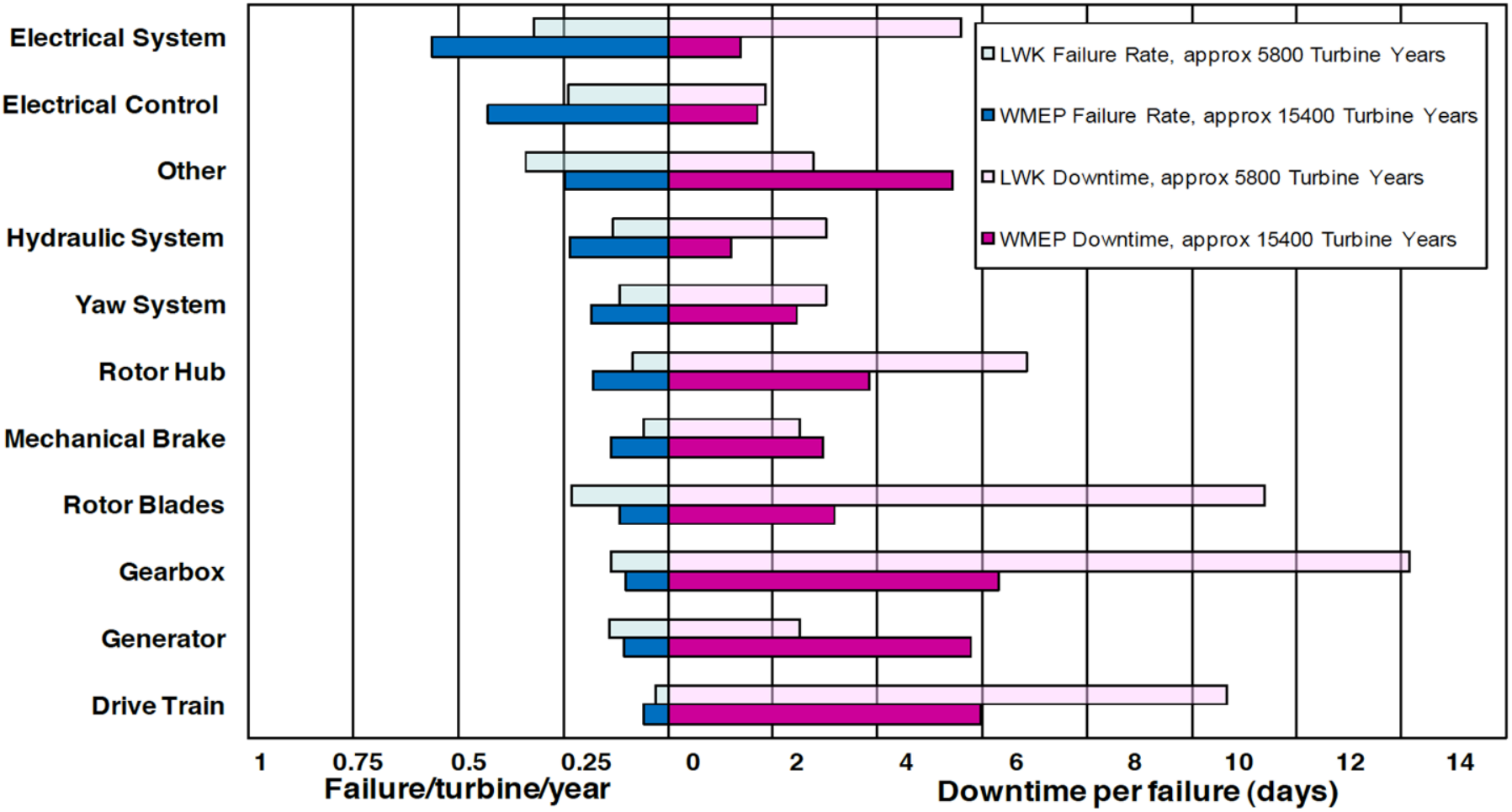
# Materials criticality is affecting us *today*

- 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.

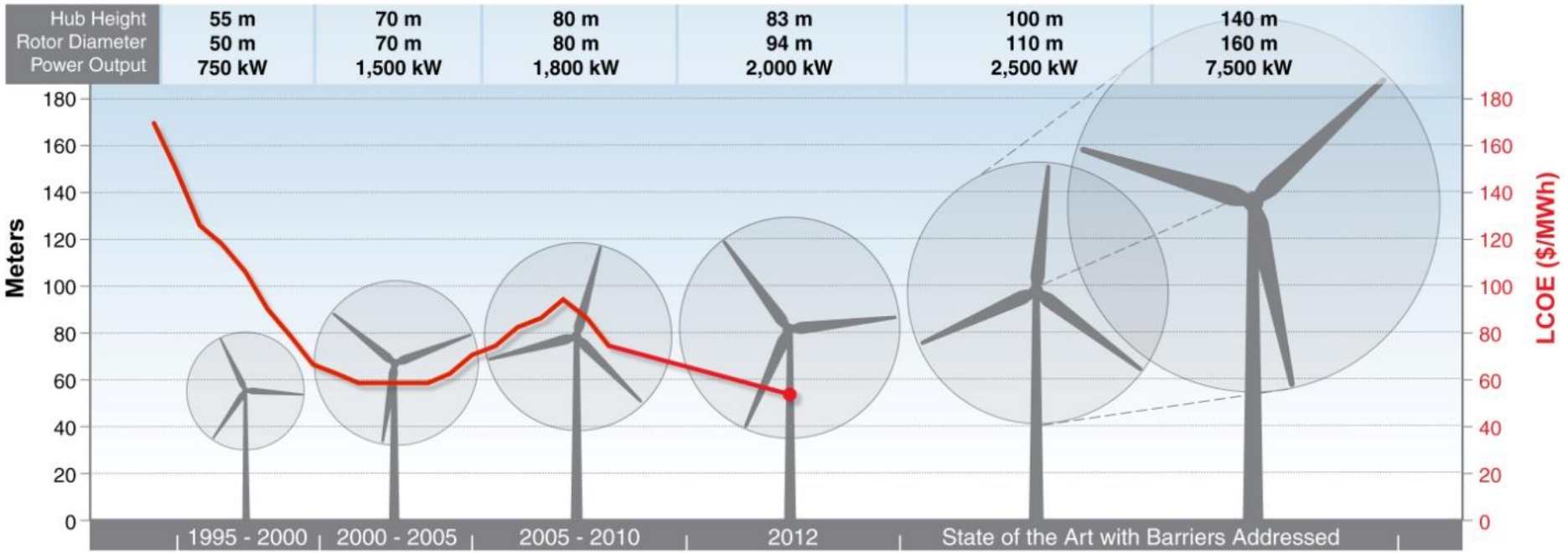
# Wind turbine failures




**WMEP**: the Wissenschaftliches Mess- und Evaluierungsprogramm (WMEP) database was accomplished from 1989 to 2006 and contains failure statistics from 1,500 wind turbines.

