MINERALS NEEDED FOR EMERGING GREEN TECHNOLOGIES AND CRITICAL MINERALS

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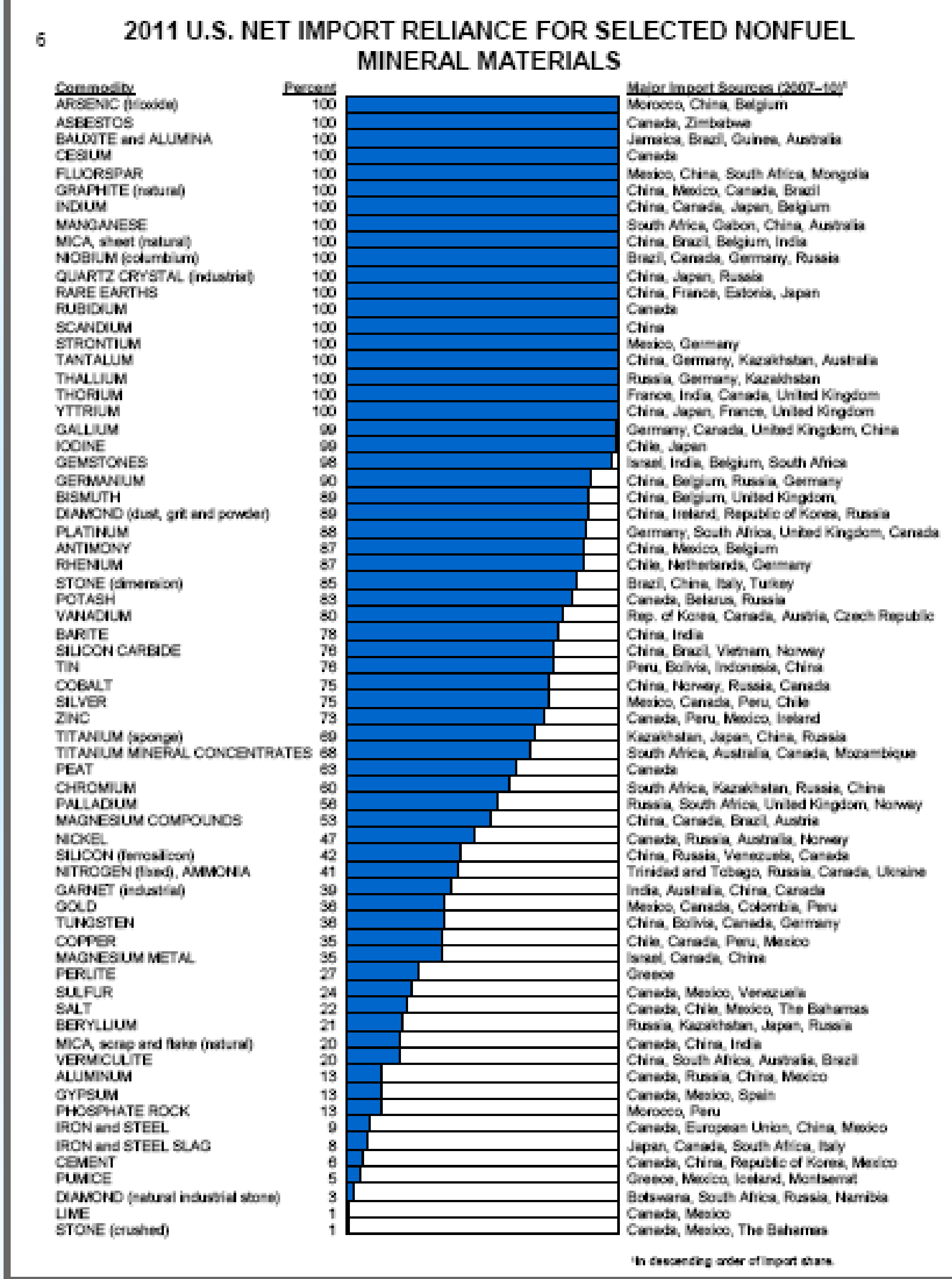
Schedule

- Field reports due April 30
- commodities presentation by students on May 7
- project presentations on May 7
- Final and project report due May 10

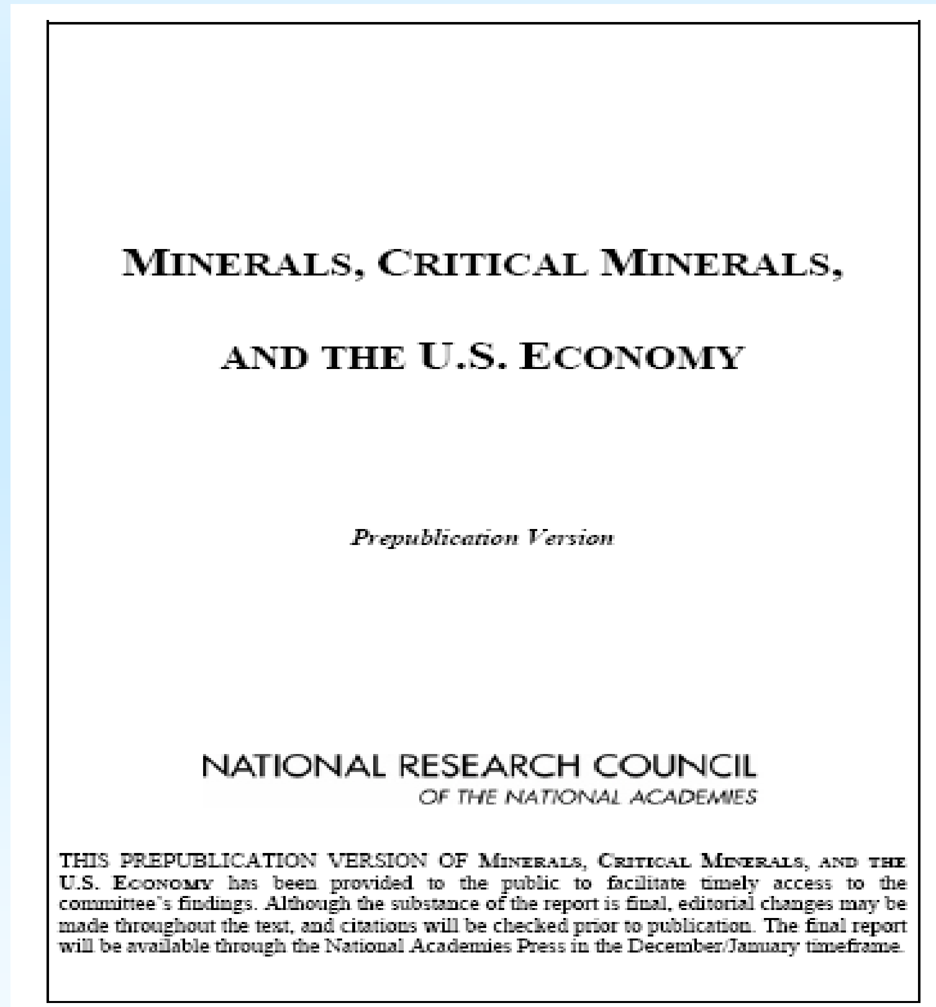
The US is 80% dependent for supply of 31 minerals.

This dependency implies criticality.



Essential for industry and emerging technologies and few or no substitutes exist

- All minerals have the potential to be critical
- Essential in use and subject to supply risk
- Differs over the short term, moderate term, and long term



MINERALS, CRITICAL MINERALS,

AND THE U.S. ECONOMY

Prepublication Version

NATIONAL RESEARCH COUNCIL

OF THE NATIONAL ACADEMIES

THIS PREPUBLICATION VERSION OF MINERALS, CRITICAL MINERALS, AND THE U.S. ECONOMY has been provided to the public to facilitate timely access to the committee's findings. Although the substance of the report is final, editorial changes may be made throughout the text, and citations will be checked prior to publication. The final report will be available through the National Academies Press in the December/January timeframe.

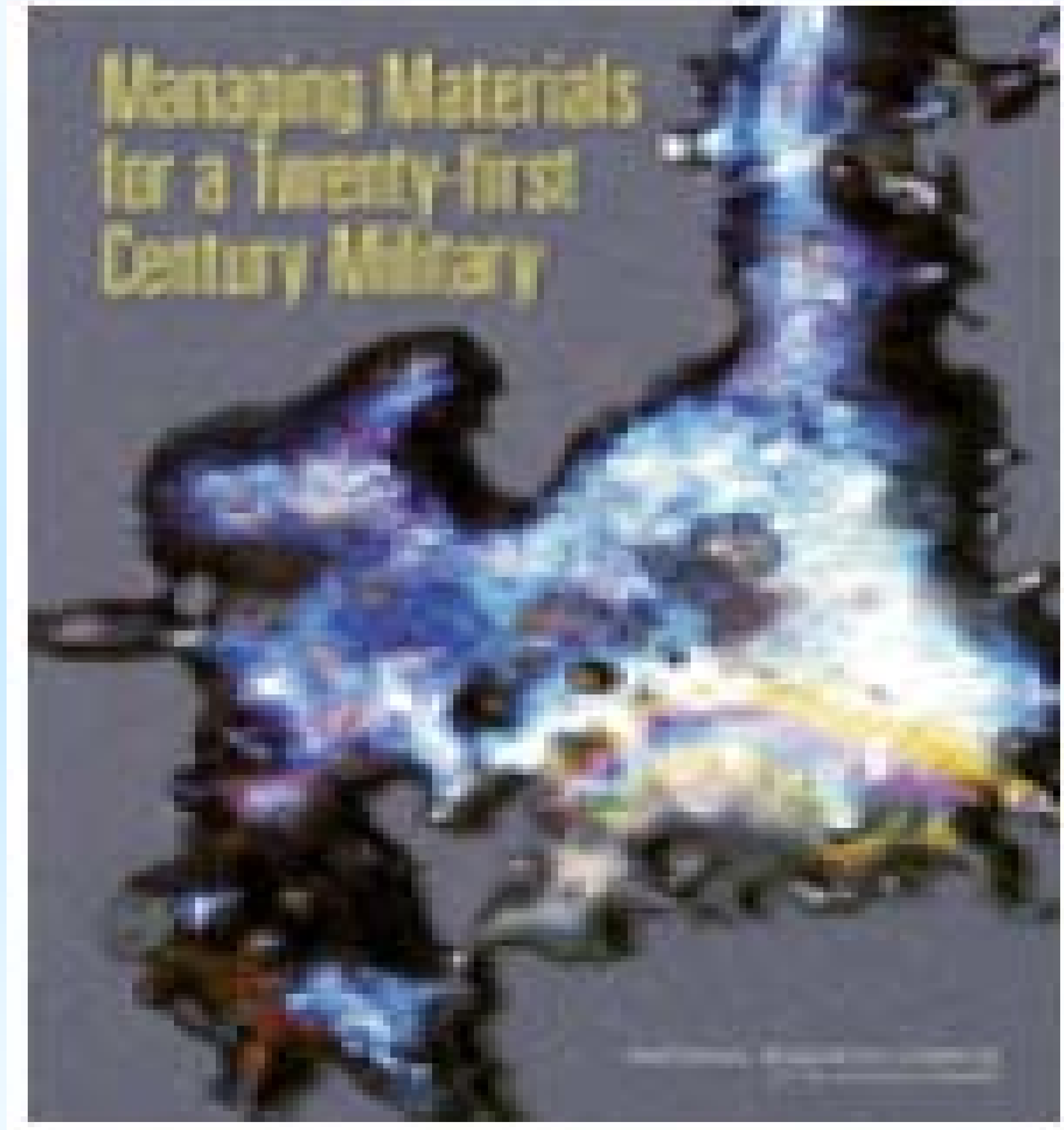
http://www.nma.org/pdf/101606_nrc_study.pdf

Strategic minerals

- National security and military needs or requirements during national emergencies

DOD

- REE
- U
- Be
- Cr
- Co
- Mn
- Ge
- PGM
- Ta
- Sn
- W
- Zn
- Al
- Bi
- B
- Cd
- Cu
- F
- Ga
- Hf
- In
- Pb



http://www.nap.edu/catalog.php?record_id=12028

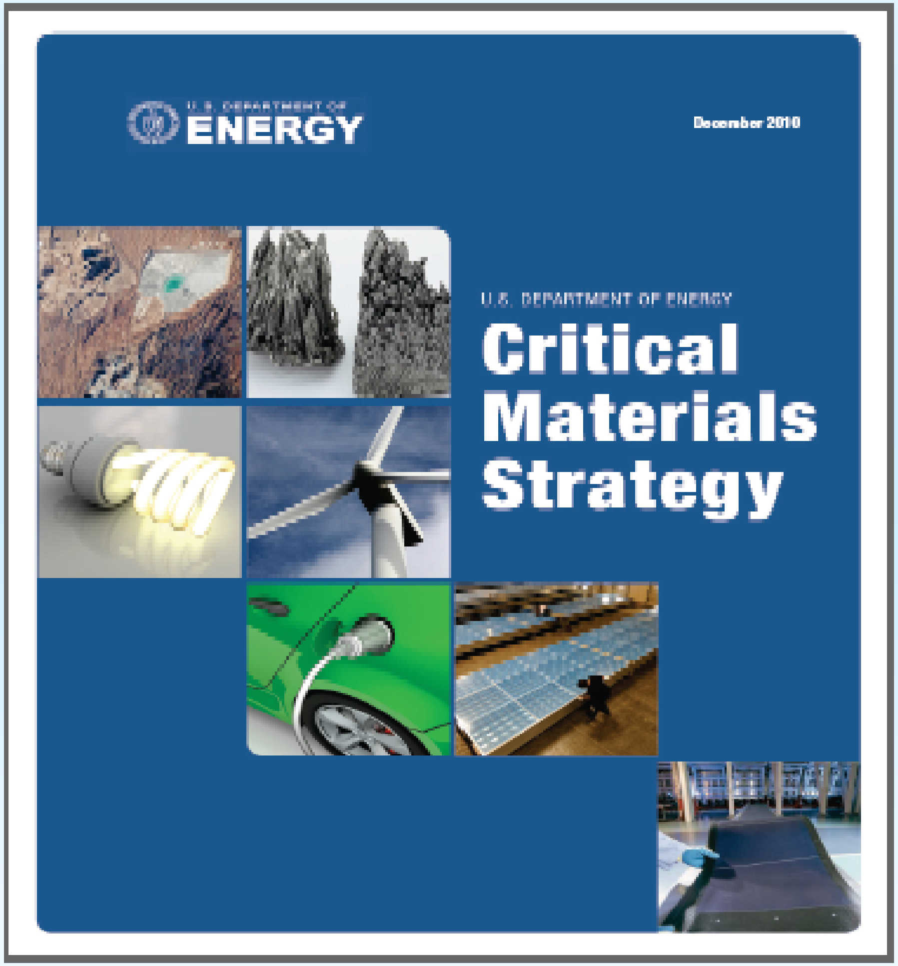
Green minor metals—basis for cleaner technology innovation

- Indium
- Germanium
- Tantalum
- PGM
- Tellurium
- Cobalt
- Lithium
- Gallium
- REE

http://www.unep.fr/shared/publications/pdf/DTIx1202xPA-Critical%20Metals%20and%20their%20Recycling%20Potential.pdf

Minerals required for clean energy technologies

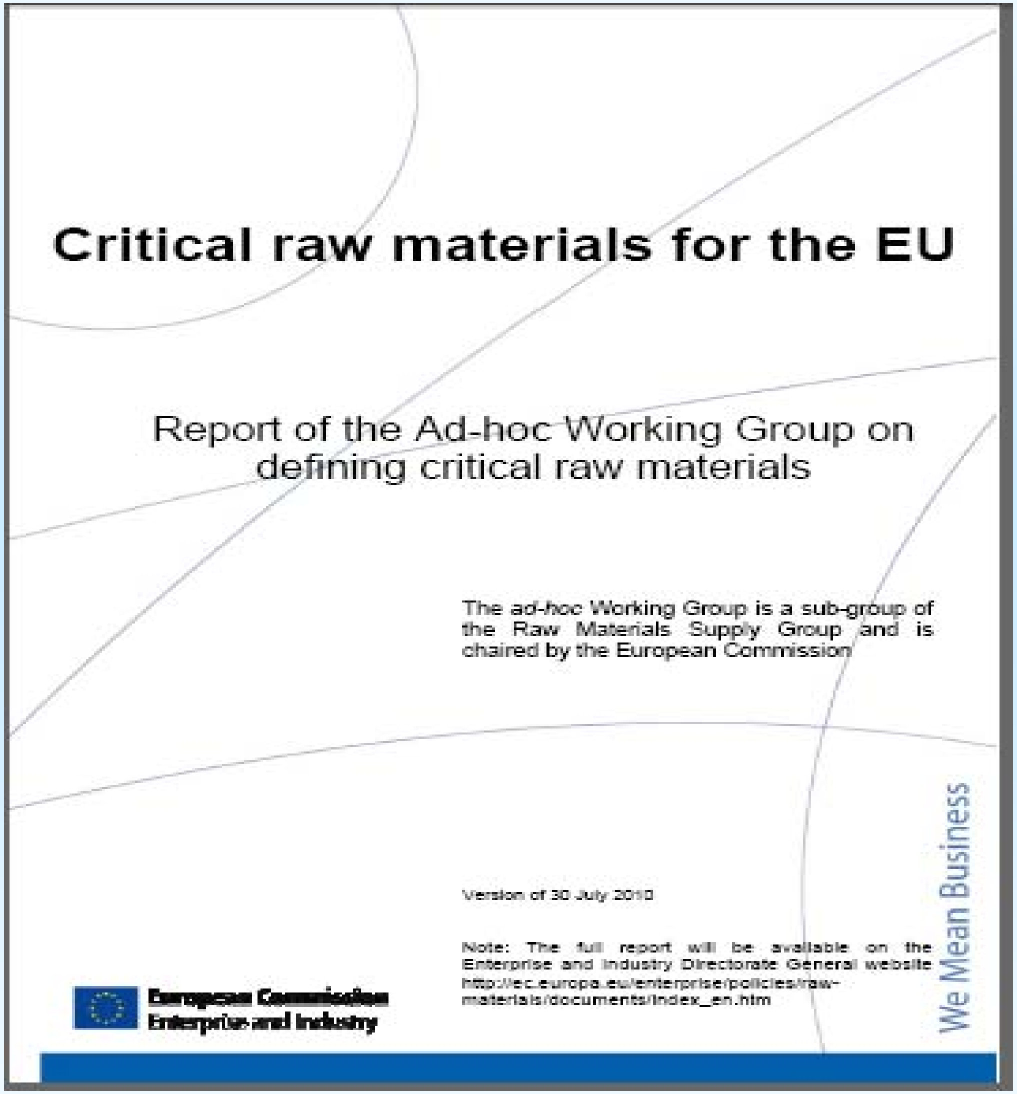
- Lithium
- Cobalt
- Gallium
- REE, Y
- Indium
- Tellurium



