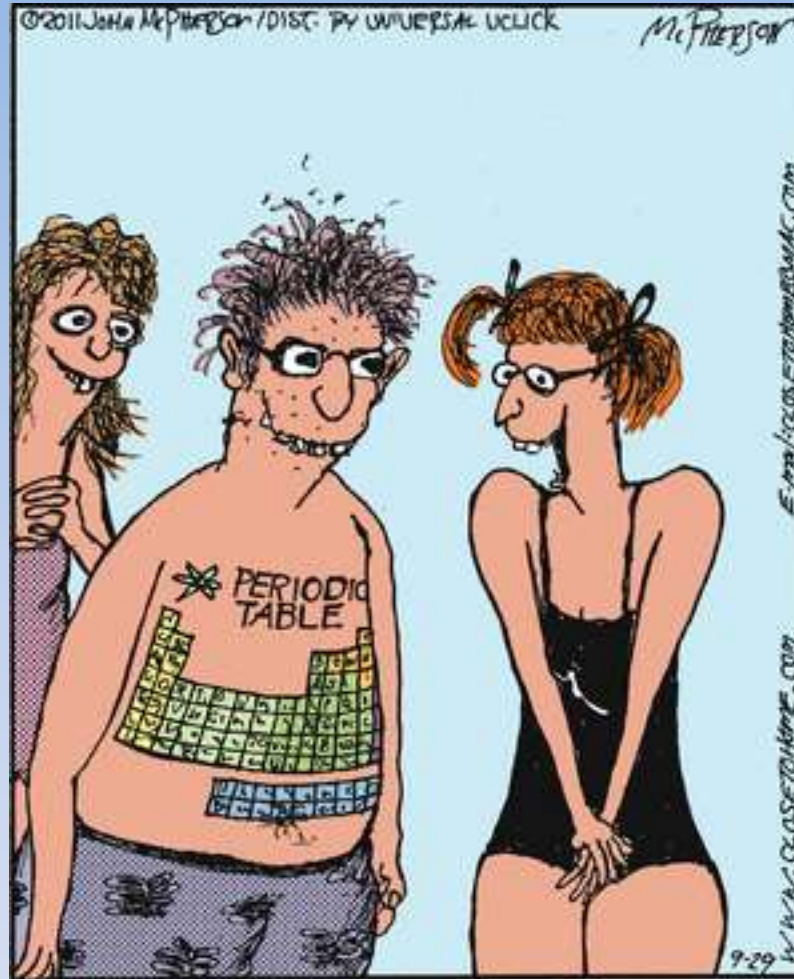


# The Rare Earths: Top Spot for the Bottom of the Periodic Table

S. R. Trout  
October 21, 2013





Geek tattoos.



# Outline

- Background
  - Personal
  - Rare Earths
- Rare Earth Sources
- Rare Earth Applications
  - Lighting
  - Catalysts
  - Magnets
- Recycling
- The Future, Why is it so complicated?



# Background



- Stops along the way
- Univ. of Pennsylvania
- Companies
  - Recoma
  - Crucible
  - Hitachi
  - Magnequench
  - Molycorp
- Academic
  - Metro State University of Denver
  - Marian University
  - Alma College
  - Ellis University
  - Ivy Tech
- Consulting



# Rare Earths

		Sc															
		Y															
		La															

Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu



# Rare Earths

- Ores contain all rare earths except Pm
- The rare earths are chemically very similar
- There is no shortage of ore
  - Bastnasite & Monazite are the most common
- Most ores are rich in Ce, La, Nd and Pr
  - *Not all rare earths are rare in the Earth*
- Magnetic, optical, electronic and catalytic properties vary widely
- The lanthanide contraction
- Producers try to balance supply and demand
  - And are *rarely* successful!



## China Restarts Rare Earth Shipments to Japan

By KEITH BRADSHER  
Published: November 19, 2010

HONG KONG — [China](#) resumed exports of crucial minerals to [Japan](#) on Friday for the first time in almost two months, Japanese government officials and an industry executive said.

### Related in Opinion

Room for Debate: Can the U.S. Compete on Rare Earths?

Chinese customs agents were not only processing the paperwork for shipments of the minerals, known as [rare earths](#), but were also allowing dock workers to load containers of rare earths on ships bound for Japan on

Friday afternoon, the Japanese officials and the executive said.