**LWK**: failure statistics published by Landwirtschaftskammer Schleswig-Holstein (LWK) from 1993 to 2006. It contains failure data from more than 650 wind turbines.

# Wind turbine evolution




Source: *NREL Technical Report, NREL/TP-5000-61063, January 2014*

# Magnet Requirements

- For permanent-magnet direct-drive wind turbines, an Nd-Fe-B generator magnet weighs about *0.5 tonnes of magnet per megawatt* of peak rated power.
- This translates to about *0.13 tonnes of rare earth per megawatt* of peak rated power.
- European offshore wind capacity is growing at nearly 5,000MW per year, creating a demand for ~*650 tonnes* of rare earths.
- Annual world production of Nd metal is ~*16,500 tonnes*.

# Critical materials are not new

- “The stone age did not end for lack of stone” – *Sheik Ahmed Zaki Yamani*.

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

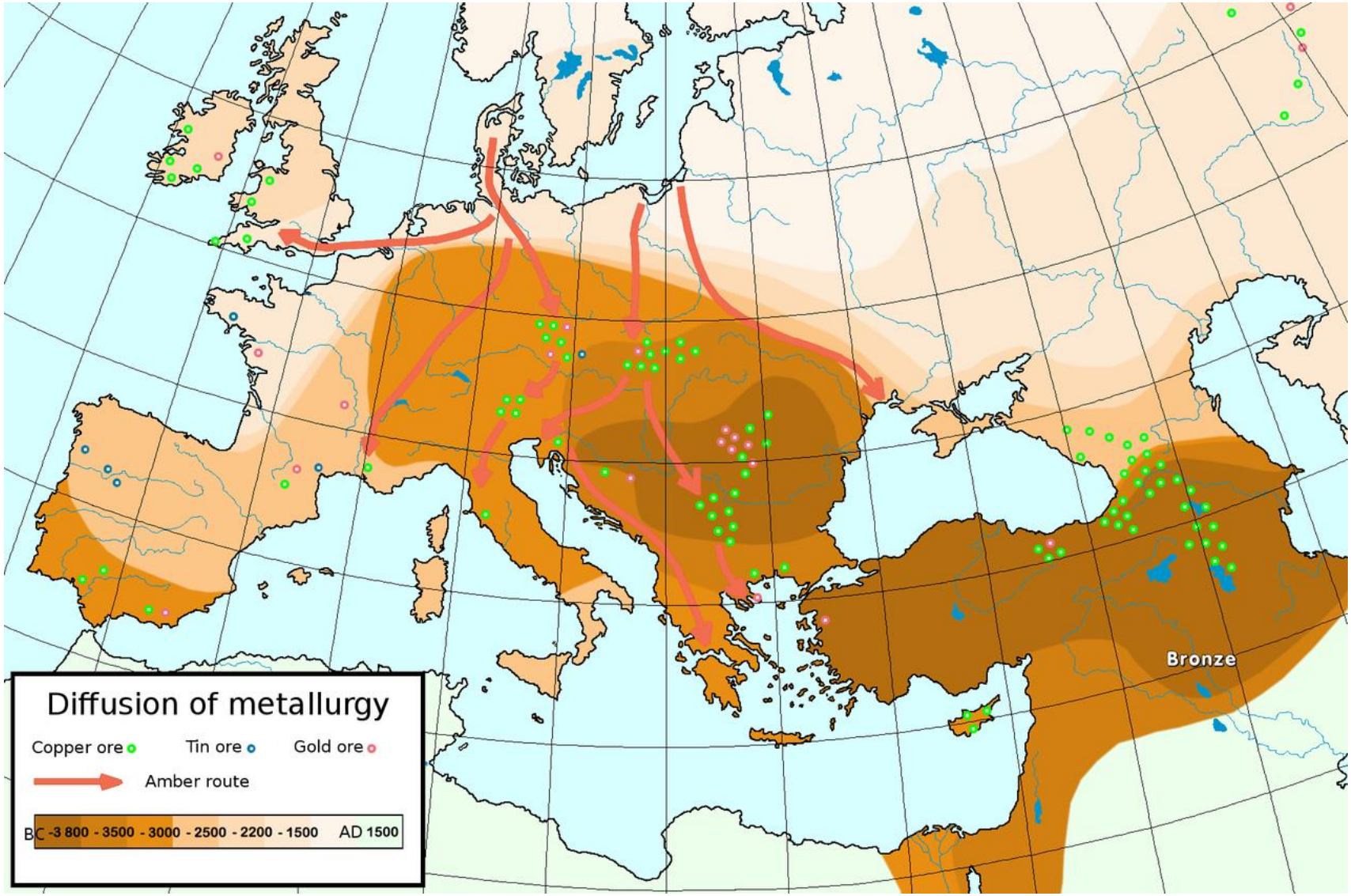
- The bronze age replaced the copper age because bronze was better than copper.

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

# Iron vs. Bronze, 1200 BC

- Processing
  - Bronze is manufactured at 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