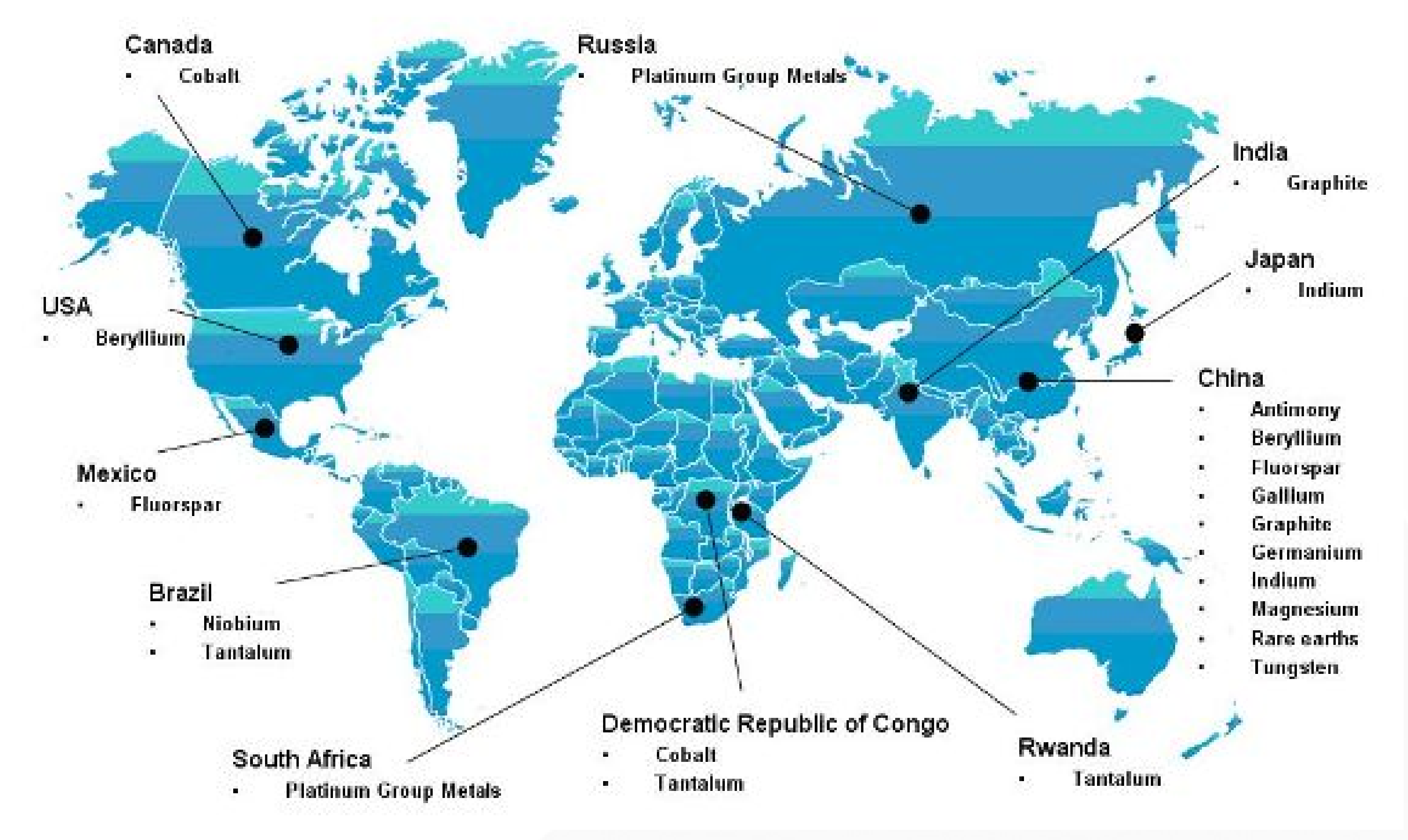
http://www.energy.gov/news/documents/criticalmaterialsstrategy.pdf

European Union

- Antimony
- Beryllium
- Cobalt
- Fluorspar
- Gallium
- Germanium
- Graphite
- Indium
- Magnesium
- Niobium
- PGM
- REE
- Tantalum
- Tungsten



http://ec.europa.eu/enterprise/policies/raw-materials/files/docs/report-b_en.pdf


Canada
Cobalt
Russia
Platinum Group Metals
India
Graphite
Japan
Indium
USA
Beryllium
China
Antimony
Beryllium
Fluorspar
Gallium
Graphite
Germanium
Indium
Magnesium
Rare earths
Tungsten
Mexico
Fluorspar
Brazil
Niobium
Tantalum
Democratic Republic of Congo
Cobalt
Tantalum
Rwanda
Tantalum
South Africa
Platinum Group Metals

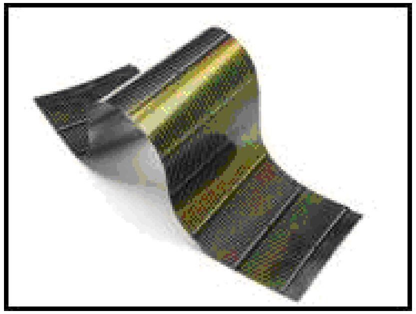
Global demand of the emerging technologies analysed for raw materials in 2006 and 2030 related to today's total world production of the specific raw material (Updated by BGR April 2010)

Raw material	**Production 2006 (t)**	**Demand from emerging technologies 2006 (t)**	**Demand from emerging technologies 2030 (t)**	**Indicator1) 2006**	**Indicator1) 2030**
Gallium	152 6)	28	603	0,18	3,97
Indium	581	234	1.911	0,40	3,29
Germanium	100	28	220	0,28	2,20
Neodymium (rare earth)	16.800	4.000	27.900	0,23	1,66
Platinum (PGM)	255	very small	345	0	1,35
Tantalum	1.384	551	1.410	0,40	1,02
Silver	19.051	5.342	15.823	0,28	0,83
Cobalt	62.279	12.820	26.860	0,21	0,43
Palladium (PGM)	267	23	77	0,09	0,29
Titanium	7.211.000 2)	15.397	58.148	0,08	0,29
Copper	15.093.000	1.410.000	3.696.070	0,09	0,24

1The indicator measures the share of the demand resulting from driving emerging technologies in total today's demand of each raw material in 2006 and 2030; 2) Ore concentrate

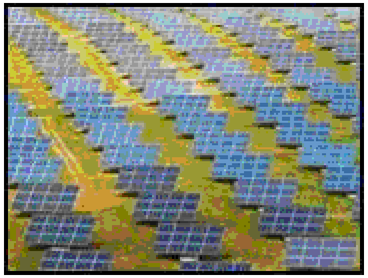
WHAT ARE GREEN TECHNOLOGIES?

Thin Film CIGS Solar



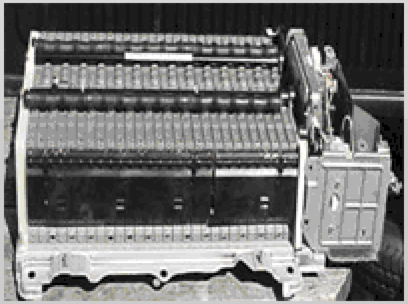
Lithium Battery

Solar Arrays



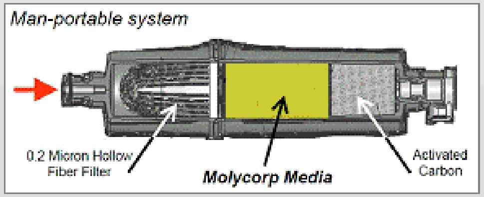
Catalytic Converter

Ga Galistan Thermometer



Battery pack for second generation Toyota Prius.

Source: hybridcars.com

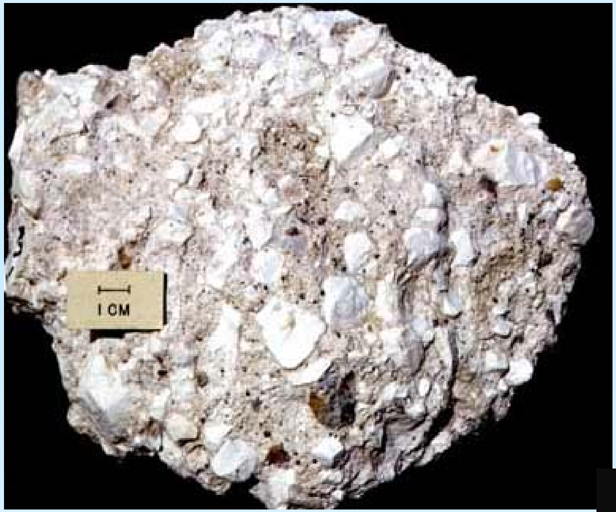


What are green technologies?

- Environmental technologies or clean technologies
- Future and existing technologies that conserve energy and natural resources and curb the negative impacts of human involvement, i.e. environmental friendly (modified from Wikipedia)
  - Alternative power (wind turbines, solar energy)
  - Hybrid and electric cars
  - Batteries
  - Magnets
- Other technologies
  - Water purification
  - Desalination
  - Carbon capture and storage

WHAT MINERALS ARE USED IN THESE GREEN TECHNOLOGIES?

Beryl

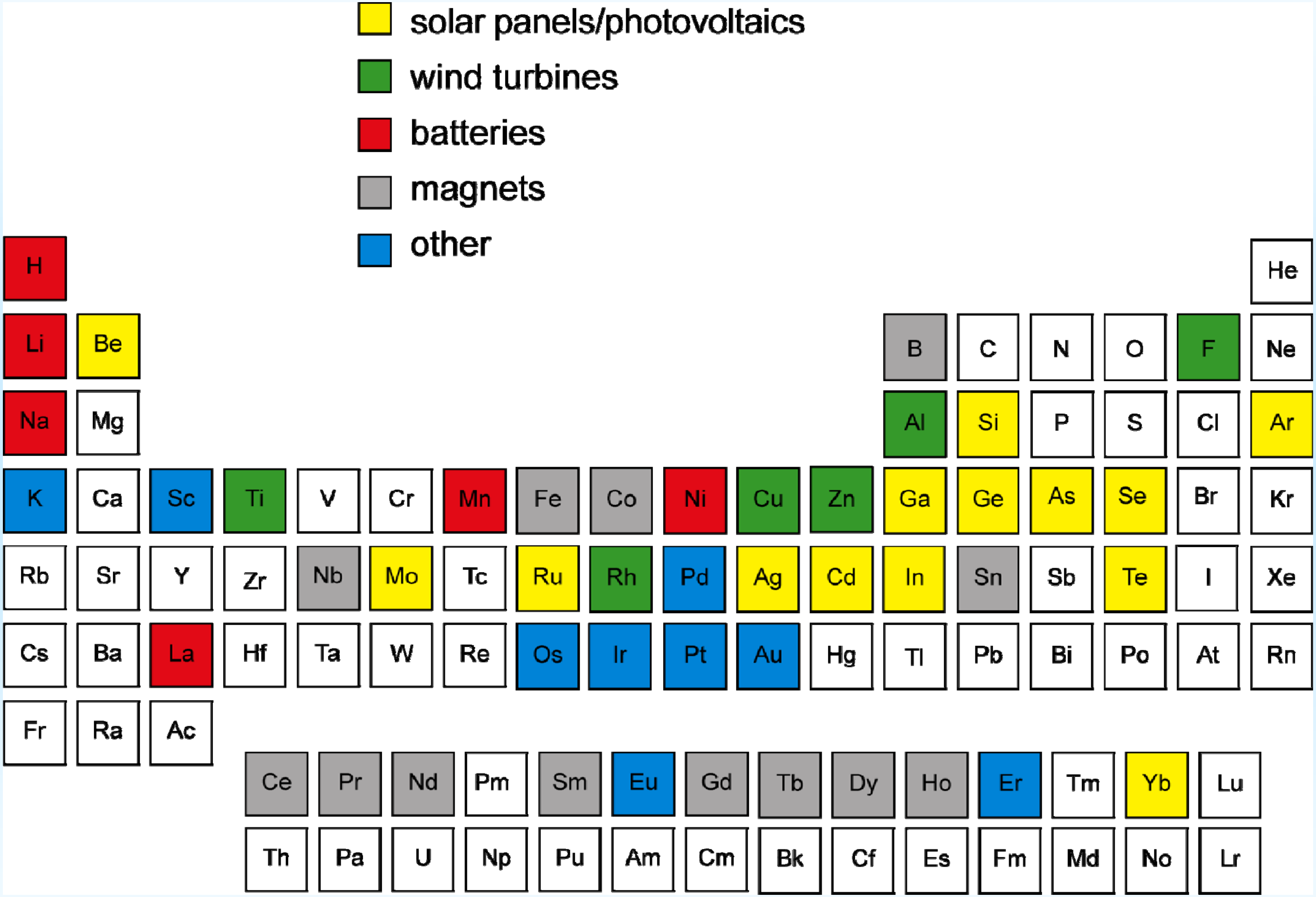


beryllium tuff (USGS OF 98-524)

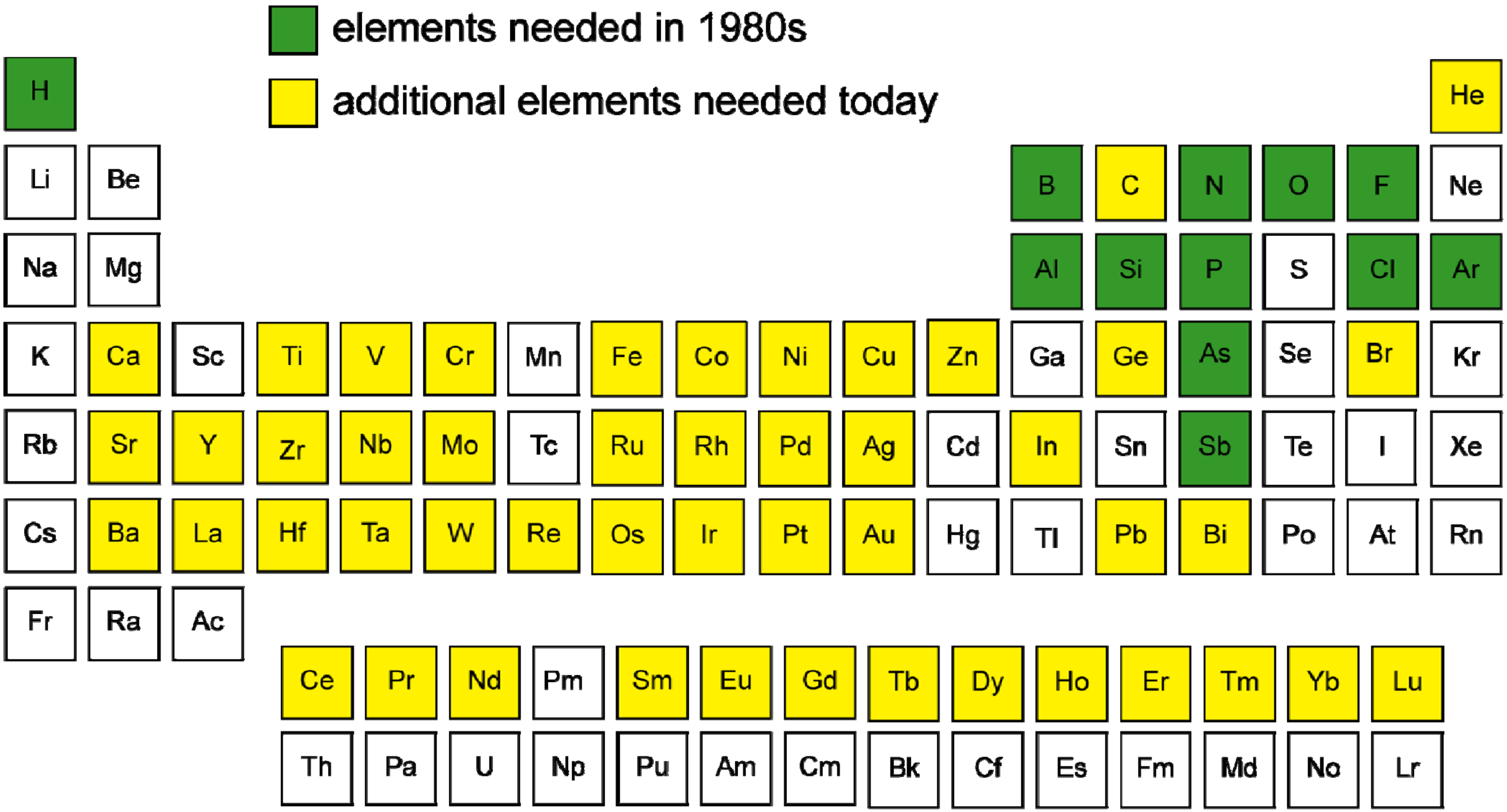
Bismuthinite - Bi_2S_3.