"Everything is flowing," said the rare earth industry executive, who insisted on anonymity because of lingering diplomatic sensitivity about the Chinese embargo, which Beijing had never announced or formally acknowledged.

But an official at another company said that delays persisted for its shipments, a difficulty that suggested not all export restrictions had been lifted.

Although China had allowed shipments of the minerals to resume to the United States and Europe after a brief suspension in late October, deliveries to Japan had remained suspended — even after Chinese custom agents had started processing the shipping paperwork a few weeks ago.

RECOMMEND

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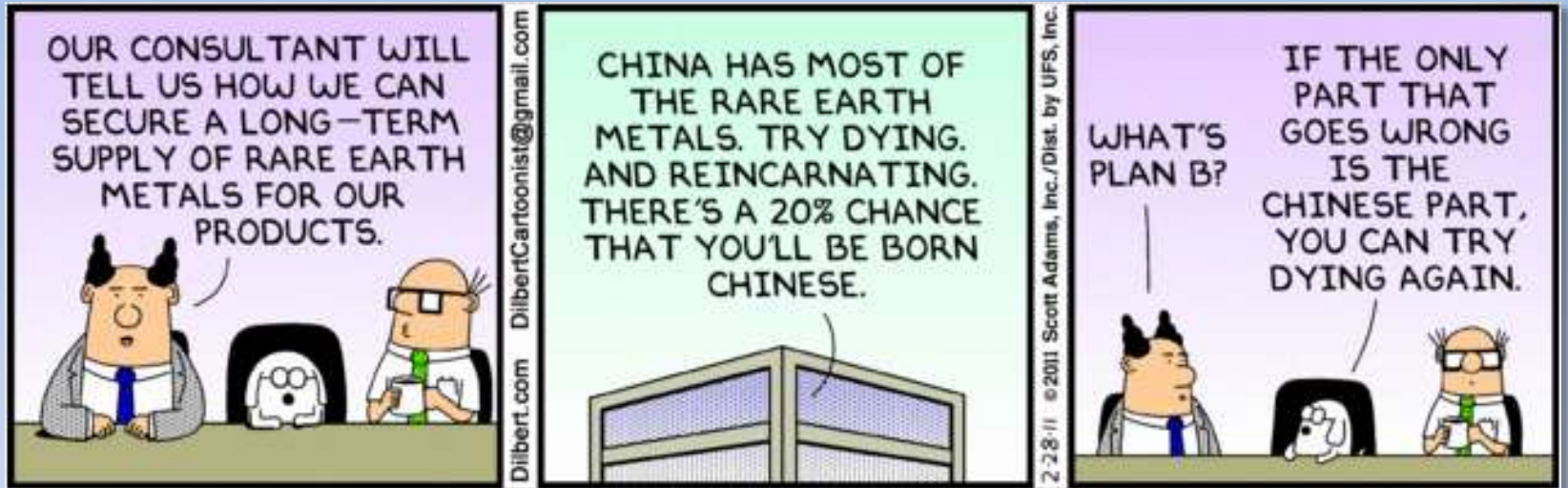
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A New Comedy

ST. OLAF



Spontaneous Materials



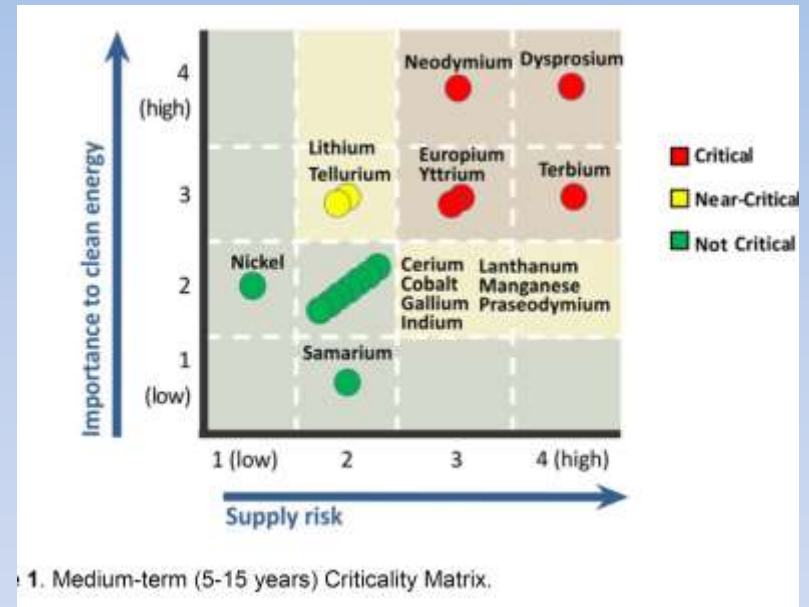
*Dilbert*, February 28, 2011





# Critical Materials Hub

- DOE Program
  - \$120 million, 5 years
  - National Labs
  - Academe
  - Industry
- Reduce criticality