# Bronze age trade and industry



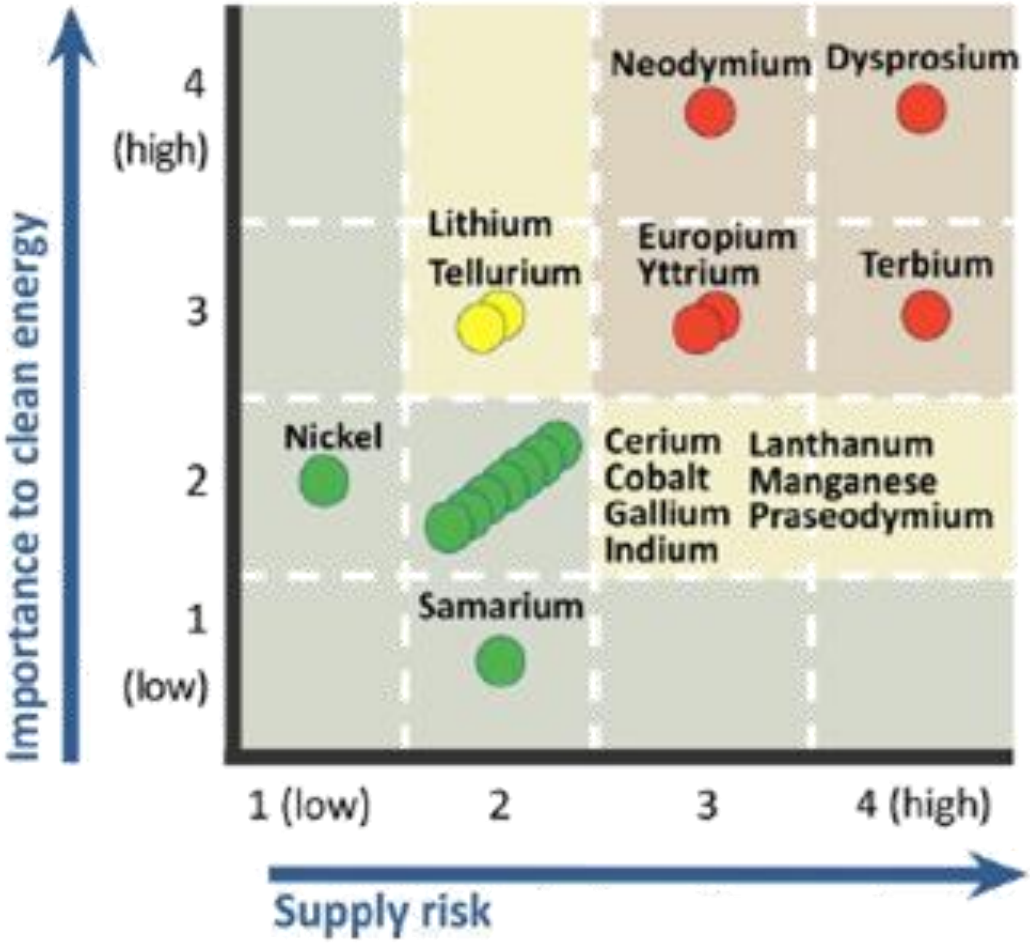

*Wikipedia* (After M. Otte (2007) Vers la Préhistoire, de Boeck, Bruxelles)

# The Bronze Age Collapse ~1200 BC

- "Global" events
  - Natural disasters: earthquakes, climate change, famine
  - Wars, revolts, invasions
  - Collapse of trade; collapse of civilization
- Bronze becomes unavailable
  - Possibly because Cyprus is overtaken by war, making copper inaccessible.
- Responses include
  - Recycling
  - Source diversification
  - Materials substitution: eventual emergence of the iron age

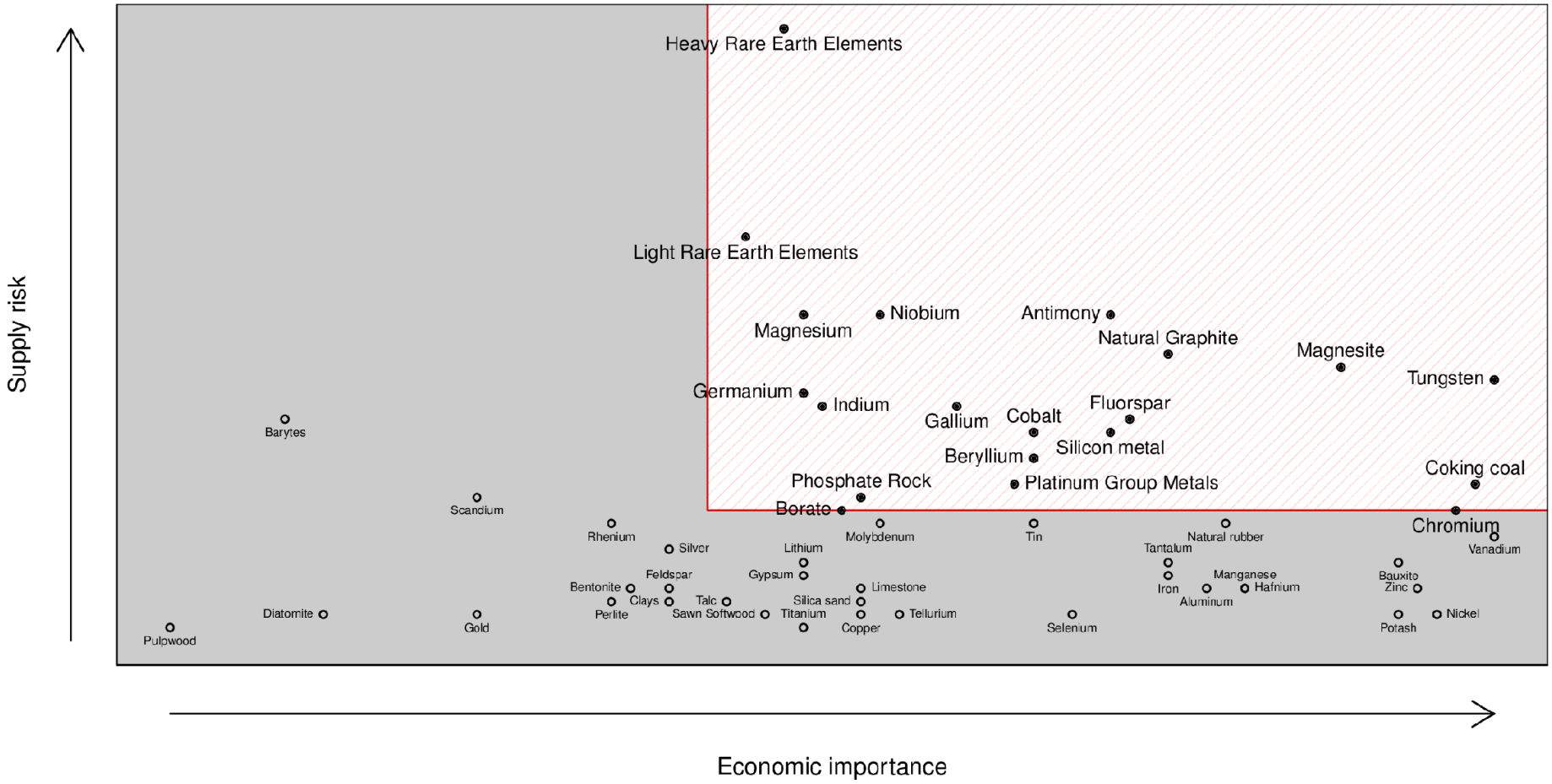
# How is criticality assessed?

- Identifies the *propensity* for supply-chain problems to occur. It does not predict that they *will*.
- Identifies the need for *appropriate attention*, not panic.
- Depends on location, industry-sector, and time.