Monazite http://mineral.galleries.com

Kernite http://www.borax.com


solar panels/photovoltaics
wind turbines
batteries
magnets
other
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
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

Elements in Computer Chips
(National Research Council, 2007)



Common minerals

- Cement/concrete
- Copper
- Steel
- Aluminum
- Titanium

TABLE 2.2 Some Minerals and Their Weights and Properties in Today's Automobile

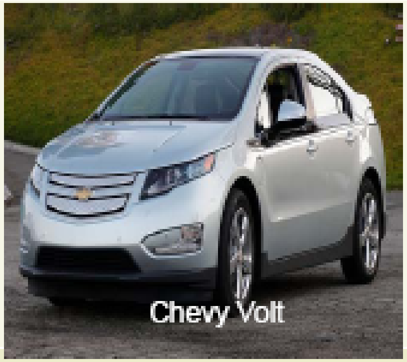
Mineral	2006 Weight (pounds/kilograms)	Property
Iron & Steel	2124/ 963	High strength, durability (frame, motor)
Aluminum	240/109	Light weight (frame, motor)
Carbon	50/23	Bond strengthener (tires and other rubber parts)
Copper	42/19	Electrical conductivity
Silicon	41/19	Bonding properties (windshields and windows)
Lead	24/11	Conductor (storage batteries)
Zinc	22/10	Galvanizer, strengthens in metal alloys (die cast parts and galvanized metal)
Manganese	17/8	Hardens as metal alloy
Chromium	15/7	Corrosion resistance and hardness as metal alloy
Nickel	9/4	Strength at elevated temperature and corrosion resistance as metal alloy
Magnesium	4.5/2	Alloying element with other metals like aluminum
Sulfur	2/0.9	Strengthens rubber tires
Molybdenum	1/4.5	Strength and toughness as metal alloy
Vanadium	<1/<0.45	Strengthens, hardens, lighter weight as metal alloy
Platinum	0.05-0.10 troy ounce/ 1.5 – 3.0 grams	Catalytic properties (catalytic converters)

http://www.nma.org/pdf/101606_nrc_study.pdf

Table 2-1. Materials in Clean Energy Technologies and Components

		CLEAN ENERGY TECHNOLOGIES AND *COMPONENTS*				
		Solar Cells	Wind Turbines	Vehicles		Lighting
	MATERIAL	*PV films*	*Magnets*	*Magnets*	*Batteries*	*Phosphors*
Rare Earth Elements	Lanthanum				●	●
	Cerium				●	●
	Praseodymium		●	●	●	
	Neodymium		●	●	●	
	Samarium		●	●		
	Europium					●
	Terbium					●
	Dysprosium		●	●		
	Yttrium					●
	Indium	●				
	Gallium	●				
	Tellurium	●				
	Cobalt				●	
	Lithium				●	

The Promise of Clean Energy Applications for REPM

Applications		Typical Quantity of REO per unit
Traditional – disc drives, personal electronic devices, etc.		Grams
Hybrid and electric vehicles – direct drives and electric assist motors		Kilograms
Direct Drive Wind Turbines		Metric Ton

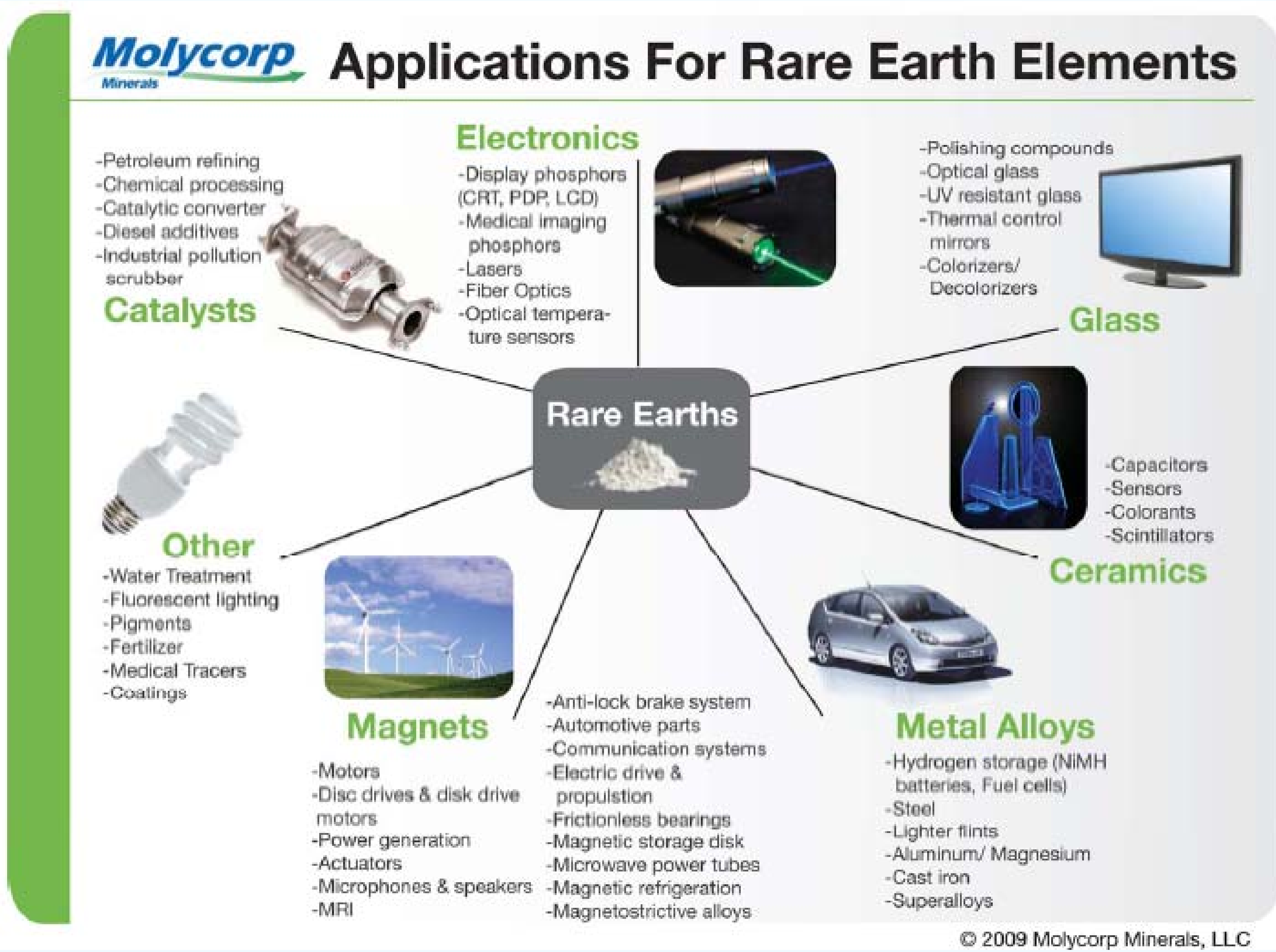
http://www.reitausa.org/storage/Challenges%20Facing%20New%20Global%20Rare%20Earth%20Separation%20Plants.pdf

Toyota Prius

2.2 lbs Nd in magnets

22-33 lbs La in batteries

http://www.molycorp.com/hybrid_ev.asp


Molycorp Minerals
Applications For Rare Earth Elements
Electronics
-Display phosphors (CRT, PDP, LCD)
-Medical imaging phosphors
-Lasers
-Fiber Optics
-Optical temperature sensors
-Petroleum refining
-Chemical processing
-Catalytic converter
-Diesel additives
-Industrial pollution scrubber
Catalysts
-Polishing compounds
-Optical glass
-UV resistant glass
-Thermal control mirrors
-Colorizers/ Decolorizers
Glass
Rare Earths
-Capacitors
-Sensors
-Colorants
-Scintillators
Ceramics
Other
-Water Treatment
-Fluorescent lighting
-Pigments
-Fertilizer
-Medical Tracers
-Coatings
Magnets
-Motors
-Disc drives & disk drive motors
-Power generation
-Actuators
-Microphones & speakers
-MRI
-Anti-lock brake system
-Automotive parts
-Communication systems
-Electric drive & propulsion
-Frictionless bearings
-Magnetic storage disk
-Microwave power tubes
-Magnetic refrigeration
-Magnetostrictive alloys
Metal Alloys
-Hydrogen storage (NiMH batteries, Fuel cells)
-Steel
-Lighter flints
-Aluminum/ Magnesium
-Cast iron
-Superalloys
© 2009 Molycorp Minerals, LLC

Significant Growth in Portable Lithium-Ion

Batteries

→ **Mobile Electronics**

WESTERN LITHIUM

Aerospace

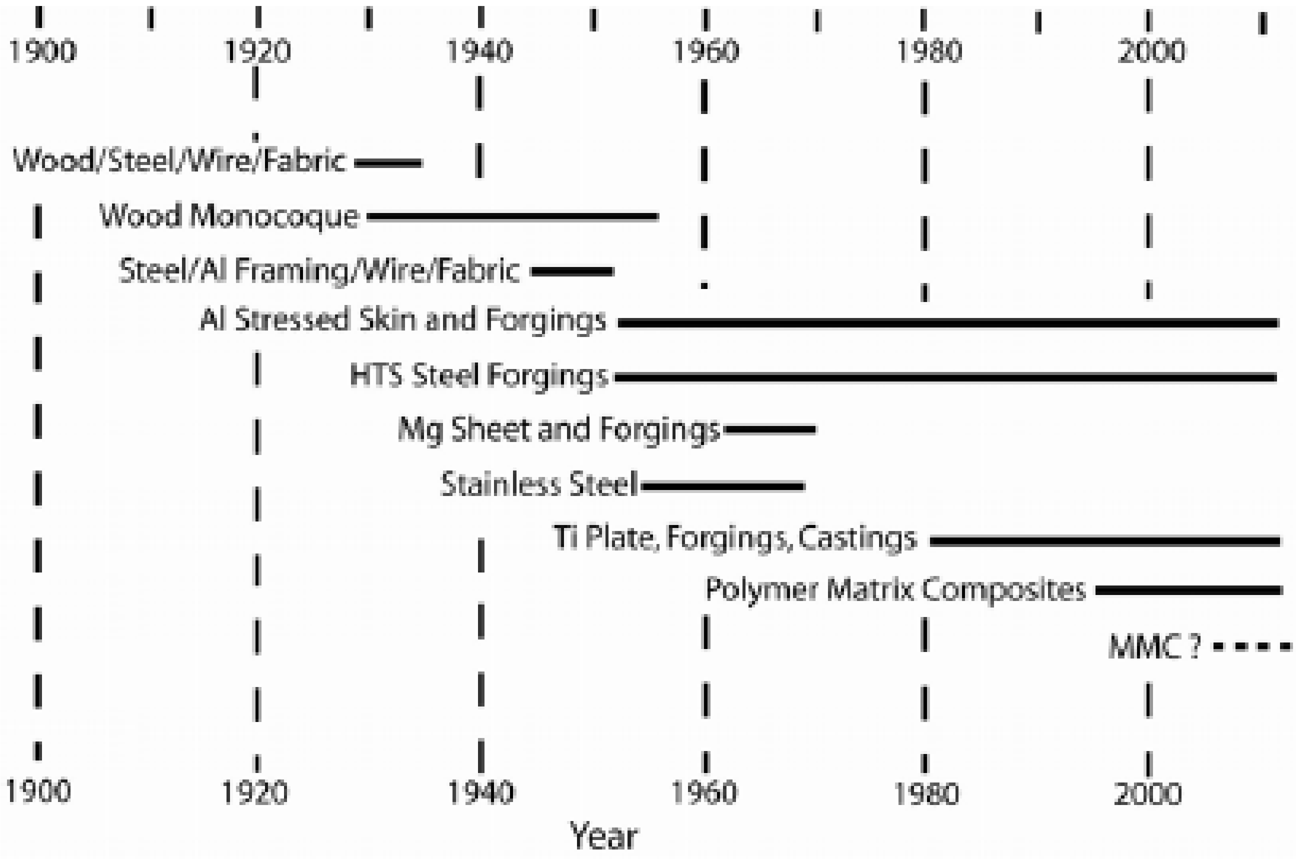


FIGURE 2.1 Aerospace frame materials and time of their introduction. Adapted after Air Force Scientific Advisory Board (1996)

http://www.nma.org/pdf/101606_nrc_study.pdf

Photovoltaics

- Specialty
  - Commercial
    - Silicon
    - Silver
    - **Tellurium**
    - Cadmium
  - Emerging
    - **Indium**
    - **Selenium**
    - Molybdenum
    - **Gallium**
    - Germanium
    - Arsenic
    - Ruthenium
  - Many minor materials (Ni, P, Zn, Sn, S, N, H, more)
- Bulk
  - Steel
  - Aluminum
  - **Copper**
  - Adhesive
  - Insulating
  - Concrete
  - Plastic

Ken Zweibel, GW Solar Institute, “Minerals for a Green Society”, Metallurgical Society of America, Feb 4, 2010

Photovoltaics

Approximate Amounts (2010)

	Thickness (microns), g/m2 (90% use)	g/W	Cost ($/g, $/W, $/m2; bulk, pure)	Competing Uses	Concern (mid- & long-term)
Te	3 um; 10-12 g	0.1 g/W (@ 110 W/m2)	$0.3/g, $0.03/W, $3.3/m2	Few and small	Price & Supply, and Intrinsic Availability
In	1-2 um; 2-4 g (In/Ga = 4)	0.02-0.04 g/W (@ 110 W/m2)	$0.5/g, $0.02/W, $1.5/m2	LCD (large and valuable)	Price & Supply, and Intrinsic Availability
Ga	1-2 um; 0.5-1 g (In/Ga =4)	0.005-0.01 g/W (@ 110 W/m2)	$0.5/g, $0.005/W, $0.4/m2	Few and small	Price & Supply, and Intrinsic Availability
Mo	1 um; 10 g	0.1 g/W (@ 110 W/m2)	$0.02/g, $0.002/W, $0.2/m2	Large	Price
Se	1-2 um; 3.5-7 g/m2	0.03-0.06 g/W (@ 110 W/m2)	$0.1/g, $0.005/W, $0.5/m2	Large and valuable	Price & Supply, and Intrinsic Availability
Ag	30 g/m2	0.2 g/W (@ 160 W/m2)	$0.5/g, 0.09/W, $15/m2	Large and valuable	Price
Cu				Large and valuable	Price

Ken Zweibel, GW Solar Institute, “Minerals for a Green Society”, Metallurgical Society of America, Feb 4, 2010

Photovoltaics

Approximate Future (2030) Amounts

	Thickness (microns), g/m2 (90% use)	g/W	Cost ($/g, $/W, $/m2; bulk, pure feedstock), 2010 prices	Competing Uses	How?
Te	2/3 um; 2 g	0.013 g/W (@ 150 W/m2)	$0.5/g, $0.007/W, $1/m2	Few and small	Thinner CdTe, Higher Efficiency
In	0.75 um; 1.5 g (In/Ga = 4)	0.01 g/W (@ 160 W/m2)	$1/g, $0.01/W, $1.5/m2	LCD (large and valuable)	Thinner CuInSe2 Alloy, Higher Efficiency
Ga for CIS	0.75 um; 0.4 g (In/Ga =4)	0.0025 g/W (@ 160 W/m2)	$1/g, $0.0025/W, $0.4/m2	Few and small	Thinner CuInSe2 Alloy, Higher Efficiency
Mo	0.5 um; 5 g	0.03 g/W (@ 160 W/m2)	$0.02/g, $0.0006/W, $0.1/m2	Large	Thinner Mo contact, Higher Efficiency
Se	0.75 um; 2.6 g/m2	0.016 g/W (@ 160 W/m2)	$0.2/g, $0.003/W, $0.5/m2	Large and valuable	Thinner CuInSe2 Alloy, Higher Efficiency
Ag	15 g/m2	0.07 g/W (@ 220 W/m2)	$1/g, 0.1/W, $15/m2	Large and valuable	Higher Efficiency
Cu				Large and valuable	