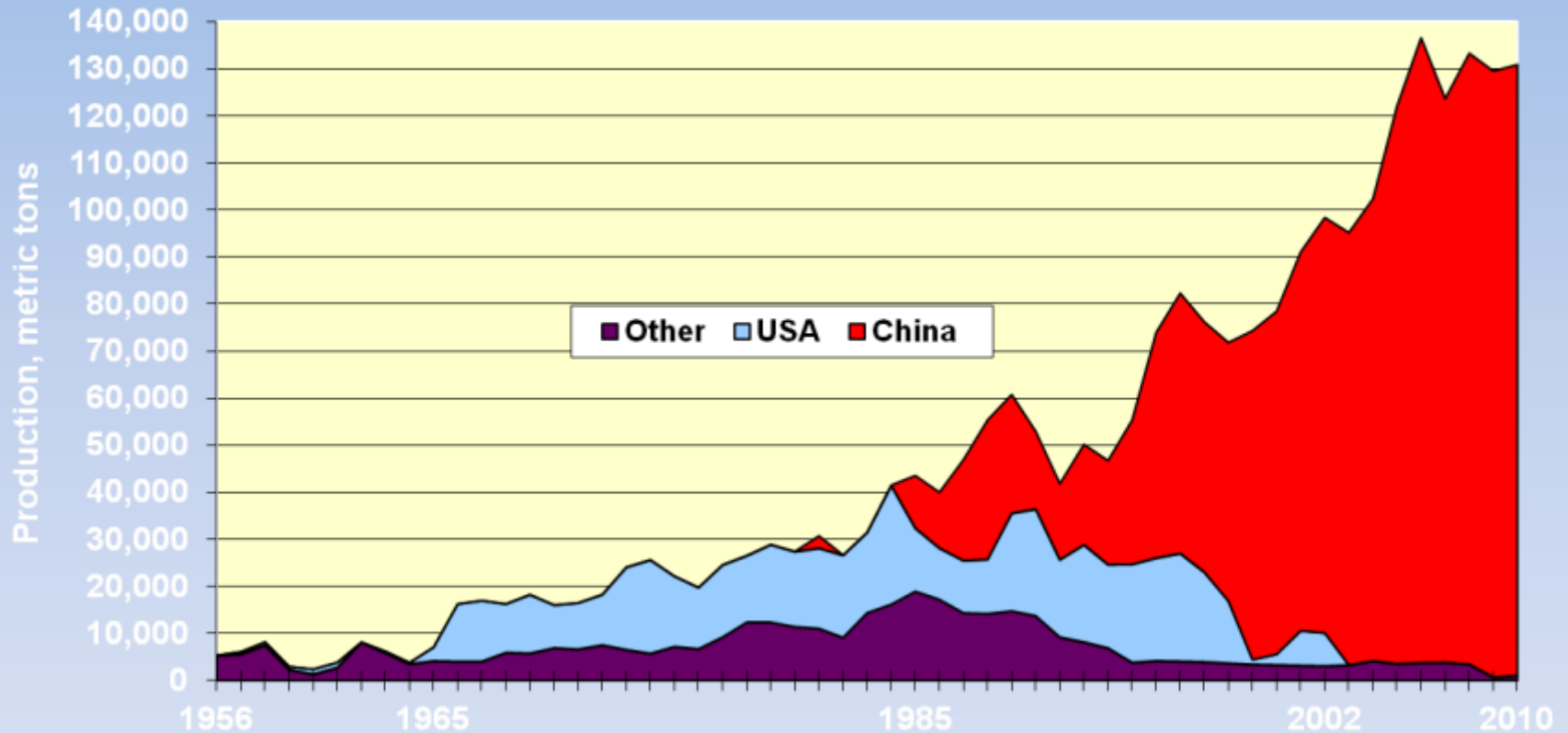
Source: DOE Announcement May 2012



# Recent RE Metal Prices



# Global Rare Earth Production Trends



Source: U.S. Geological Survey

**ST. OLAF**



Spontaneous Materials



Bayan Obo mine ,  
near Baotou, China  
Photo from Google Earth





Mountain Pass, CA,  
source: Molycorp



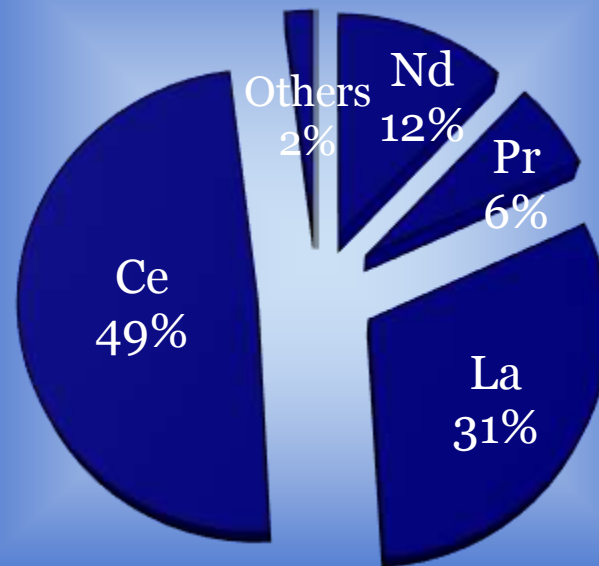
# Rare Earth Sources

- Active mines
  - China
    - Baotou
    - Ionic Ores
- Mines coming on stream
  - USA
    - Mountain Pass, CA
  - Australia
    - Mt. Weld
- Under Development
  - Australia
    - Nolan's Bore
  - Canada
    - Hoidas Lake
    - Nechalacho
  - India
  - Brazil
  - Vietnam
  - Russia