DOE Medium Term Outlooks: *2015 – 2025*

# Critical materials for the European Union




European Commission, May 2014

# EU critical materials for decarbonization

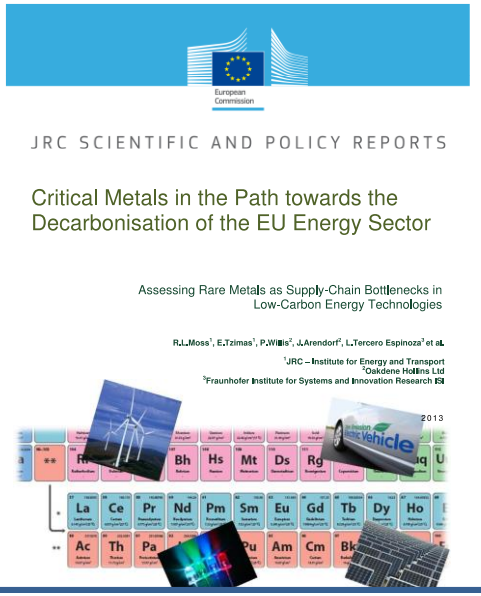


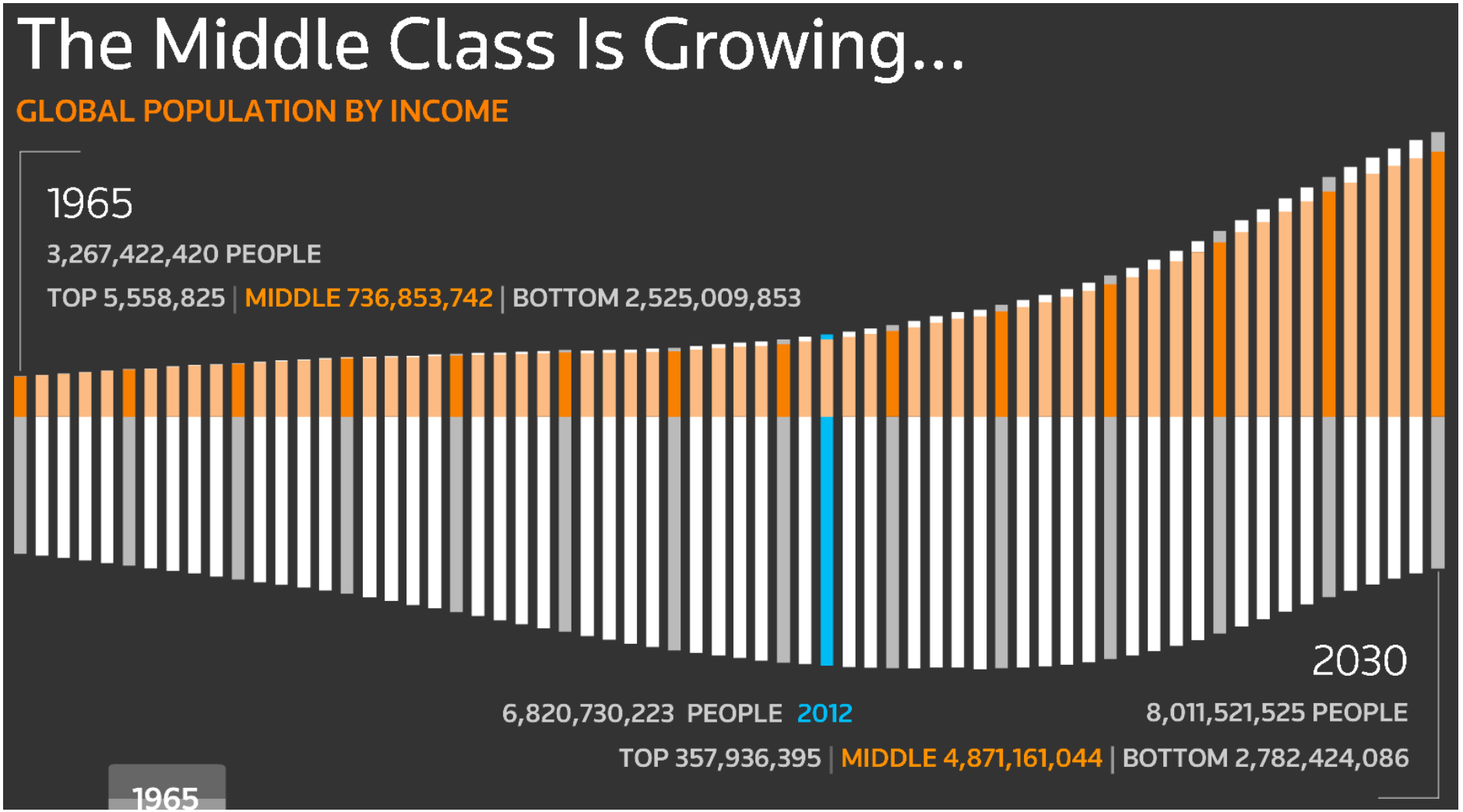

*Table 1: Criticality ratings of shortlisted raw materials*

| High | High-Medium | Medium | Medium-Low | Low |
|---|---|---|---|---|
| REE: Dy, Eu, Tb, Y | Graphite | REE: La, Ce, Sm, Gd | Lithium | Nickel |
| REE: Pr, Nd | Rhenium | Cobalt | Molybdenum | Lead |
| Gallium | Hafnium | Tantalum | Selenium | Gold |
| Tellurium | Germanium | Niobium | Silver | Cadmium |
| | Platinum | Vanadium | | Copper |
| | Indium | Tin | | |
| | | Chromium | | |