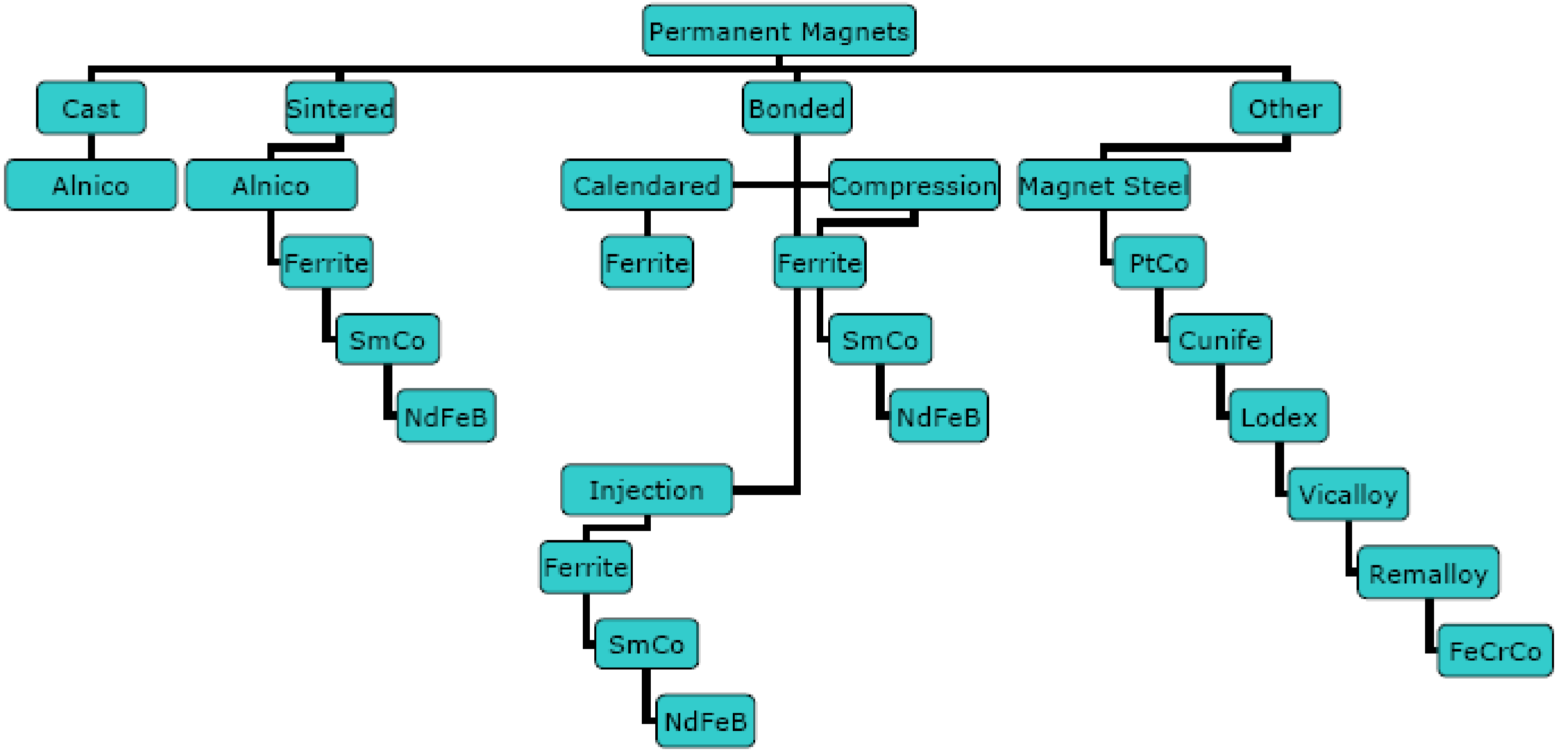
Ken Zweibel, GW Solar Institute, “Minerals for a Green Society”, Metallurgical Society of America, Feb 4, 2010

Permanent Magnets

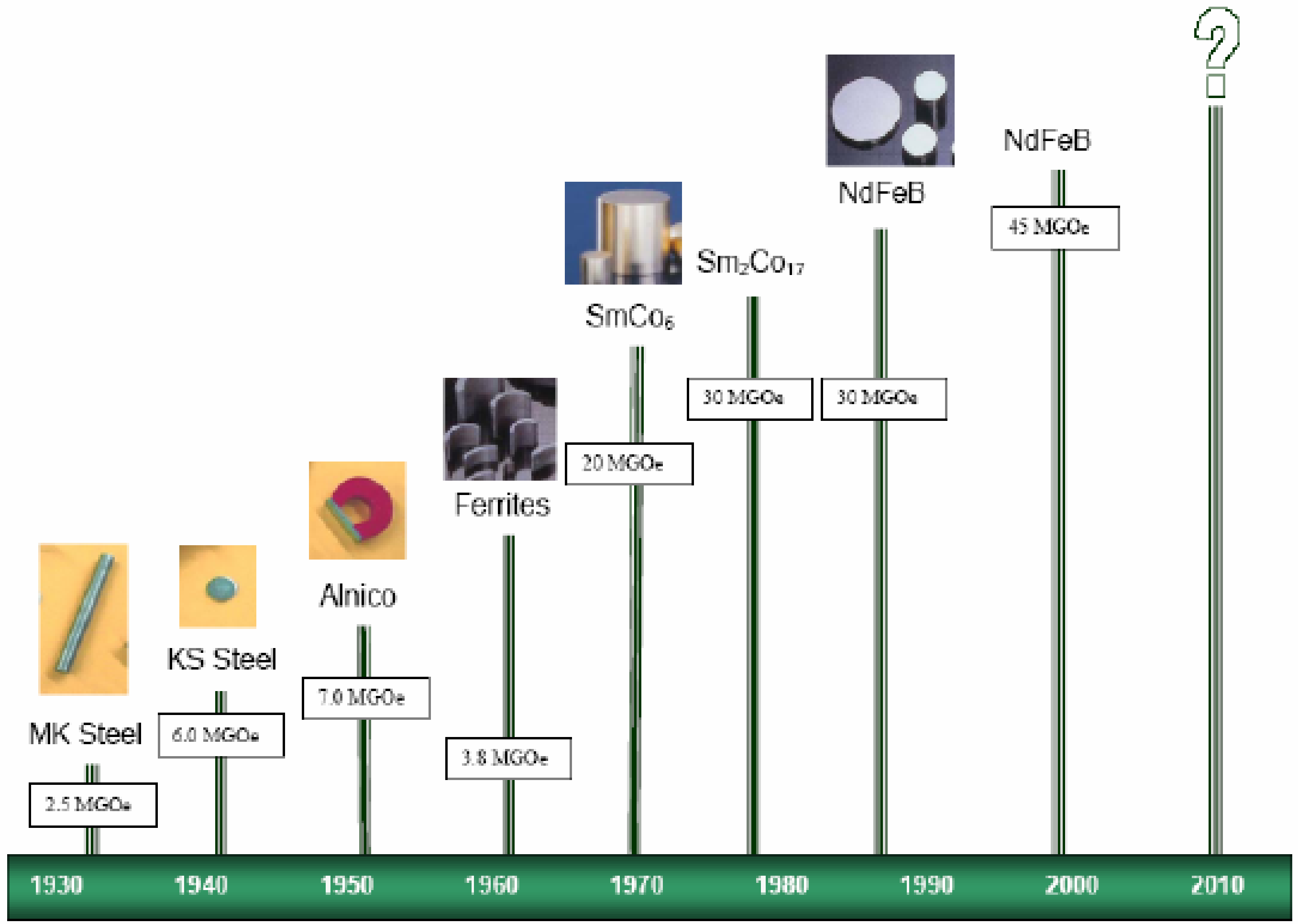
- Automotive
- Electronics
- Appliances
- Medical
- Military
- Aerospace
- Automation
- Wind turbines

- Fe
- Sm-Co
- Nd-Fe-B
- Cu-Ni-Fe
- Fe-Cr-Co
- Al-Ni-Co

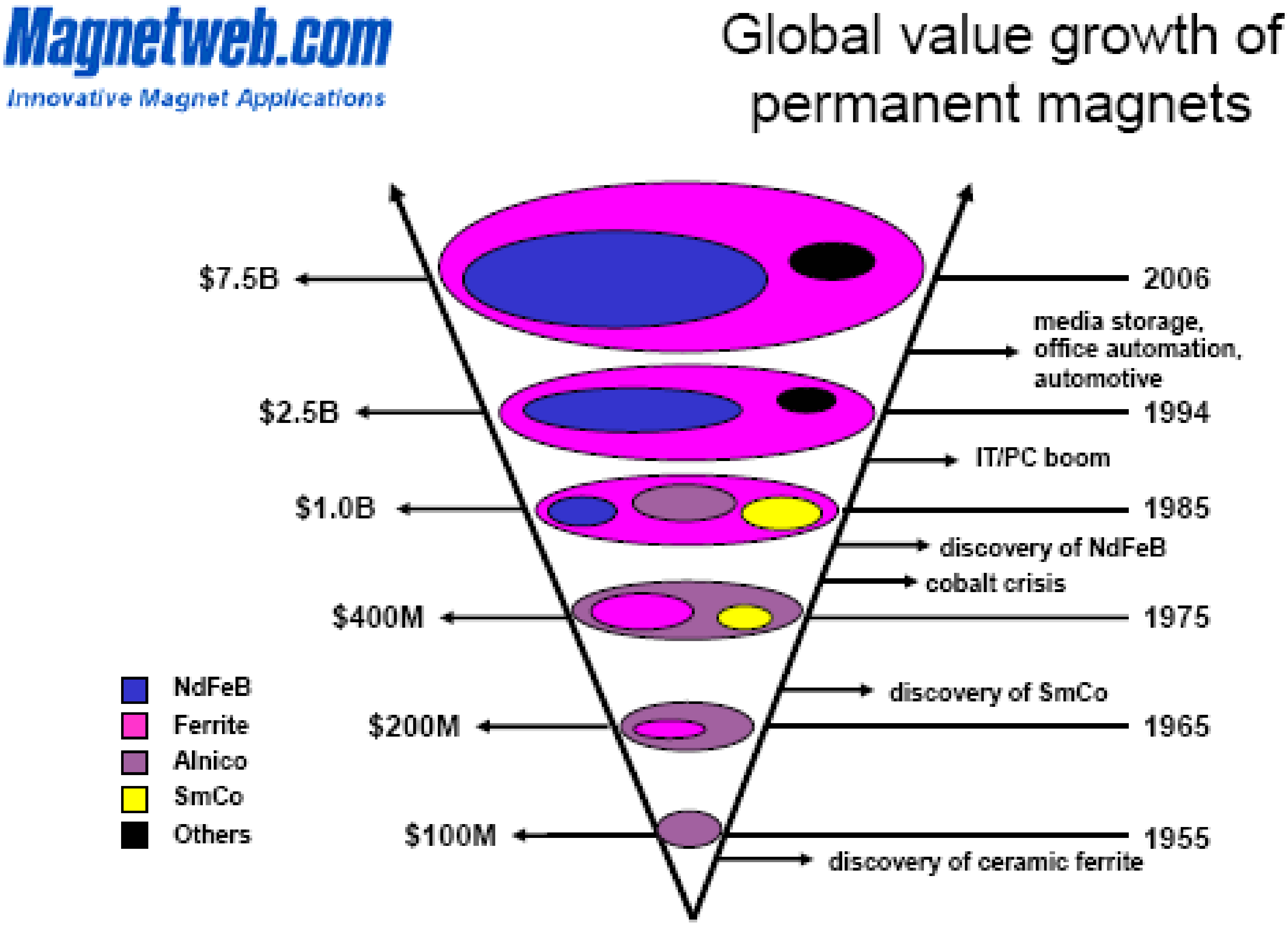
The Magnet Family



History of Magnetic Materials

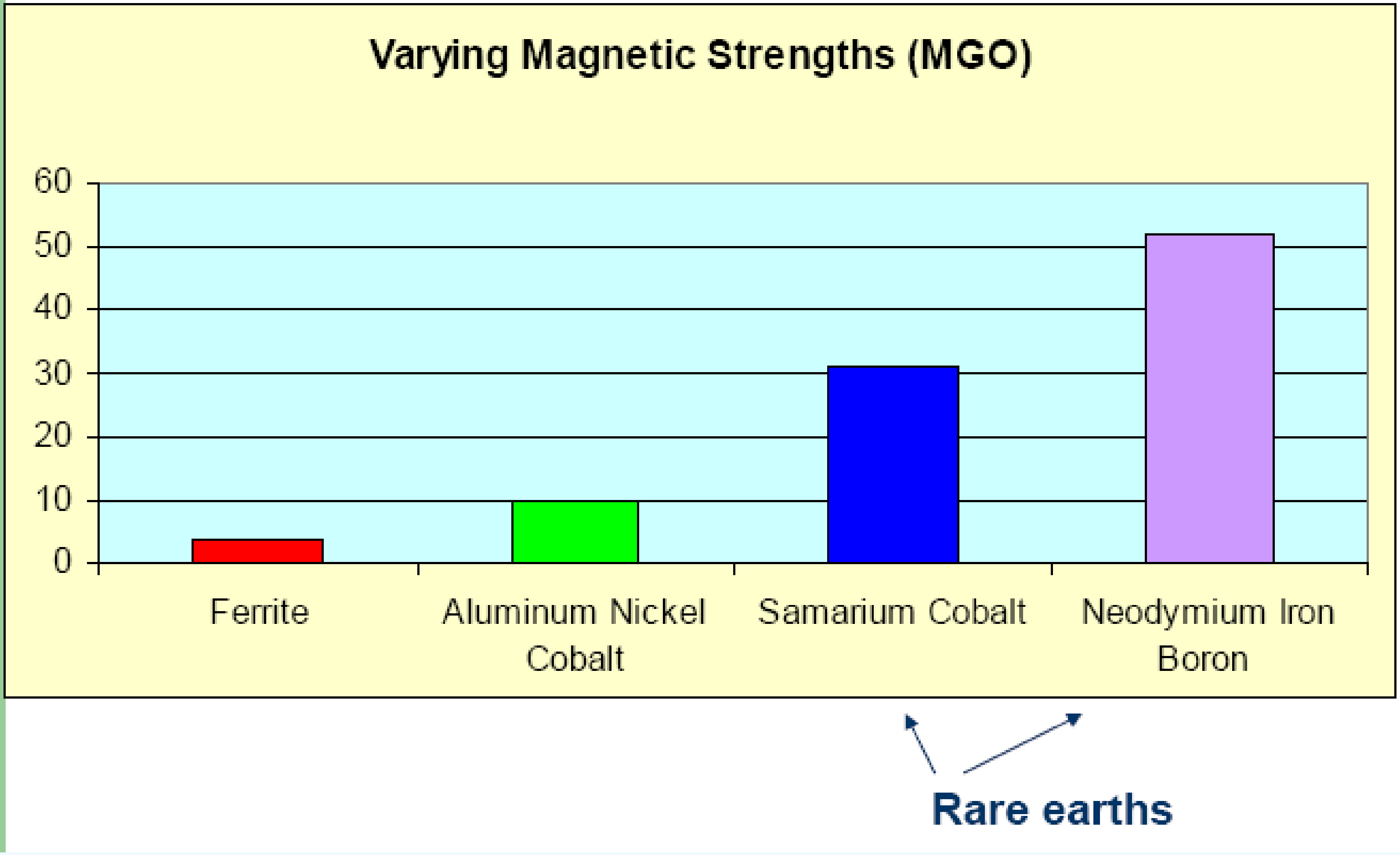


Global value growth of permanent magnets

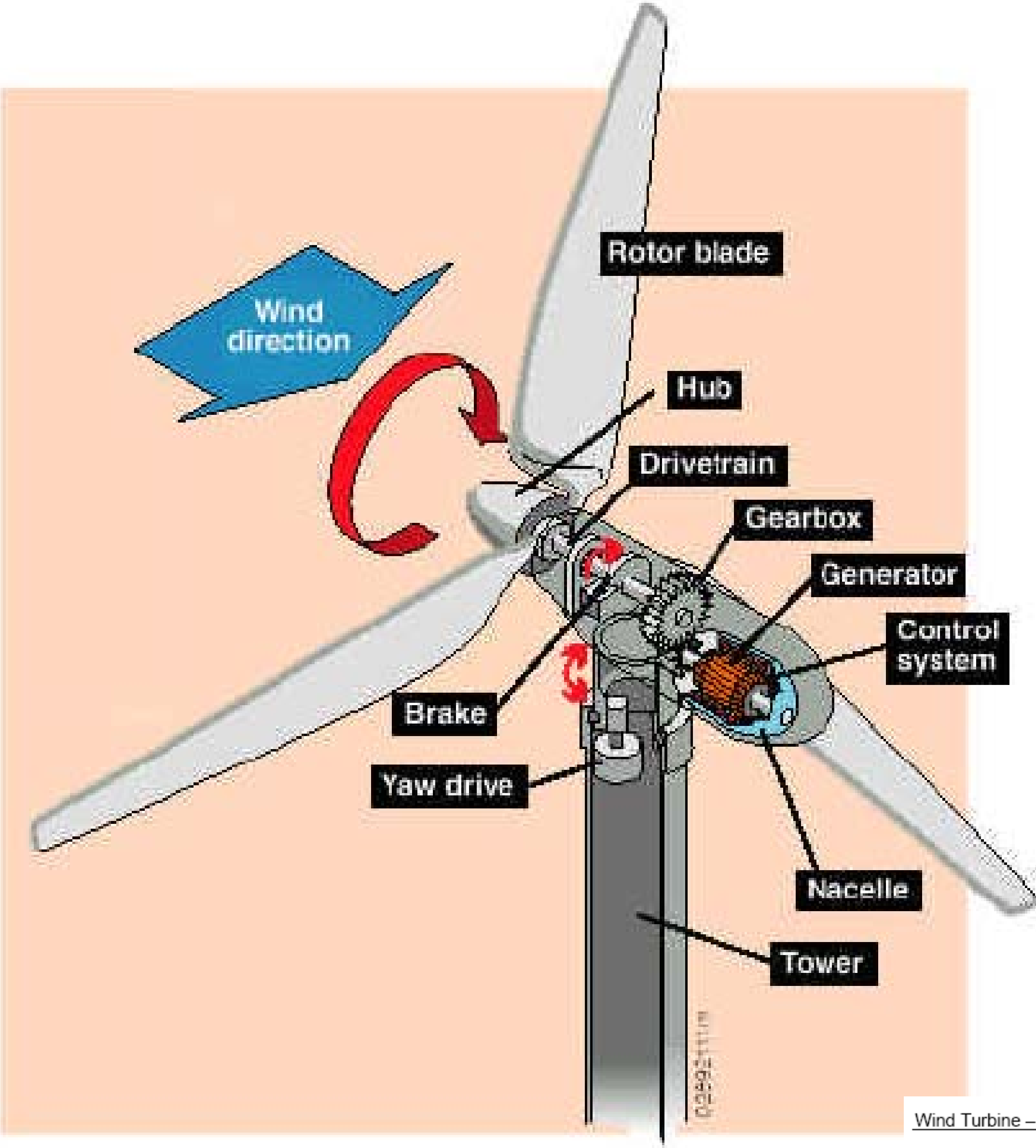


2007 Magnetics Conference

Permanent Magnet Types & Strength



Wind turbines



Wind Turbine Nomenclature

Wind Turbine - Materials and Manufacturing Fact Sheet

Prepared for the Office of Industrial Technologies, US Department of Energy
By Princeton Energy Resources International, LLC.
Dan Ancona and Jim McVeigh