# Rare Earths

## Bastnasite Ore

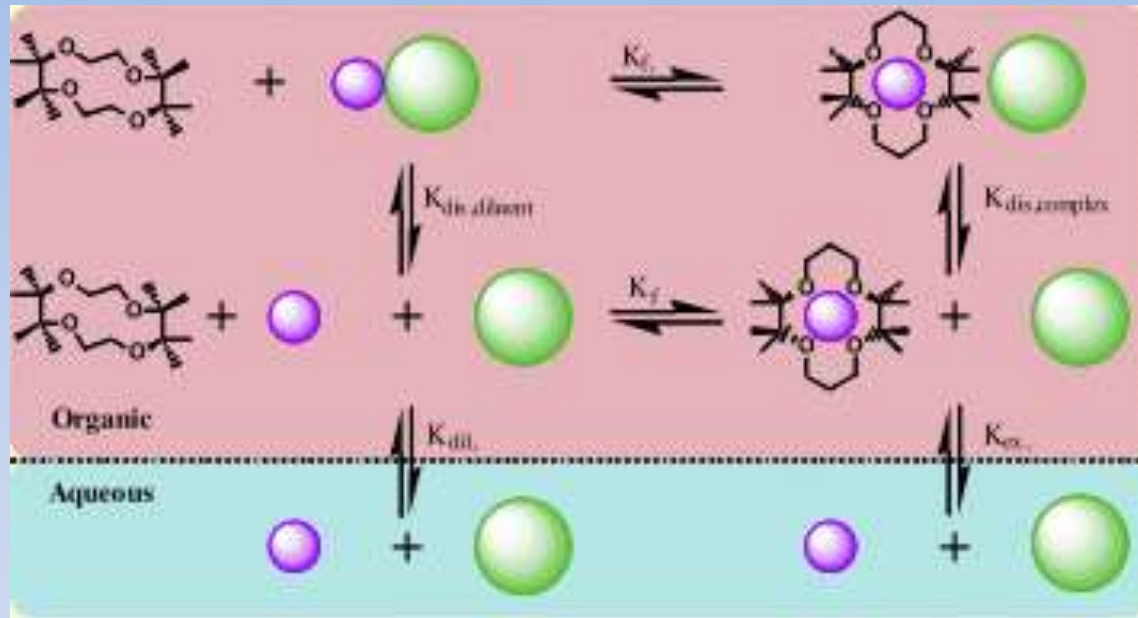


**ST. OLAF**



Spontaneous Materials

# Separating the Rare Earths

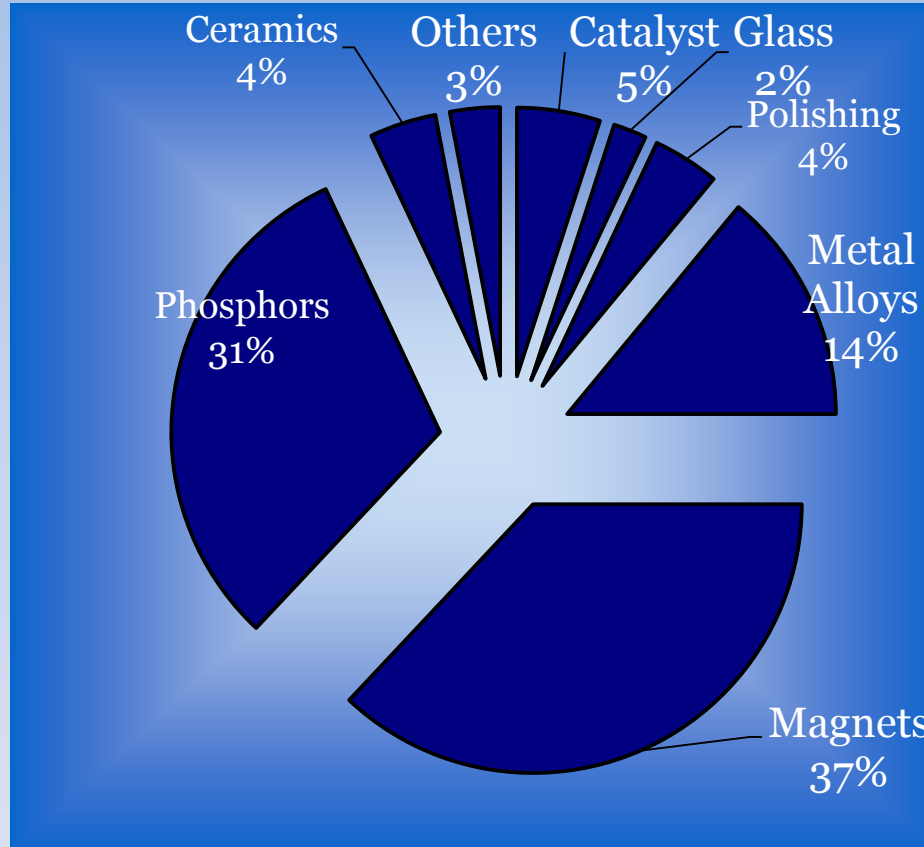


Source: ORNL





# Rare Earth Markets



Do the markets change over time?