# Why should we worry?

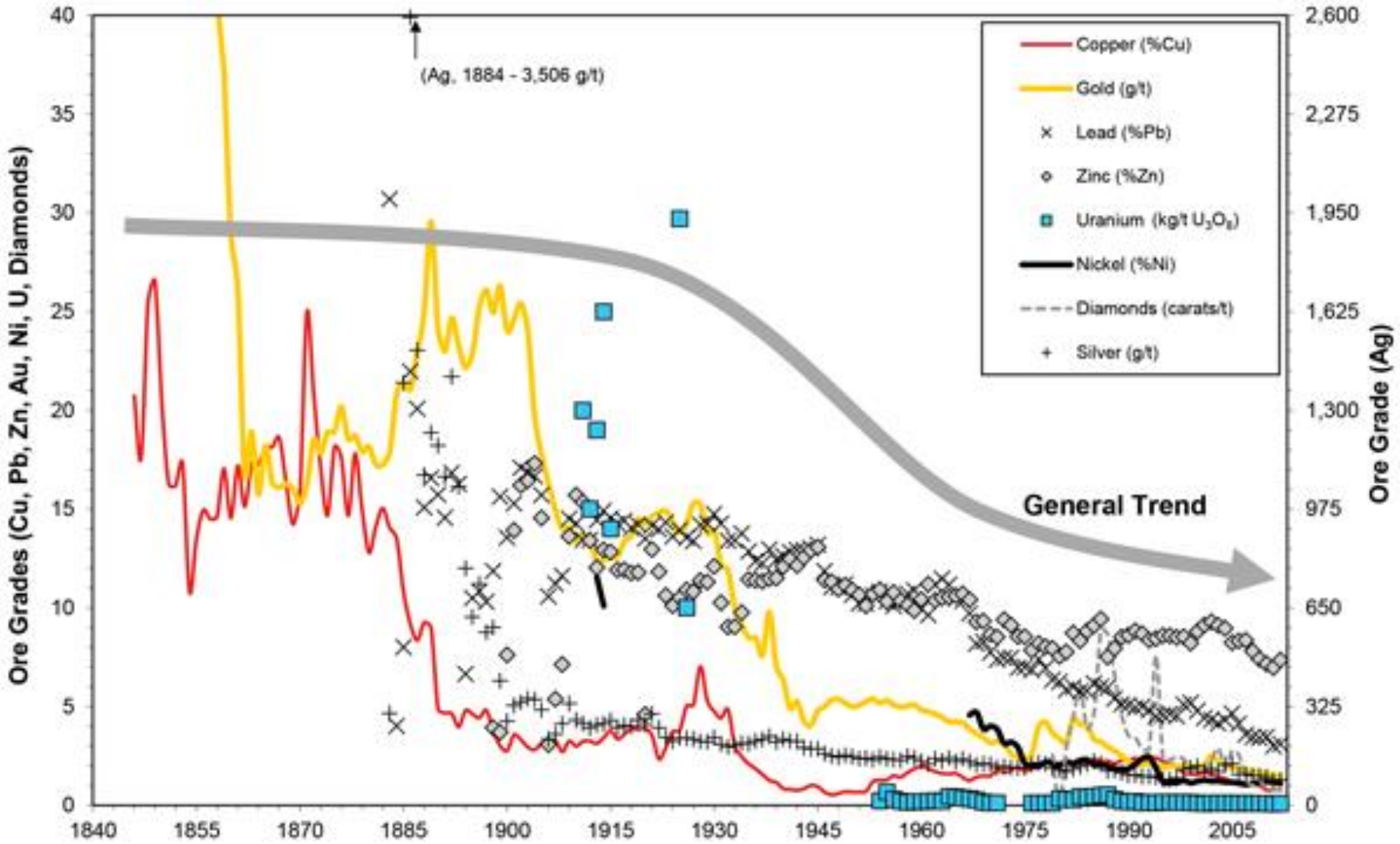
## Long-term price trends are quite reassuring

# *But…* there are more consumers coming

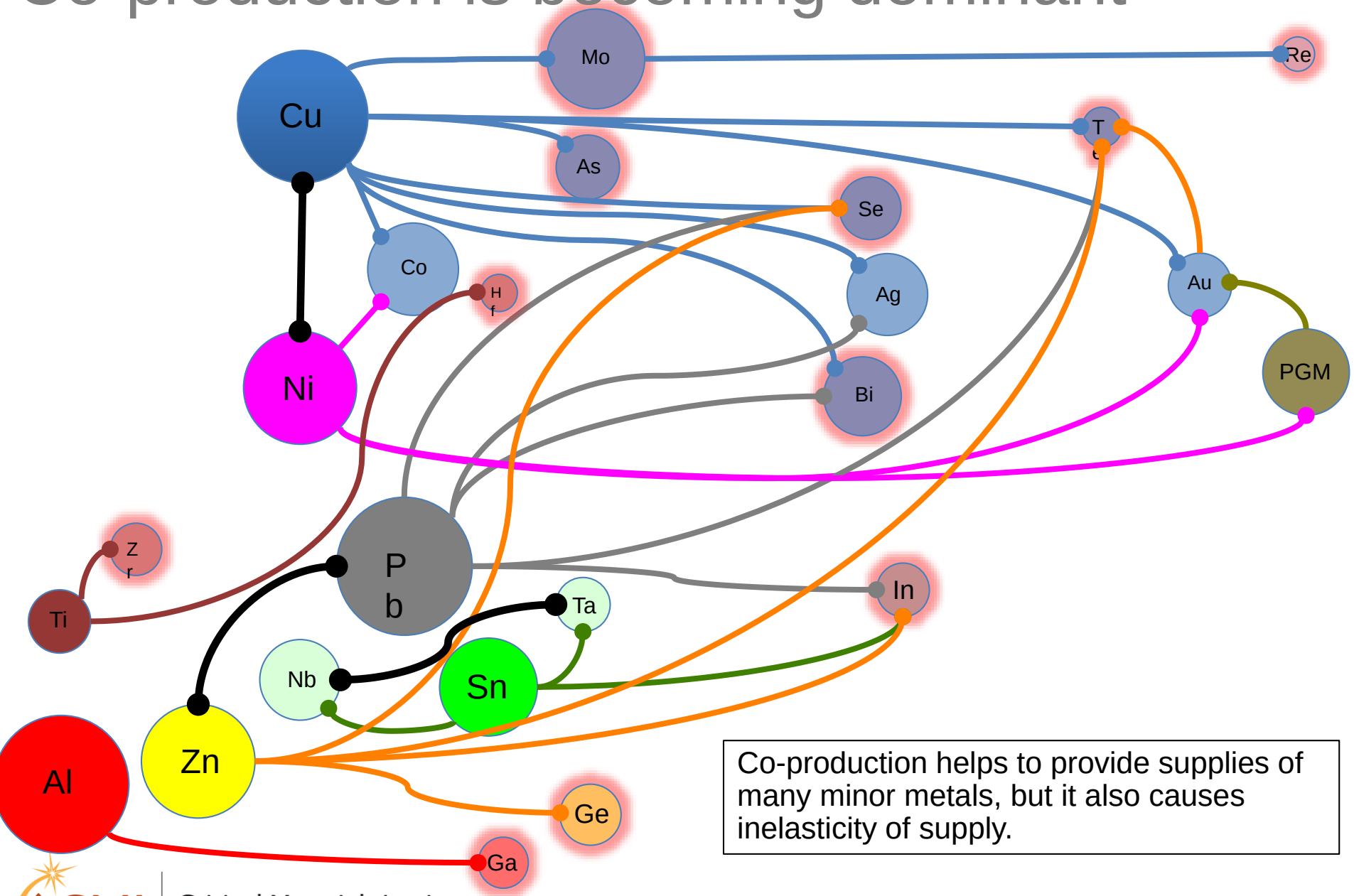



http://www.reuters.com/middle-class-infographic

# Ore grades are declining



# Co-production is becoming dominant




Co-production helps to provide supplies of many minor metals, but it also causes inelasticity of supply.