Table 1. Turbine Component Weight and Cost

Component	% of Machine Weight	% of Machine Cost [5]
Rotor	10-14	20-30
Nacelle and machinery, less	25-40	25
Gearbox and drivetrain	5-15	10-15
Generator systems	2-6	5-15
Weight on Top of Tower	35-50	N/A
Tower	30-65	10-25

Table 3. Percentage of Materials Used in Current Wind Turbine Component

	Large Turbines and *(Small Turbines*[1]*)*							
Component/ Material (% by weight)	**Permanent Magnetic Materials**	**Pre-stressed Concrete**	**Steel**	**Aluminum**	**Copper**	**Glass Reinforced Plastic**[4]	**Wood Epoxy**[4]	**Carbon Filament Reinforced Plastic**[4]
Rotor								
Hub			*(95)* - 100	*(5)*				
Blades			5			95	*(95)*	*(95)*
Nacelle[2]	*(17)*		*(65)* - 80	3 - 4	14	1 - *(2)*		
Gearbox[3]			98 -*(100)*	*(0)* - 2	*(<1)* - 2			
Generator	*(50)*		*(20)* - 65		*(30)* - 35			
Frame, Machinery & Shell			85 - *(74)*	9 - *(50)*	4 - *(12)*	3 - *(5)*		
Tower		2	98	*(2)*				

Notes:
1. Small turbines with rated power less than 100 kW- (listed in italics where different)
2. Assumes nacelle is 1/3 gearbox, 1/3 generator and 1/3 frame & machinery
3. Approximately half of the small turbine market (measured in MW) is direct drive with no gearbox
4. Rotor blades are either glass reinforced plastic, wood-epoxy or injection molded plastic with carbon fibers

Wind Turbine - Materials and Manufacturing Fact Sheet

Prepared for the Office of Industrial Technologies, US Department of Energy

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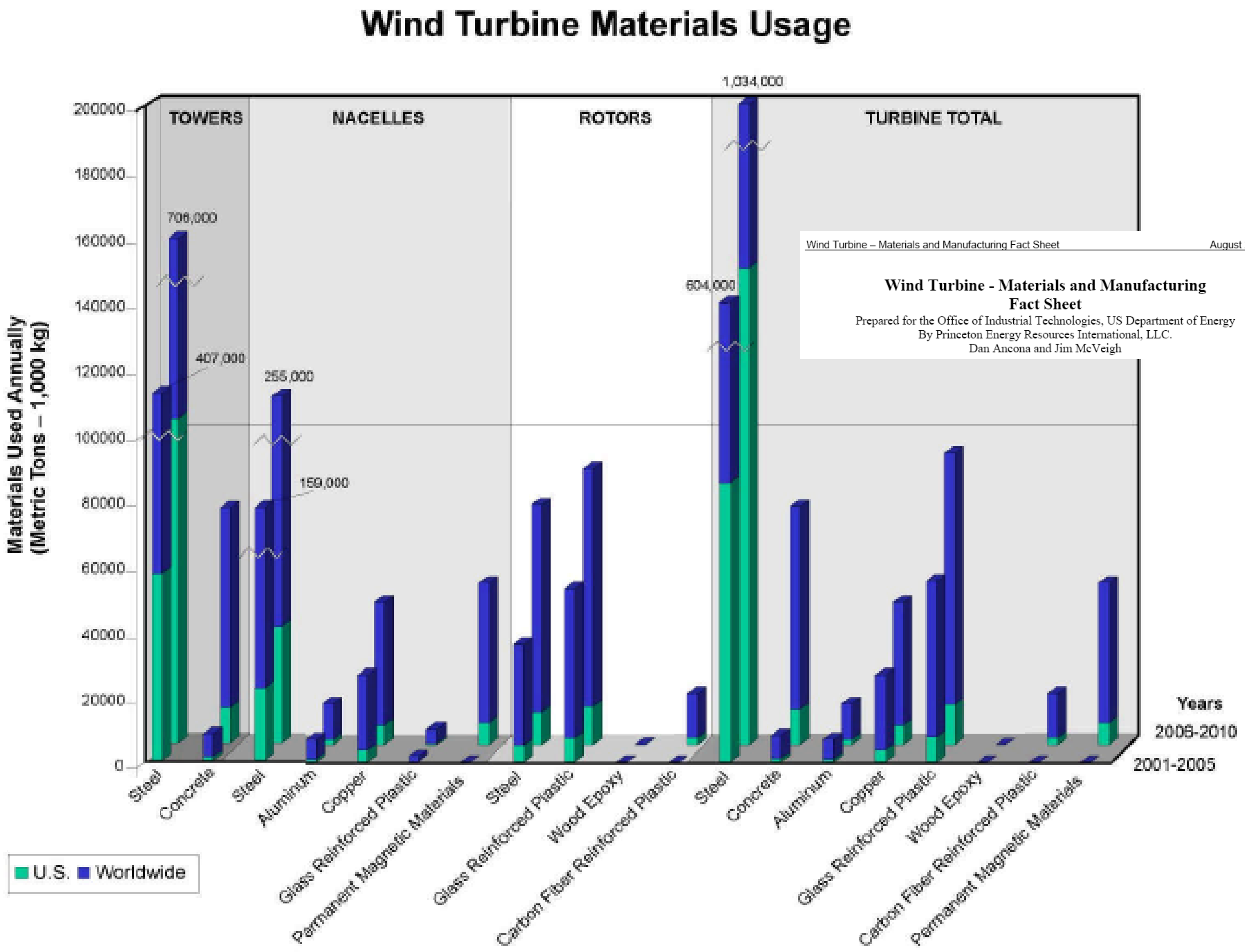

Wind Turbine – Materials and Manufacturing Fact Sheet August 29, 2001

Wind Turbine - Materials and Manufacturing Fact Sheet

Prepared for the Office of Industrial Technologies, US Department of Energy
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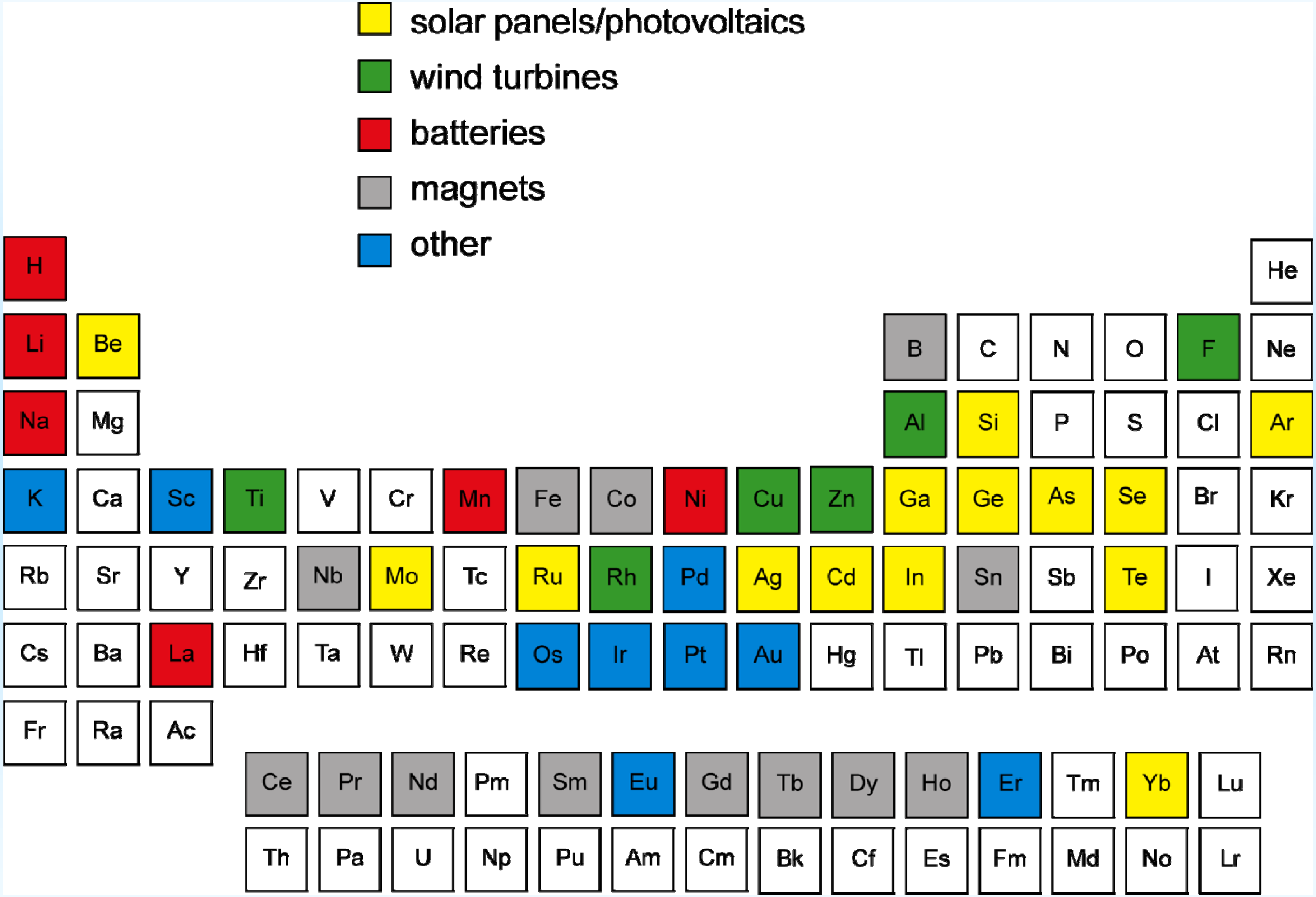

solar panels/photovoltaics
wind turbines
batteries
magnets
other
H
He
Li
Be
B
C
N
O
F
Ne
Na
Mg
Al
Si
P
S
Cl
Ar
K
Ca
Sc
Ti
V
Cr
Mn
Fe
Co
Ni
Cu
Zn
Ga
Ge
As
Se
Br
Kr
Rb
Sr
Y
Zr
Nb
Mo
Tc
Ru
Rh
Pd
Ag
Cd
In
Sn
Sb
Te
I
Xe
Cs
Ba
La
Hf
Ta
W
Re
Os
Ir
Pt
Au
Hg
Tl
Pb
Bi
Po
At
Rn
Fr
Ra
Ac
Ce
Pr
Nd
Pm
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
Th
Pa
U
Np
Pu
Am
Cm
Bk
Cf
Es
Fm
Md
No
Lr

Indium in solar panels

- 50 metric tons required for enough solar panels to provide 1 gigawatt of energy
- $500/kg in 2009
- 2008—US used 800 megawatts of energy by solar panels connected to the grid (0.1% total US energy)
- 600,000 metric tons reserves in the world in 2009
  - Zinc sulfide deposits
  - Tin-tungsten veins
  - Porphyry copper deposits

Ingots of Indium.

Beryllium

- Nuclear industry
  - Fuel rods
  - Shielding
- Telecommunications
- Modules for engine control computers, including in hybrid automobiles
- Solar industry in energy focusing assembly and storage units

FACT SHEET | CELL PHONE

What's in my Cell Phone?

- **Arsenic (gallium arsenide in the amplifier and receiver).** Mined in China, Chile, Morocco, Peru, Kazakhstan, Russia, Belgium and Mexico.
- **Copper (circuitry).** Mined in Chile, United States, Peru, China, Australia, Russia, Indonesia, Canada, Zambia, Poland, Kazakhstan and Mexico.
- **Gallium (gallium arsenide).** Mined in China, Germany, Kazakhstan and Ukraine.
- **Gold (circuitry).** Mined in China, United States, Australia, South Africa, Peru, Russia, Canada, Uzbekistan, Ghana, Papua New Guinea, Indonesia, Brazil, Mexico and Chile.
- **Magnesium compounds (phone case).** Mined in China, Turkey, North Korea, Russia, Slovakia, Austria, Spain, Australia, Brazil, Greece, India and the United States.
- **Palladium (circuitry).** Mined in Russia, South Africa, Canada, United States and Zimbabwe.
- **Platinum (circuitry).** Mined in South Africa, Russia, Canada, Zimbabwe, United States and Colombia.
- **Silver (circuitry).** Mined in Peru, Mexico, China, Australia, Chile, Russia, United States, Poland, Bolivia and Canada.
- **Tungsten (circuitry).** Mined in China, Russia, Canada, Austria, Bolivia and Portugal.
- A multitude of **petroleum products** are used in cellular phones.

INTERESTING FACTS

- About 130 million cell phones are retired annually in the United States. Collectively, these cell phones weigh about 14,000 metric tons. Annually retired cell phones contain almost 2,100 metric tons of copper, 46 metric tons of silver, 3.9 metric tons of gold, 2 metric tons of palladium, and 0.04 metric tons of platinum.
- Recovery and recycling of cell phones are in the early stages of development, as is the case for recycling of electronics in general. For cell phone recycling to grow, recycling must become economically viable. Efficient recovery infrastructure, product designs that simplify dismantling, and other changes are needed to facilitate the growth of cell phone recycling.
- Gallium arsenide is used in the amplifier and receiver.
- Magnesium compounds are alloyed to make the cell phone cases.

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www.mii.org www.smenet.org

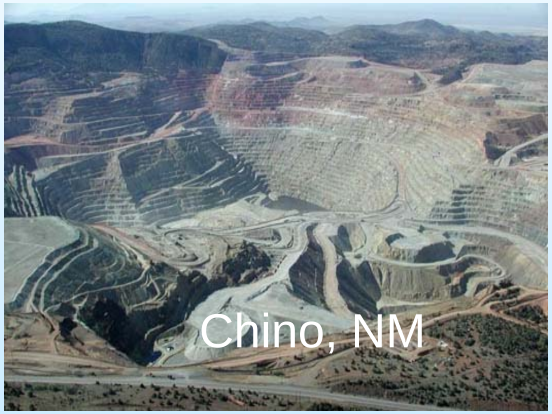
Graphite

- graphite comes in three forms: amorphous, flake and vein/lump. Amorphous graphite contains 70-75% carbon and is the most common. Flake graphite is 85-90% carbon and is used for higher value applications like batteries. Vein/lump graphite is 90-96% carbon and is most valuable because it requires the least processing.
- graphite is used in refractories – used to line high-temperature equipment; pencils; lithium-ion batteries – used in consumer electronics and electric vehicles; fuel cells; and Pebble Bed nuclear reactors. It is used in foundries, lubricants and brake linings. Graphite is also used to produce graphene, a tightly packed single layer of carbon atoms that can be used to make inexpensive solar panels, powerful transistors, and even a wafer-thin tablet that could be the next-generation iPad. Graphene, extremely light and strong, has been called "the world's next wonder material."
- the closure of graphite mines in China, which produces 75% of the world's graphite, has resulted in a fall in global graphite production to 1.3 million tonnes per annum in 2011. Like rare earths, China is restricting the export of graphite to protect its own domestic industries. The second largest producer is India, followed by Brazil, North Korea, Austria and Canada.
- Graphite exploration is focused in Canada, with eight companies exploring properties in Quebec and Ontario. Europe has a number of mothballed mines that could return to production.

- The United States, Europe and China have included graphite among a short list of critical metals.
- the US Geological Service estimates the graphite market to be 10 times the size of the market for rare earth elements. The graphite market is about the same size as the market for nickel. 60% of the market is amorphous graphite and 40% is flake graphite. Most of the growth is in flake graphite (see bullet point below)
- natural graphite can be processed to make synthetic graphite useful for high-value applications like lithium-ion batteries, but the process is expensive – $10,000 to $20,000/ton versus $3-4,000/t for flake graphite. The result is a race to find the best flake graphite deposits.
- graphite is different from gold, silver, copper, etc because users require a specific carbon purity level. "It's security of supply that keeps you up at night," says Berry.
- 33% of the graphite market produces refractories and crucibles (used in foundries); only 5% is for batteries. But the lithium-ion battery market is expected to grow by 25% a year.
- Three of the largest lithium-ion battery makers in the world, GS Yuasa Corp, LG Chem and Liotech, a consortium between Russia and China, are building the largest lithium-ion battery plant in the world, in Russia. "Just these three heavy hitters in the battery space are making multi-million dollar bets on the future of lithium-ion technology, which cannot push forward without graphite," says Berry.
- future uses of graphite could include vanadium-redox batteries and hydrogen fuel cells. Graphite could also potentially replace silicon in microchips and silver used in solar panels.
- by 2020 world consumption of graphite will be 1.9m tonnes, which does not include graphite needed for batteries, fuel cells and Pebble Bed nuclear reactors.

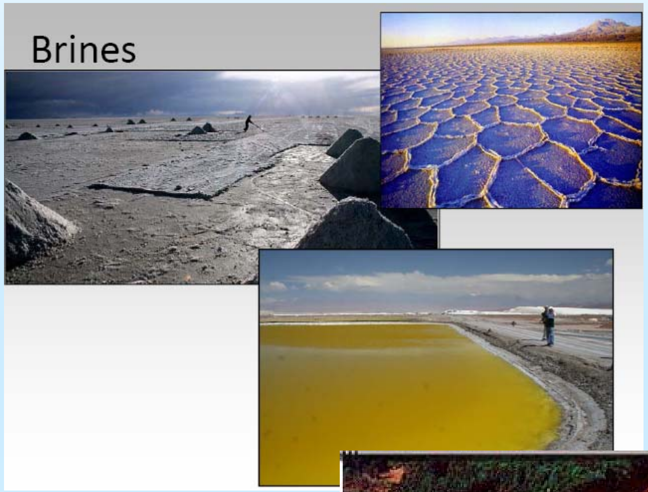
- China will require 400,000 tonnes of large flake graphite for Pebble Bed nuclear reactors and lithium-ion batteries will require 327,000 tonnes. The current supply of large flake graphite is 400,000t, so there will be a need to double the supply of large flake graphite used in batteries and nuclear reactors in the next eight years. "The takeaway is if you buy into the electrification thesis, and I'm halfway right, demand should easily outstrip supply," says Berry.

WHERE ARE THESE MINERALS FOUND?



Chino, NM

Mountain Pass carbonatite, CA



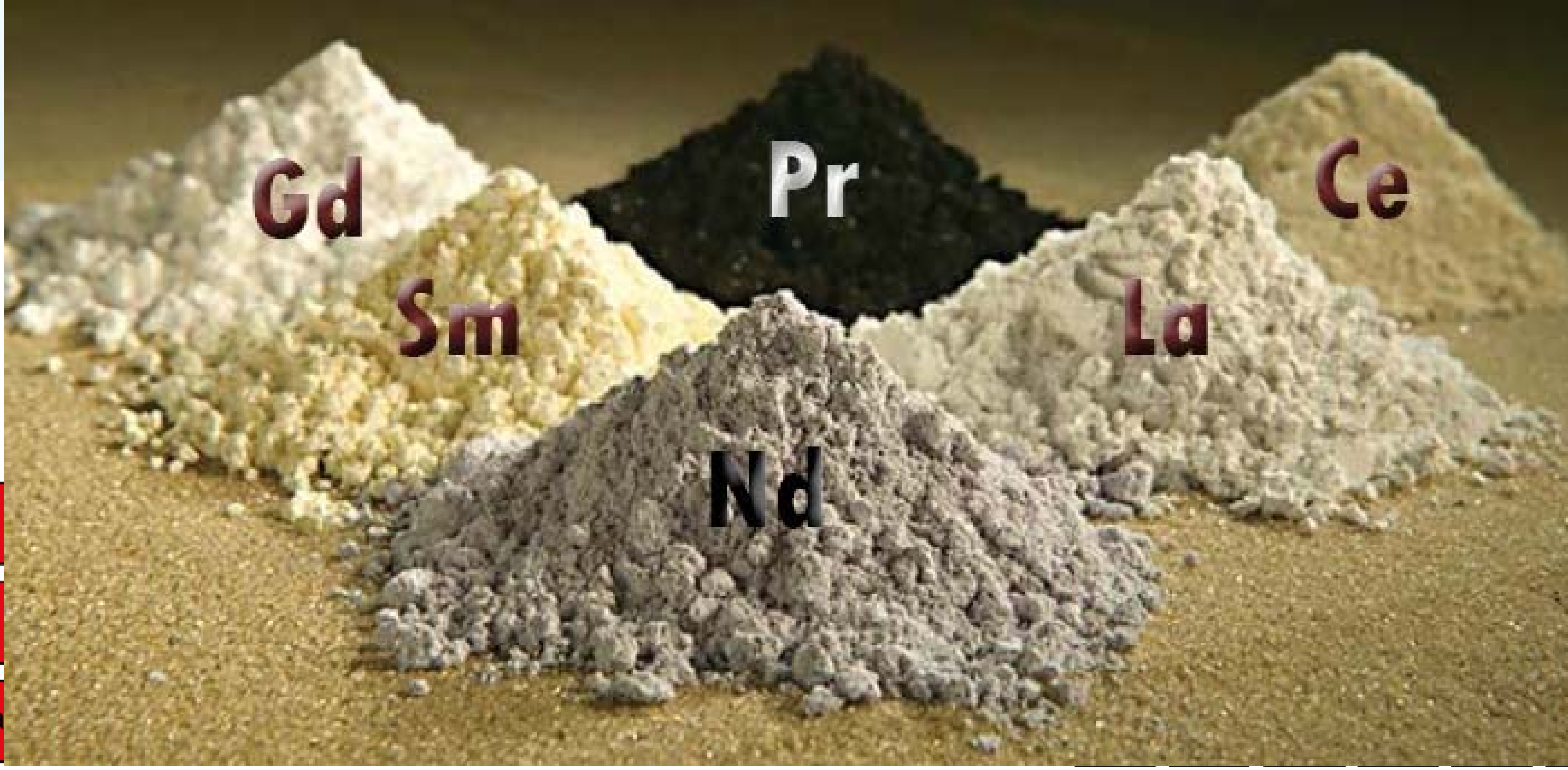
Sanastee beach placer sandstone,San Juan County, NM

Companhia Brasileira de Metalurgia e Mineração (CBMM), open pit mine for Nb, Minas Gerais, Brazil

http://www.us.cbmm.com.br/english/sources/mine/operat/f_operat.htm

WHERE ARE THESE MINERALS FOUND?

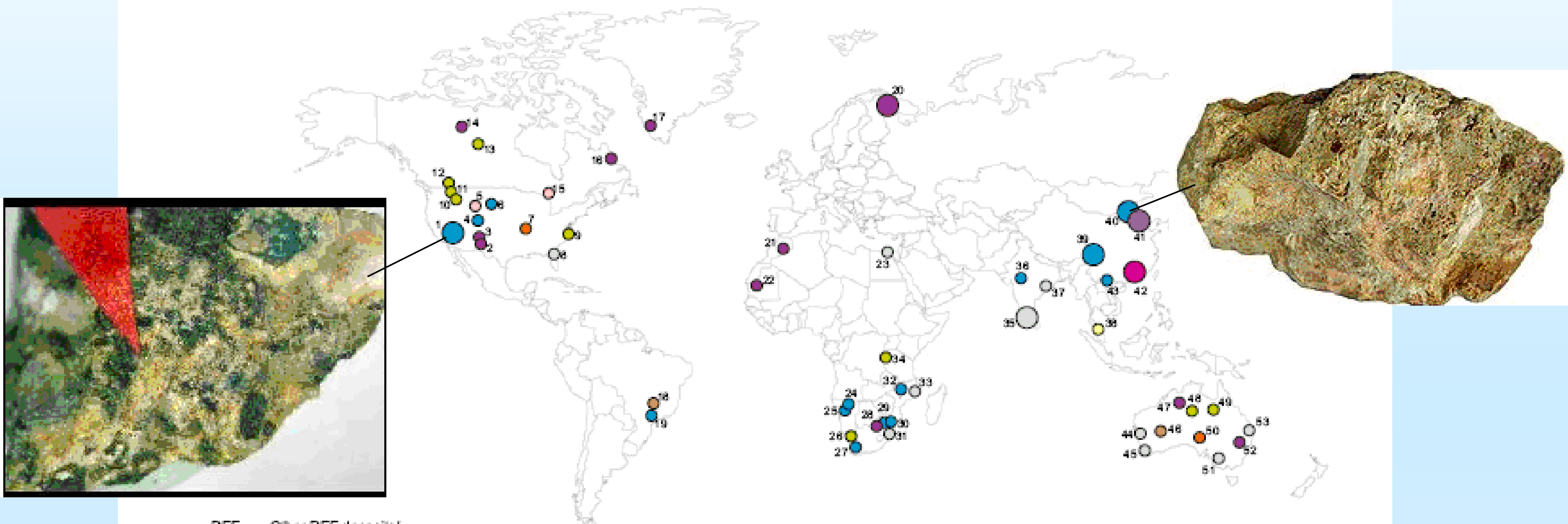
- Minerals are found in specific mineral deposits containing predominantly one or more of the minerals—Cu, Pb, Zn, Ni, PGM, Fe, Mo, **REE**, Be, U, etc.
- Minerals are found as a by-product or trace element in another type of mineral deposits and would be recovered only if metallurgical technologies are available and economically feasible—Cd, Se, Mo, Te, Au, Ag, etc.
- Minerals are extracted from the material remaining after refining of metals (anode slimes, refinery wastes)—Ga, Ge, In, etc.



H																	le
Li																	le
Na																	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															

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

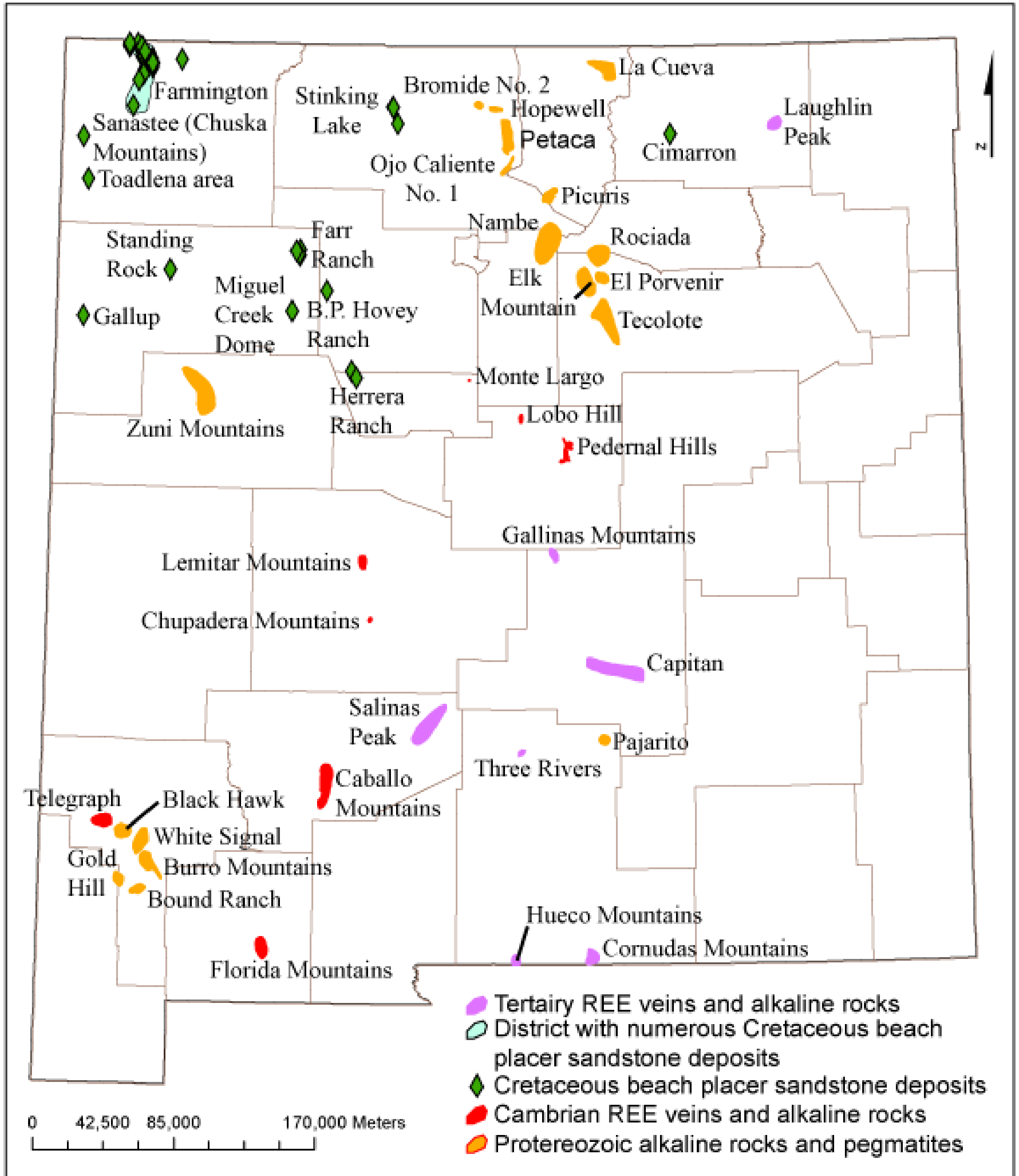
Rare Earth Elements



REE mines	Other REE deposits/ occurences		
●	●	Carbonatite-associated	Primary deposits
●	●	Alkaline igneous rock-associated	Primary deposits
	●	Iron-REE deposits	Primary deposits
	●	Hydrothermal deposits exclusive alkaline settings	Primary deposits
●	●	Marine placers	Secondary deposits
	●	Alluvial placers	Secondary deposits
	●	Paleoplacers	Secondary deposits
	●	Lateritic deposits	Secondary deposits
●	●	Ion-adsorption clays	Secondary deposits

1 Mountain Pass, USA
2 Pajarito Mountain, USA
3 Gallinas Mountains, USA
4 Iron Hill, USA
5 Bald Mountain, USA
6 Bear Lodge, USA
7 Pea Ridge, USA
8 Green Cove Springs, USA
9 Carolina placers, USA
10 Lemhi Pass, USA
11 Snowbird, USA
12 Rock Canyon Creek, Canada
13 Hoidas Lake, Canada
14 Thor Lake, Canada
15 Elliot Lake, Canada
16 Strange Lake, Canada
17 Ilímaussaq complex, Greenland
18 Araxa, Brazil
19 Barro do Itapirapua, Brazil
20 Lovozero and Khibina complexes, Russia
21 Tamazeght complex, Morocco
22 Bou Naga, Mauritania
23 Nile Delta and Rosetta, Egypt
24 Etaneno, Namibia
25 Okorusu, Namibia
26 Steenkampskraal, South Africa
27 Zandkopsdrift, South Africa
28 Pilanesberg Complex, South Africa
29 Naboomspruit, South Africa
30 Palabora, South Africa
31 Richards Bay, South Africa
32 Kangankunde, Malawi
33 Congolone, Mozambique
34 Karonge, Burundi
35 Chavara, India
36 Amba Dongar, India
37 Orissa, India
38 Perak, Malaysia
39 Maoniuping/Dalucao, China
40 Bayan Obo, China
41 Weishan, China,
42 Xunwu/Longnan, China
43 Dong Pao, Vietnam
44 Eneabba, Australia
45 Jangardup, Australia
46 Mount Weld, Australia
47 Brockman, Australia
48 Nolans Bore, Australia
49 Mary Kathleen, Australia
50 Olympic Dam, Australia
51 WIM 150, Australia
52 Dubbo Zirconia, Australia
53 Fraser Island, Australia

Figure 1 Map showing the global distribution of REE deposits.