Dollar basis  
2008  
Source: IMCOA



# Early Lighting Options

**Welsbach  
Candoluminescence**



Source:  
Gas Light Guys

**Edison  
Incandescence**



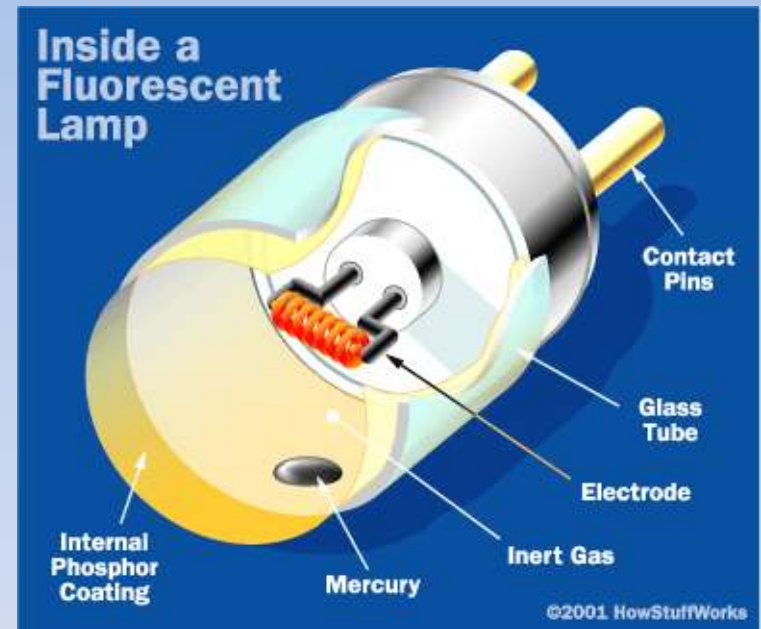
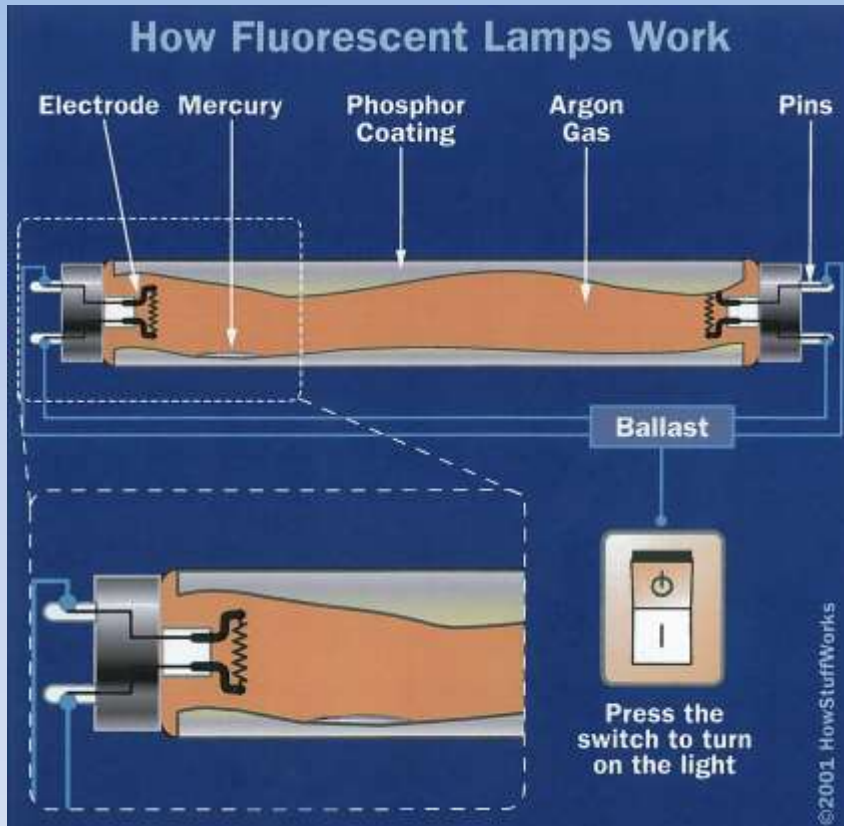
Source: Wikipedia



Source: Auer Licht



# Lighting Phosphors



Spontaneous Materials

# Lighting Phosphors

- Red:  $\text{Y}_2\text{O}_3:\text{Eu}$
- Green:  $(\text{La}, \text{Ce}, \text{Tb})\text{PO}_4$
- Blue:  $\text{BaMgAl}_{10}\text{O}_{17}:\text{Eu}$
- What we see depends on phosphor quality

Compact Fluorescent Lights (CFL)