# Technology is growing more complex

| H | | | | | | | | | | | | | | | | | He |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Li | Be | | | | | | | | | | | B | C | N | O | F | Ne |
| Na | Mg | | | | | | | | | | | Al | Si | P | S | Cl | Ar |
| K | Ca | Sc | Ti | V | Cr | Mn | Fe | Co | Ni | Cu | Zn | Ga | Ge | As | Se | Br | Kr |
| Rb | Sr | Y | Zr | Nb | Mo | Tc | Ru | Rh | Pd | Ag | Cd | In | Sn | Sb | Te | I | Xe |
| Cs | Ba | La | Hf | Ta | W | Re | Os | Ir | Pt | Au | Hg | Tl | Pb | Bi | Po | At | Rn |
| Fr | Ra | Ac | Rf | Db | Sg | Bh | Hs | Mt | Ds | Rg | Cp | | Fl | | Lv | | |

| Ce | Pr | Nd | Pm | Sm | Eu | Gd | Tb | Dy | Ho | Er | Tm | Yb | Lu |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Th | Pa | U | Np | Pu | Am | Cm | Bk | Cf | Es | Fm | Md | No | Lr |

~30 elements

| H | | | | | | | | | | | | | | | | | He |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Li | Be | | | | | | | | | | | B | C | N | O | F | Ne |
| Na | Mg | | | | | | | | | | | Al | Si | P | S | Cl | Ar |
| K | Ca | Sc | Ti | V | Cr | Mn | Fe | Co | Ni | Cu | Zn | Ga | Ge | As | Se | Br | Kr |
| Rb | Sr | Y | Zr | Nb | Mo | Tc | Ru | Rh | Pd | Ag | Cd | In | Sn | Sb | Te | I | Xe |
| Cs | Ba | La | Hf | Ta | W | Re | Os | Ir | Pt | Au | Hg | Tl | Pb | Bi | Po | At | Rn |
| Fr | Ra | Ac | Rf | Db | Sg | Bh | Hs | Mt | Ds | Rg | Cp | | Fl | | Lv | | |

| Ce | Pr | Nd | Pm | Sm | Eu | Gd | Tb | Dy | Ho | Er | Tm | Yb | Lu |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Th | Pa | U | Np | Pu | Am | Cm | Bk | Cf | Es | Fm | Md | No | Lr |

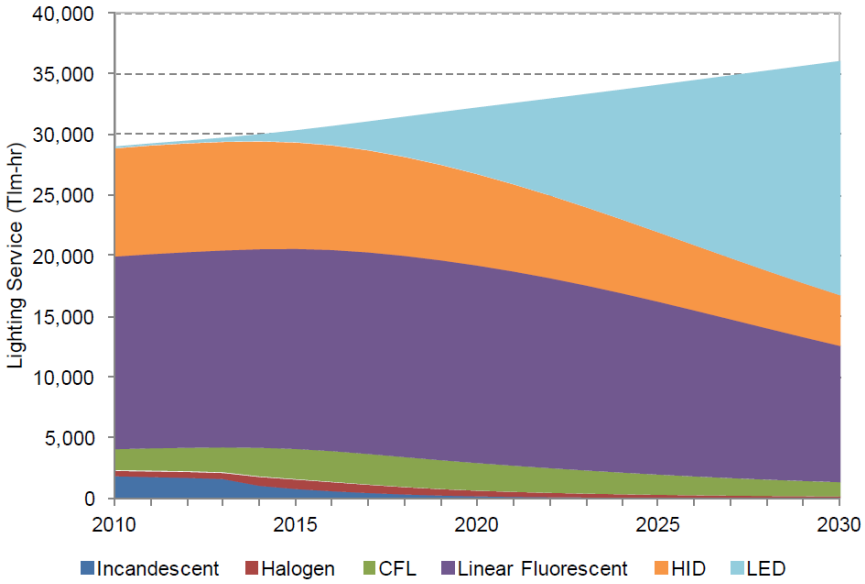
~75 elements

# Technology emergence
## Case study: electric vehicles

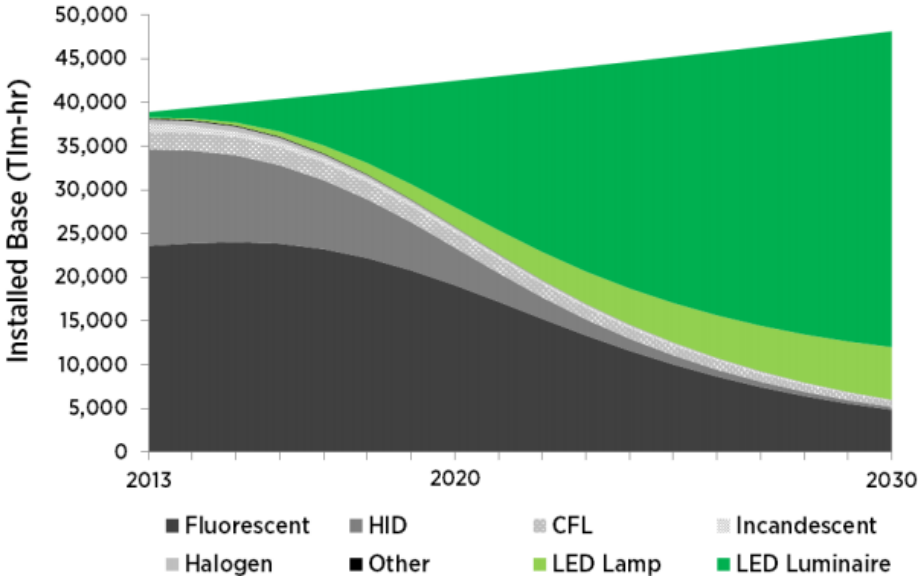
*Assumption*: The market penetration of EVs will rise when a battery technology emerges that provides all-electric range close to that of a single tank of gasoline, if the price premium is similar to that of a hybrid.

- ~15,000,000 new cars are sold in the US every year.
- ~7% of new car sales in California are hybrids.
- Guess that the market for an all-electric vehicle could rise to 1,000,000 per year.
- If the battery requires 20kg of “unobtainium” the demand is around 20,000 tonnes, for US consumption alone. This is a small percentage of current world production for some elements, but a very large percentage for others.

# Technology shifts: *lighting*



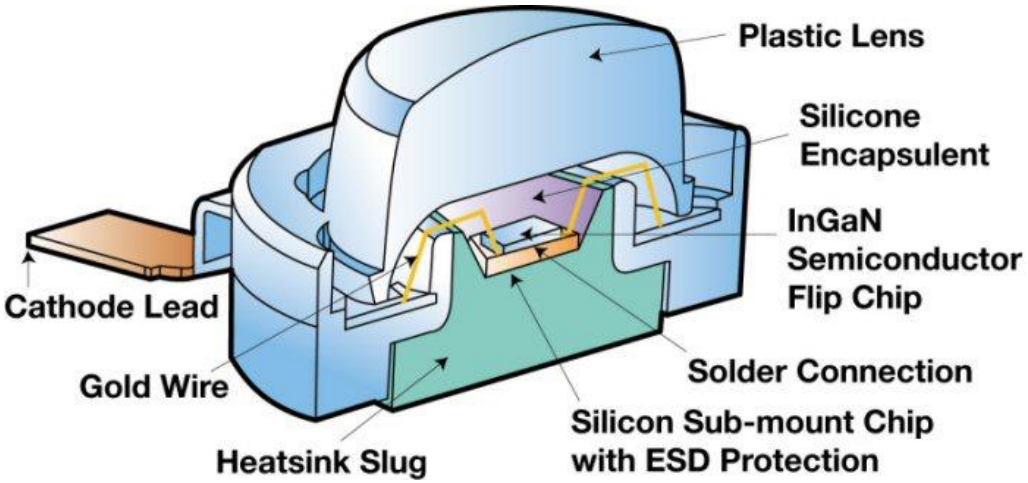

***Source: US Dept. of Energy – Energy Savings Potential of Solid-State Lighting in General Illumination Applications (January 2012)***




***Source: US Dept. of Energy – Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (August 2014)***

- Why did the forecast change so much in 2 years?
- What is the impact on materials demand

# White LED materials




Lumileds® Luxeon® emitter
(*via* LEDs Magazine)

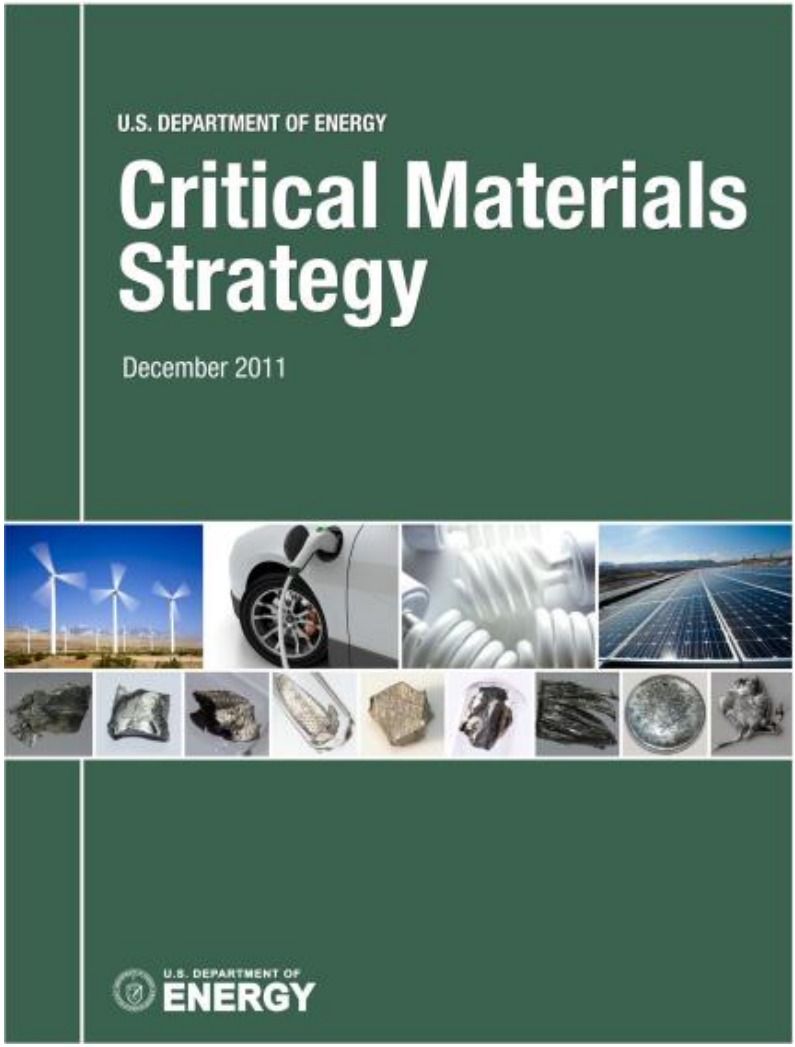
- *InGaN* LED chip produces blue light
- *Ceria*-doped *YAG* particles embedded in the silicone encapsulent absorb some of the blue and emit a broad spectrum of visible light, producing the desired white light.

# A three-pillared research strategy

## Find ways to:

- diversify our sources;
- provide alternatives to the existing materials;
- make better use of the existing supplies through recycling and re-use.

Some of these approaches work better than others for specific materials.



# Unfortunately, these approaches are slow to have impact

- Mine development, *where there is a known resource*, takes about 15 years, and has costs in the billions of dollars.

- Development and deployment of new materials takes an average of 18 years.

- There are no empirical data to suggest how long it takes for recycling programs to have an impact.

# Two 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?

# The opposite of a critical material

- Stuff you really need to get rid of, if only you could
  - Lead; Mercury; Beryllium; Thorium; Cerium; Lanthanum; Cobalt…
- Drivers
  - Economics
  - Regulations: *Reach, RoHS, Dodd-Frank…*
- We call these *ANA*CRITICAL materials
  - As with critical materials, the list might vary depending on who, when or where you ask.
  - Technical solutions often mirror those for critical materials.

# Thank You!

Questions?