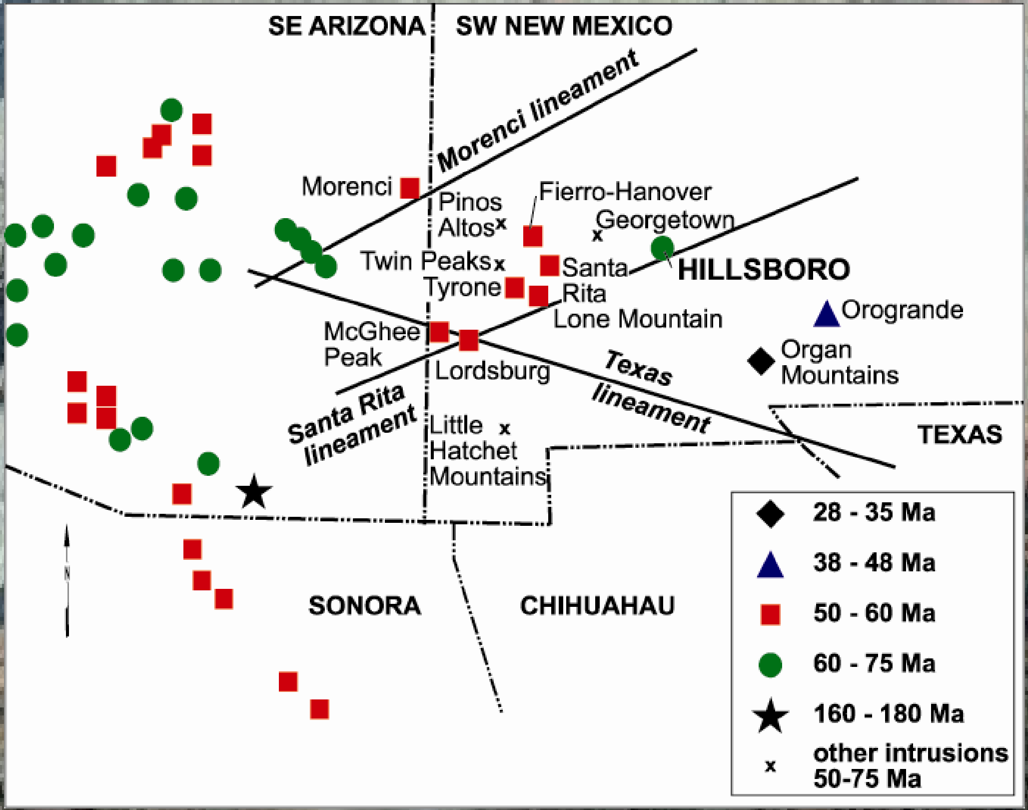


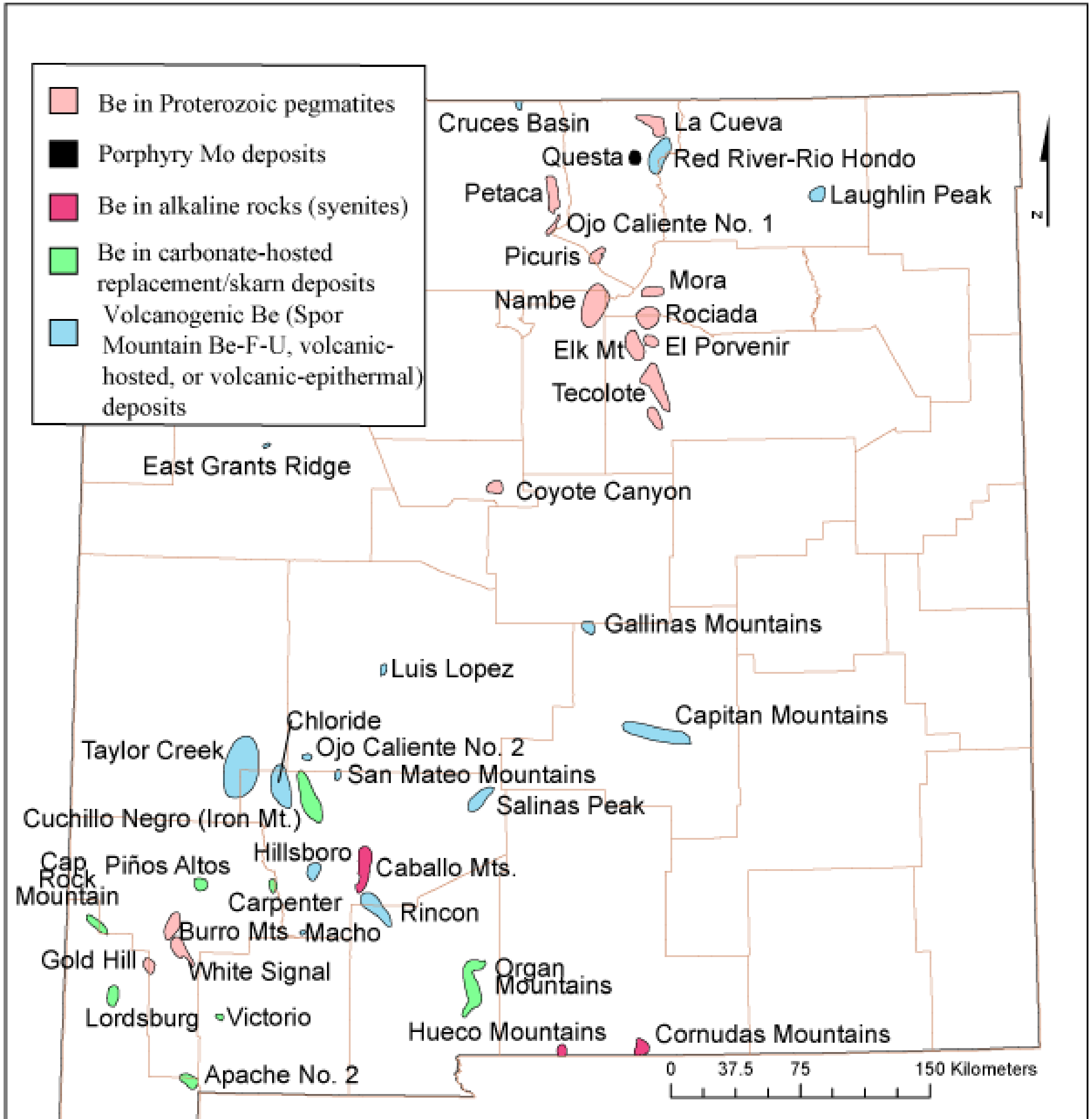
Mining districts and areas in New Mexico that contain REE deposits

Principal rare earth elements districts in the United States, which are described in this report.

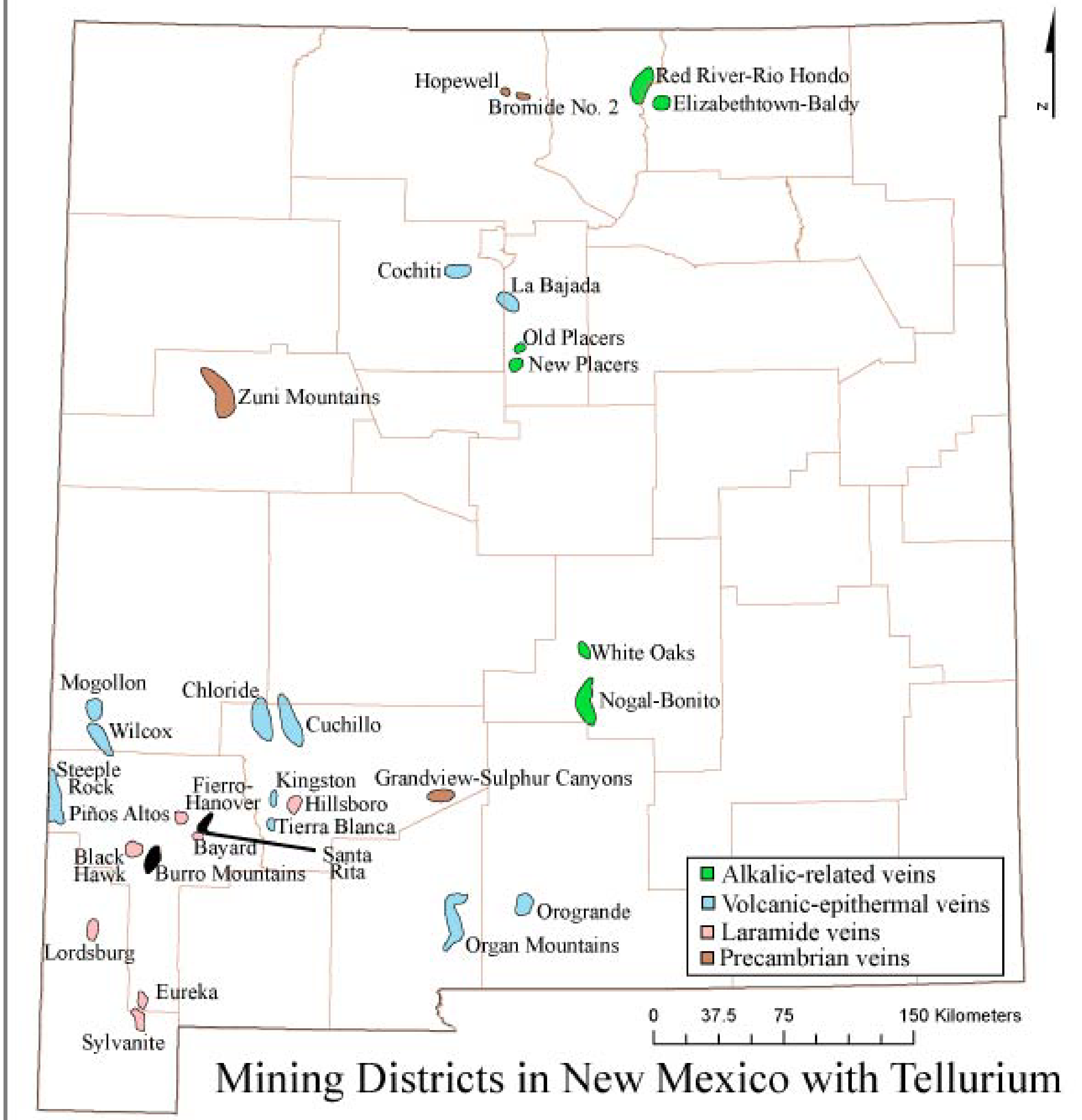
Porphyry copper deposits

- Current
  - Gold
  - Silver
  - Molybdenum
- Possible
  - Tellurium
  - Gallium
  - Germanium
  - Indium
  - Others





Mining Districts in New Mexico Containg Beryllium



Mining Districts in New Mexico with Tellurium

GENERAL COMMENTS

- Many of these minerals do not require the tonnages we are used to mine for metals like Fe, Cu, Pb, Zn—i.e. smaller deposits
- Some of these minerals are economically found in only 1-3 deposits in the world
- Some of these minerals are found in areas of the world that may not be economically unstable or particularly friendly to the U.S.
  - Minerals that provide major revenue to armed fractions for violence, such as that occurring in the Democratic Republic of Congo (GSA, Nov. 2010)
- Some of these minerals come only from the refining of metal deposits and are dependent upon that production
  - Many Cu and Au deposits utilize heap leach technology, which leaves other potential minerals unrecovered in the heap leach

Commodity	US production 2009 mt	World production 2009 mt	consumption 2009 mt	Price 2009	World reserves 2009 mt
Cu	1,190,000	15,800,000	1,660,000	$2.3/lb	540,000,000
Au	210	2,350	170	$950/oz	47,000
REO	0	124,000	7,410	varies	99,000,000
Be	120	140	140	$120/lb	15900+
Sb	0	187,000	22,400	$2.3/lb	2,100,000
As	385	52,500	3,600	$0.92/lb	1,070,000
Bi	100	7,300	1,020	$7.4/lb	320,000
Ga	0	78	20	$480/kg	1,000,000
Ge	5	14	5	$950/kg	450+
Te	W		W	$145/kg	22,000
cement	71,800,000	2,800,000,000	73,800,000	$100/mton	

Comments

- There are many REE deposits in the world, including NM
- The problem is in the processing of the REE for the manufacture of the components
- Engineers are looking for substitutions that would require other commodities and so less REE could in fact be required
- The technologies of the products are changing more rapidly then we can get mines on line

Comment

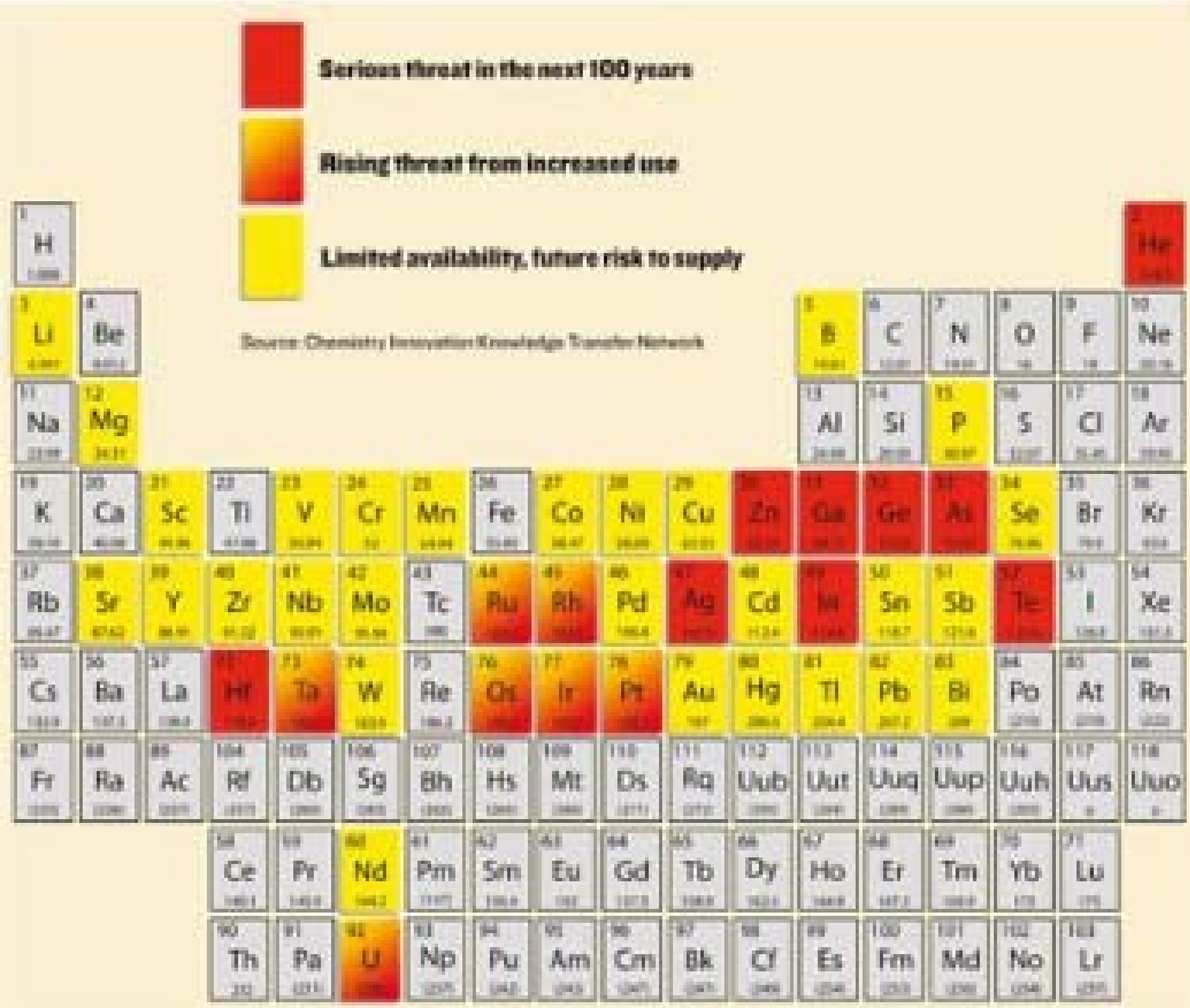
- Analytical labs are swamped (i.e., too long) and expensive
- There is a need for relatively quick, inexpensive methods to delineate drill hole targets
- Developing a procedure using a portable X-ray fluorescent instrument to use in stream sediment and soil surveys to aid in exploration
- This is one area we are looking at
  - Strategic Resources is funding this work

SOME OF THE CHALLENGES IN PRODUCING THESE TECHNOLOGIES

Key Issues with Critical Metals

- Supply Concentration due to deposit nature and location
- Supply Concentration due to government subsidies
- Cartel style supply management – quotas and stockpiles
- Resource nationalism – domestic downstream beneficiation
- Long term cost volatility & price uncertainty
- Complex recovery processes – chemical plants
- State controlled capital investment
- Small size of market for some metals & the dread of over-supply
- End product Innovation as demand driver
- Policy as disruptive demand driver
- Efficiency innovation & Jevon's Paradox
- Substitution as demand destroyer
- Failure of just-in-time procurement strategy
- Opportunity Cost: geopolitical, domestic, end-user
- The Upstream Solution
- The Downstream Solution

http://www.slideshare.net/Tehama/john-kaiser



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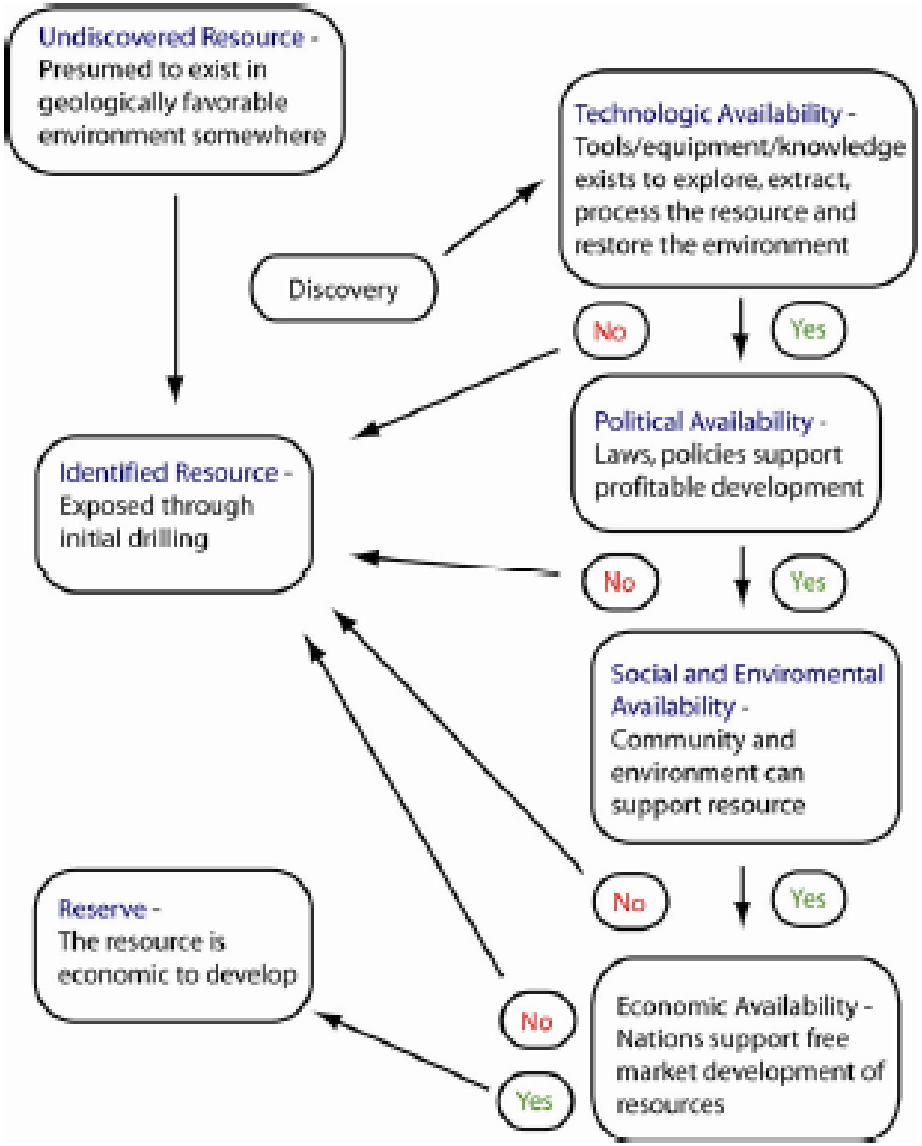


FIGURE 3.6. The availability of a mineral resource is dynamic in the five dimensions of geologic, technologic, social and environmental, political, and economic availability. Only if the extraction and processing of the resource is proved to be economically profitable is it considered a reserve.

http://www.nma.org/pdf/101606_nrc_study.pdf

5 Dimensions of Mineral Availability

WHAT Questions Must We Ask?