Source: GE Lighting



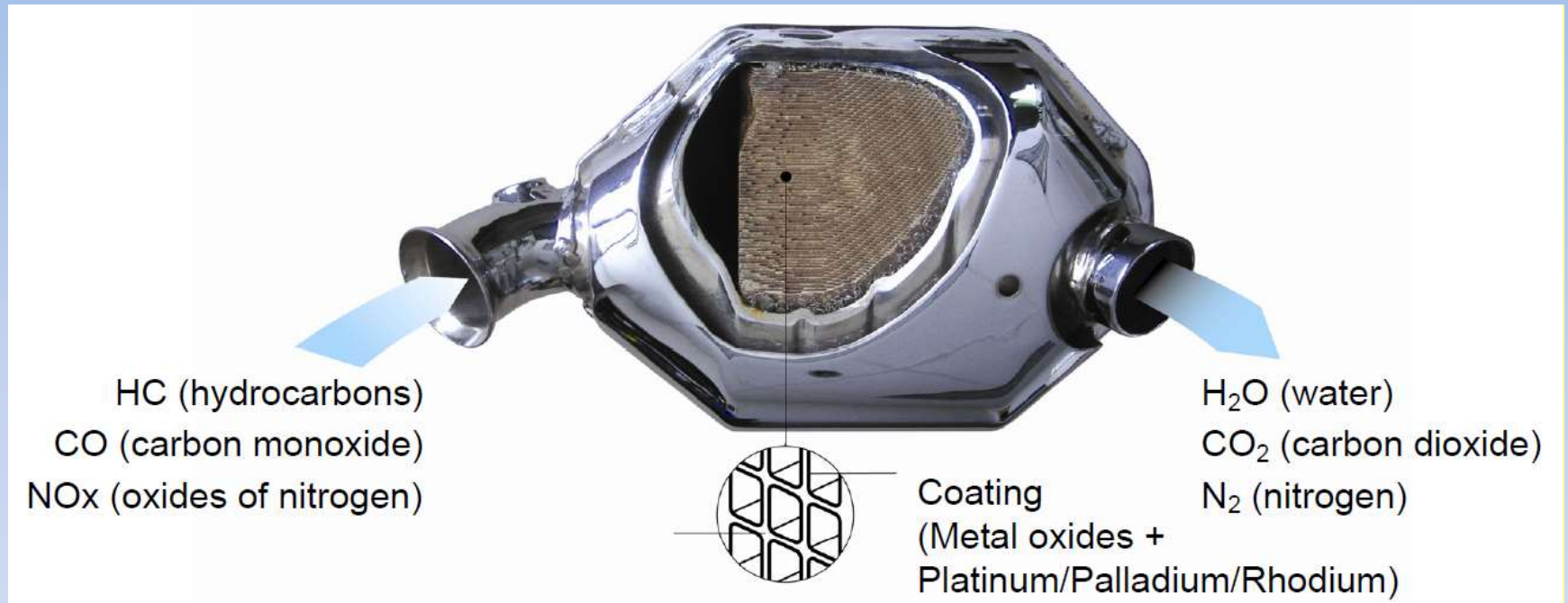
# Fluorescent Lighting

- Advantages
  - Higher output
    - 58 lu/W vs. 13.5 lu/W
  - Lower operating cost
    - 10 W vs. 40 W
  - Longer life
    - 12,000 hrs vs. 1,000 hrs
- Disadvantages
  - Slightly higher price
  - Difficulty dimming
  - Unappealing light?
    - Cheap bulb = cheap phosphor
  - Hg in bulb, special disposal preferred

Data source: GE Lighting



# Automotive Catalysts



Source: BASF



# Refining Catalysts

- Fluid Cracking Catalyst (FCC)
  - Ideal for heavy crude to make gasoline
  - Ion-exchanged zeolite (cat litter)
  - Variable demand
    - Driving season and heating season
    - Available crude



# Rare Earth Magnets

## Applications

- Hard drive
  - Voice Coil Motor (VCM)
  - Spindle motors
  - $5 \times 10^8$  per year



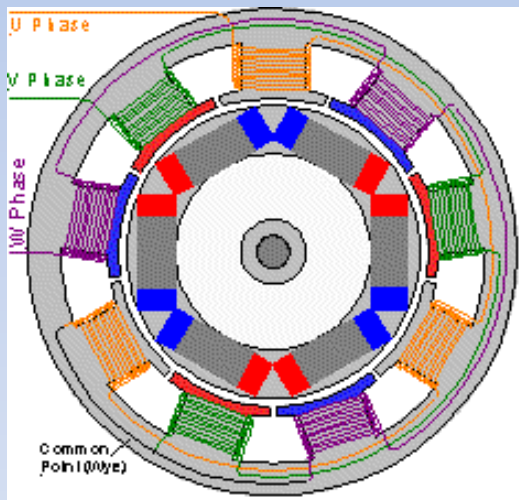
Source: Western Digital





# Rare Earth Magnets Applications

- Automotive
  - Hybrids
  - Electric vehicles



Source: Toyota



# Recycling

- Historically unimportant
  - Low value
  - Difficulty



- Interest rises and *falls* with prices
- Center of Resource Recovery and Recycling
  - Eu, Tb and Y oxides from lighting phosphors
  - Nd and Dy from magnets, mainly hard drives



# The Future

- Niels Bohr, “Prediction is very difficult, especially about the future.”
- Supply and Demand are dynamic
- Overreacting and underreacting are normal
  - Supply
  - Demand
  - Investors
  - Government
- Finding equilibrium is difficult & takes time
- Energy conservation is a major driver
- Flexible companies are most likely to survive
- Rigid companies are least likely to survive
- We need to use these materials wisely



# Rare Earths

		Sc																
		Y																
		La																

Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu