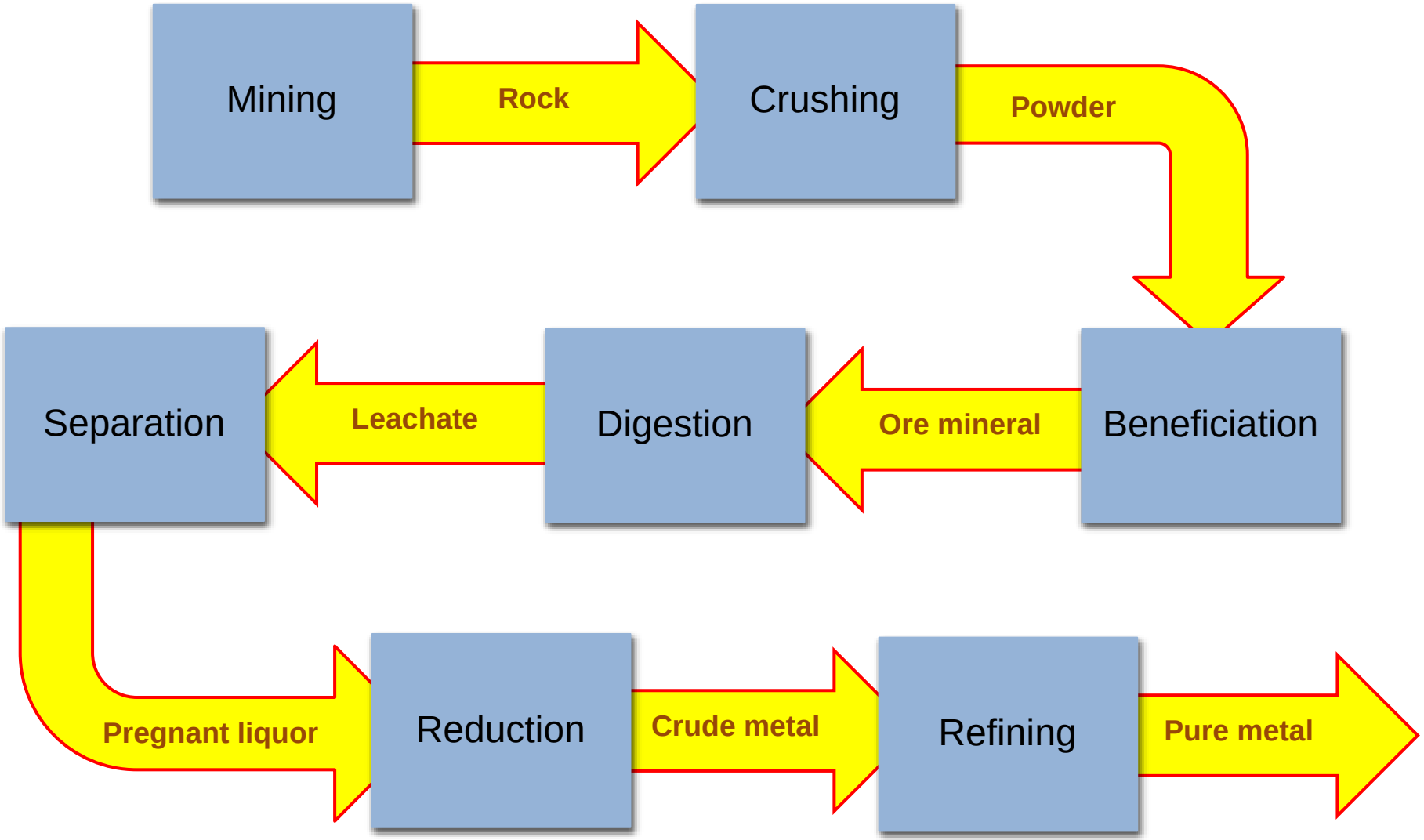
# Separation and beneficiation are difficult

- Hard disk drives contain two types of $Nd_2Fe_{14}B$ magnet
  - Voice coil magnet(s)
  - Spindle magnet

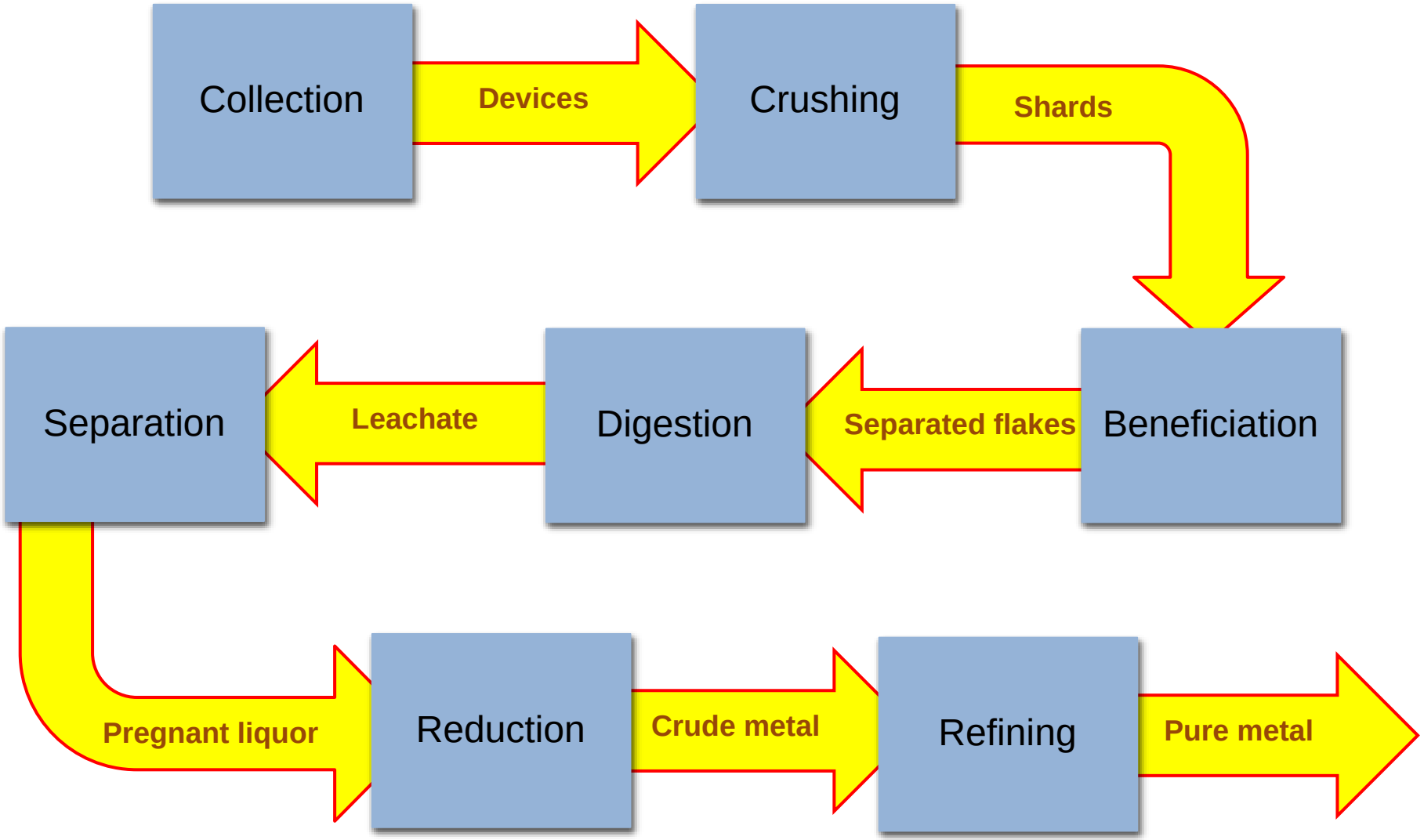
- This is the biggest single use of these magnets, consuming almost 20% of the worldwide production

- There is currently no cost-effective strategy for recycling them.
  - Shred the drive and separate?
  - Extract the magnets first?
  - Demagnetize before or after?
  - Data security issues?

# Metal production stages (schematically)



# Recycling stages (schematically)



# A popular alternative approach: *espionage!*