1 Geologic Availability

✓Does the mineral resource exist?

2 Technical Availability

✓Can we extract and process it?

3 Environmental & Social Availability

✓Can we produce it in environmentally and socially responsible and acceptable ways?

4 Political Availability

✓How do governments influence availability through their policy and actions?

5 Economic Availability

✓Can we produce it at a cost users are willing and able to pay?

Text adapted from *"Minerals, Critical Minerals, and the U.S. Economy"* by the National Research Council of the National Academies

5 Dimensions of Mineral Availability

***WHO** can help us answer these questions?*

1 **Geologic** Availability

✓Economic Geologists, Geochemists, etc.,

2 **Technical** Availability

✓Engineers (Mining, Metallurgical, Geotechnical, Reclamation, Environmental, etc.,)

3 **Environmental & Social** Availability

✓Sociologists, Anthropologists, Ecologists, Environmental Scientists & Engineers, etc.,

4 **Political** Availability

✓Policy makers and government agency professionals that understand minerals, mining, recycling and sustainable development

5 **Economic** Availability

✓Mineral, Energy and Petroleum Economists, etc.,

Criticality Index

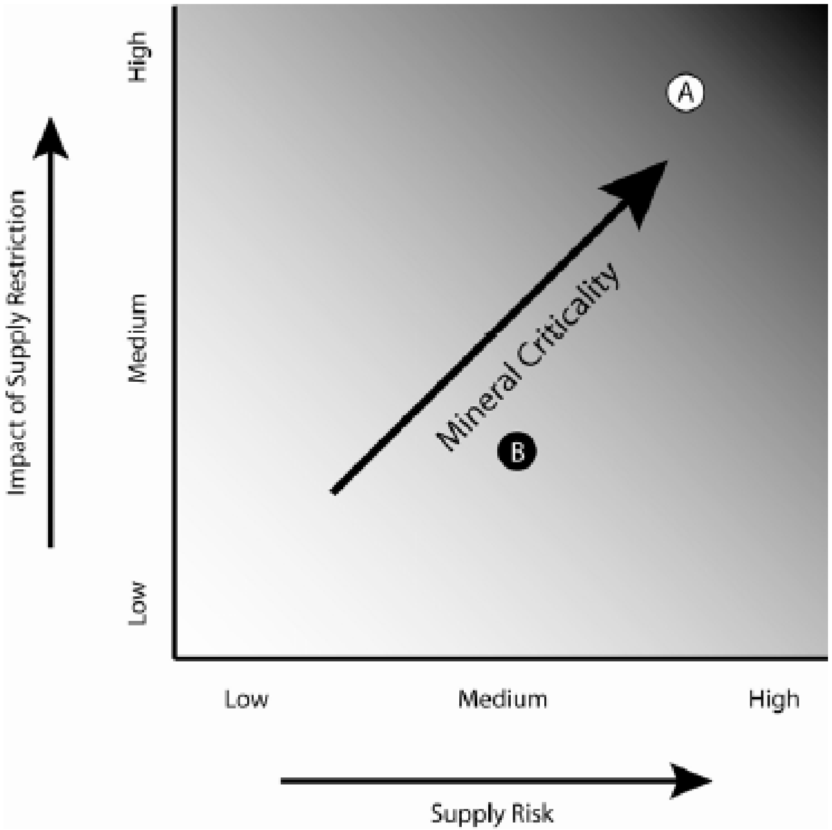
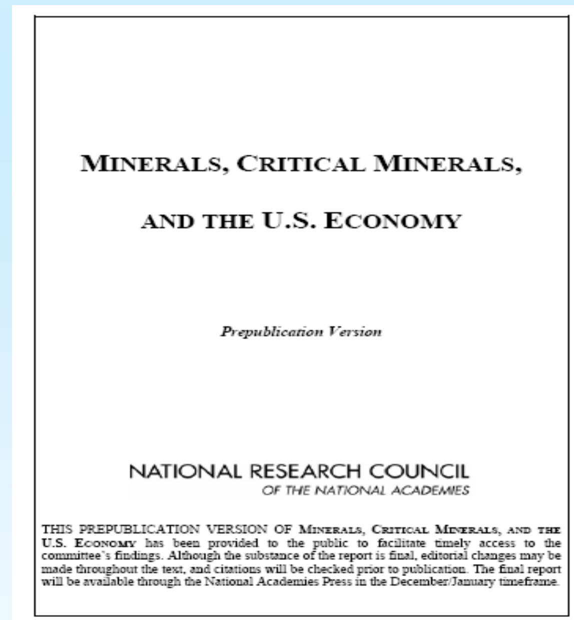


FIGURE 1.3 The criticality matrix as established in this report allows evaluation of the "criticality" of a given mineral. A specific mineral or mineral product can be placed on this figure after assessing the impact of the mineral's supply restriction should it occur (vertical axis) and the likelihood of a supply restriction (horizontal axis). The degree of criticality increases as one moves from the lower-left to the upper-right corner of the figure. In this example, Mineral A is more critical than Mineral B. More specific descriptions of the parameters used to evaluate mineral supply restrictions and their impacts are presented in Chapters 2-4.



MINERALS, CRITICAL MINERALS,

AND THE U.S. ECONOMY

Prepublication Version

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THIS PREPUBLICATION VERSION OF MINERALS, CRITICAL MINERALS, AND THE U.S. ECONOMY has been provided to the public to facilitate timely access to the committee's findings. Although the substance of the report is final, editorial changes may be made throughout the text, and citations will be checked prior to publication. The final report will be available through the National Academies Press in the December/January timeframe.

http://www.nma.org/pdf/101606_nrc_study.pdf

TABLE 4.2 Scoring the Vertical Axis of the Criticality Matrix for Example Mineral X

Application Group (End Uses) for Mineral X	Proportion of Total U.S. Market for Mineral X in Application	Impact of Supply Restriction (Values of 1 to 4)	Weighted Score (Product of Columns 2 and 3)
Aerospace propulsion	0.27	4	1.08
Pigments	0.65	4	2.60
Biomedical devices	0.8	2	0.16
Overall importance in use	1.00[a]	n.a.	3.84[b]

[a] Total proportion will always equal 1.
[b] Final weighted score.
NOTE: n.a. = not applicable.

TABLE 4.4 Relative Importance of End-Use Applications for REs

Application Group	Proportion of Total U.S. Market	Impact of supply restriction	Weighted Score
Emission control, magnets, and electronics	0.44	4	1.76
Metallurgical, optical, and ceramics	0.35	3	1.05
Other	0.13	2	0.26
Petroleum refining	0.08	1	0.08
Composite, weighted score			3.15

NOTE: Proportion of total U.S. RE use for each application was determined from the USGS (2007) information.

TABLE 4.4 Relative Importance of End-Use Applications for REs

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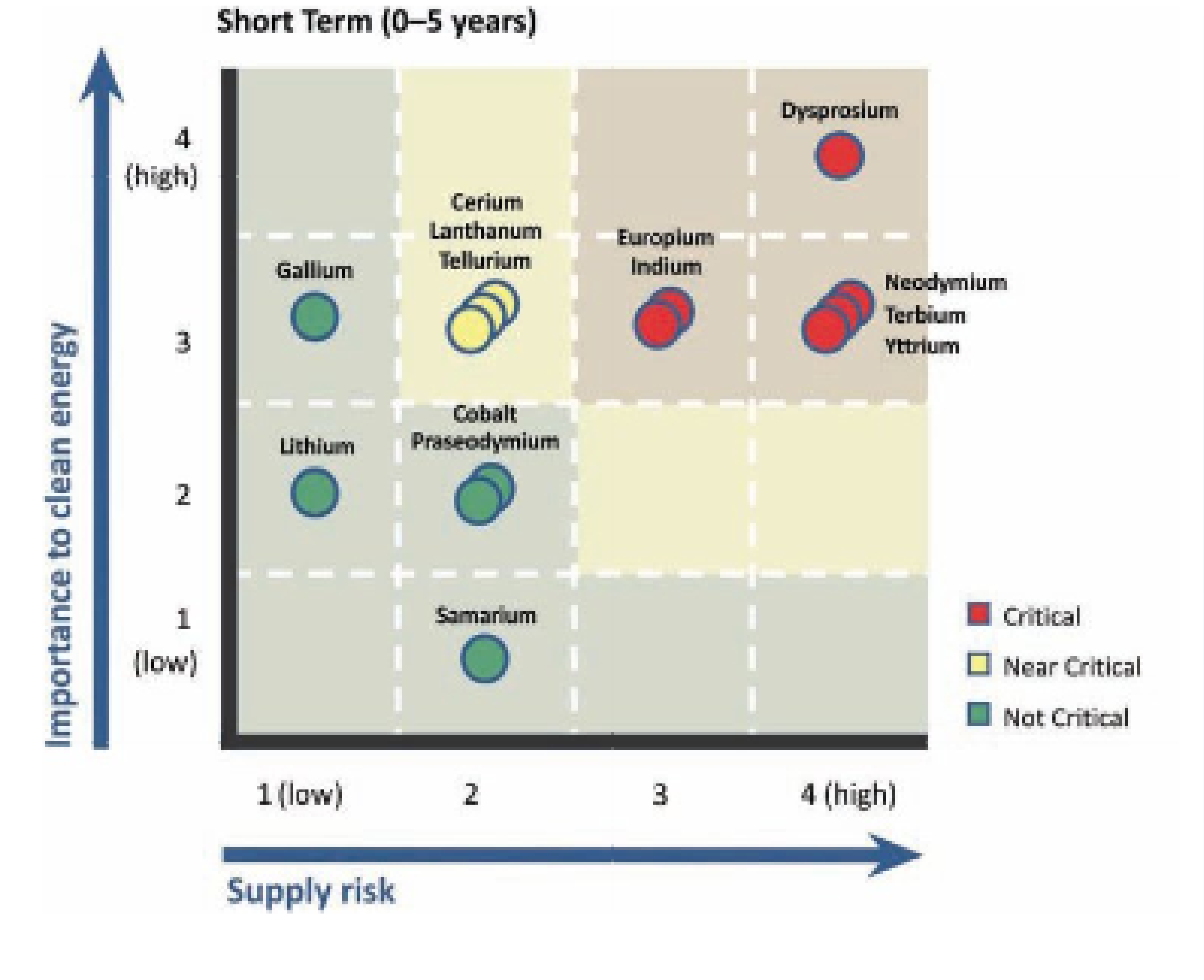
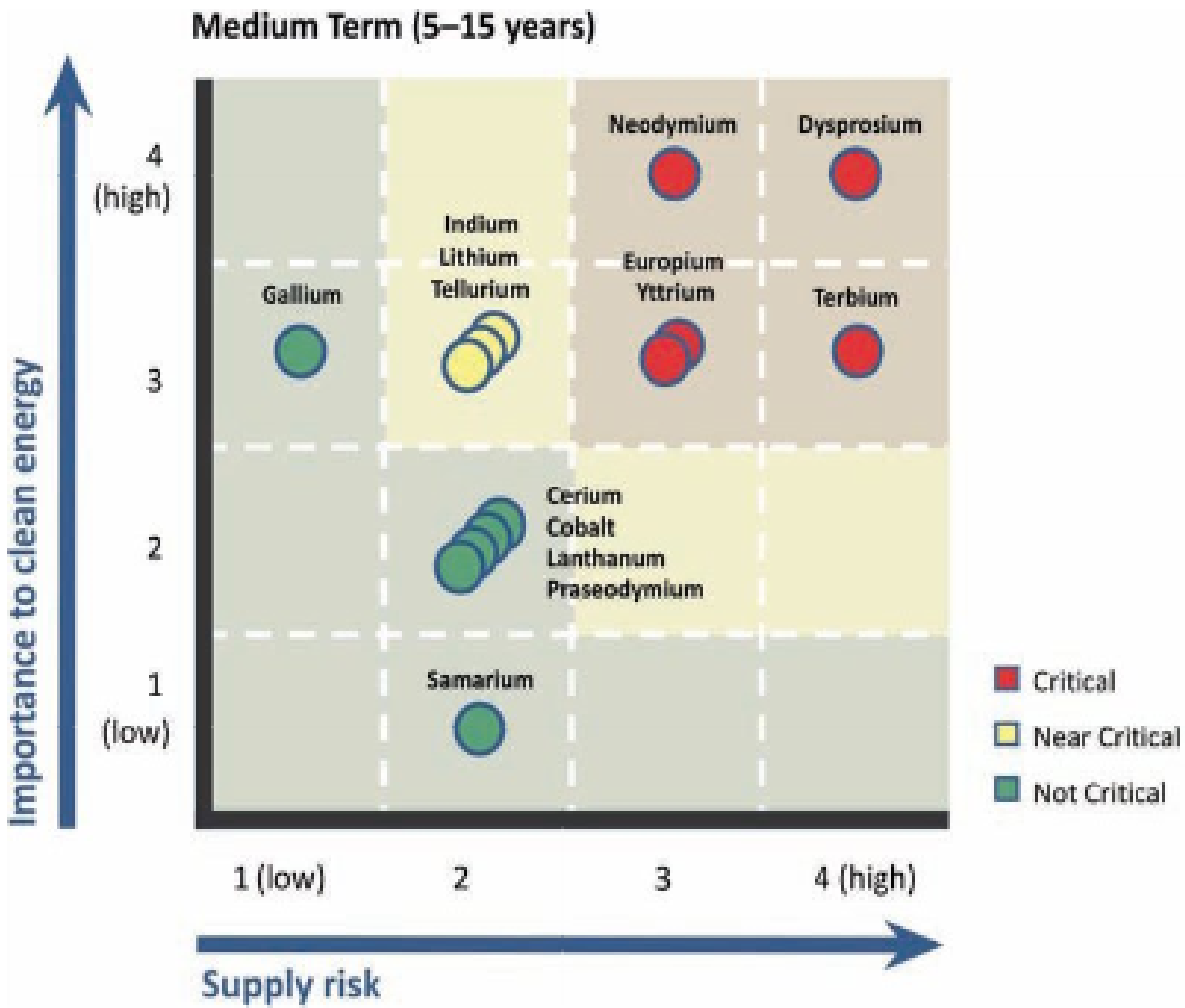

Short Term (0–5 years)
Importance to clean energy
4 (high)
3
2
1 (low)
Supply risk
1 (low)
2
3
4 (high)
Dysprosium
Cerium
Lanthanum
Tellurium
Europium
Indium
Gallium
Neodymium
Terbium
Yttrium
Cobalt
Praseodymium
Lithium
Samarium
Critical
Near Critical
Not Critical



Medium Term (5–15 years)
Neodymium
Dysprosium
Indium
Lithium
Tellurium
Gallium
Europium
Yttrium
Terbium
Cerium
Cobalt
Lanthanum
Praseodymium
Samarium
4 (high)
3
2
1 (low)
Importance to clean energy
1 (low)
2
3
4 (high)
Supply risk
Critical
Near Critical
Not Critical

Critical and strategic minerals will change with time.

1) What is the global demand likely to be?
2) What is the US supply likely to be?
3) What are the limits and obstacles to US production?
   a) land access
   b) permitting speed
4) What needs to be done to convert marginal resources into reserves?
6) What are the new types of deposits and ore-forming systems of the future?

Some of the challenges in producing these technologies

- How much of these minerals do we need?
- Are there enough materials in the pipeline to meet the demand for these technologies and other uses?
- Can any of these be recycled?
- Are there substitutions that can be used?
- Are these minerals environmental friendly—what are the reclamation challenges?
  - REE and Be are nearly always associated with U and Th and the wastes from mining REE and Be will have to accommodate radioactivity and radon

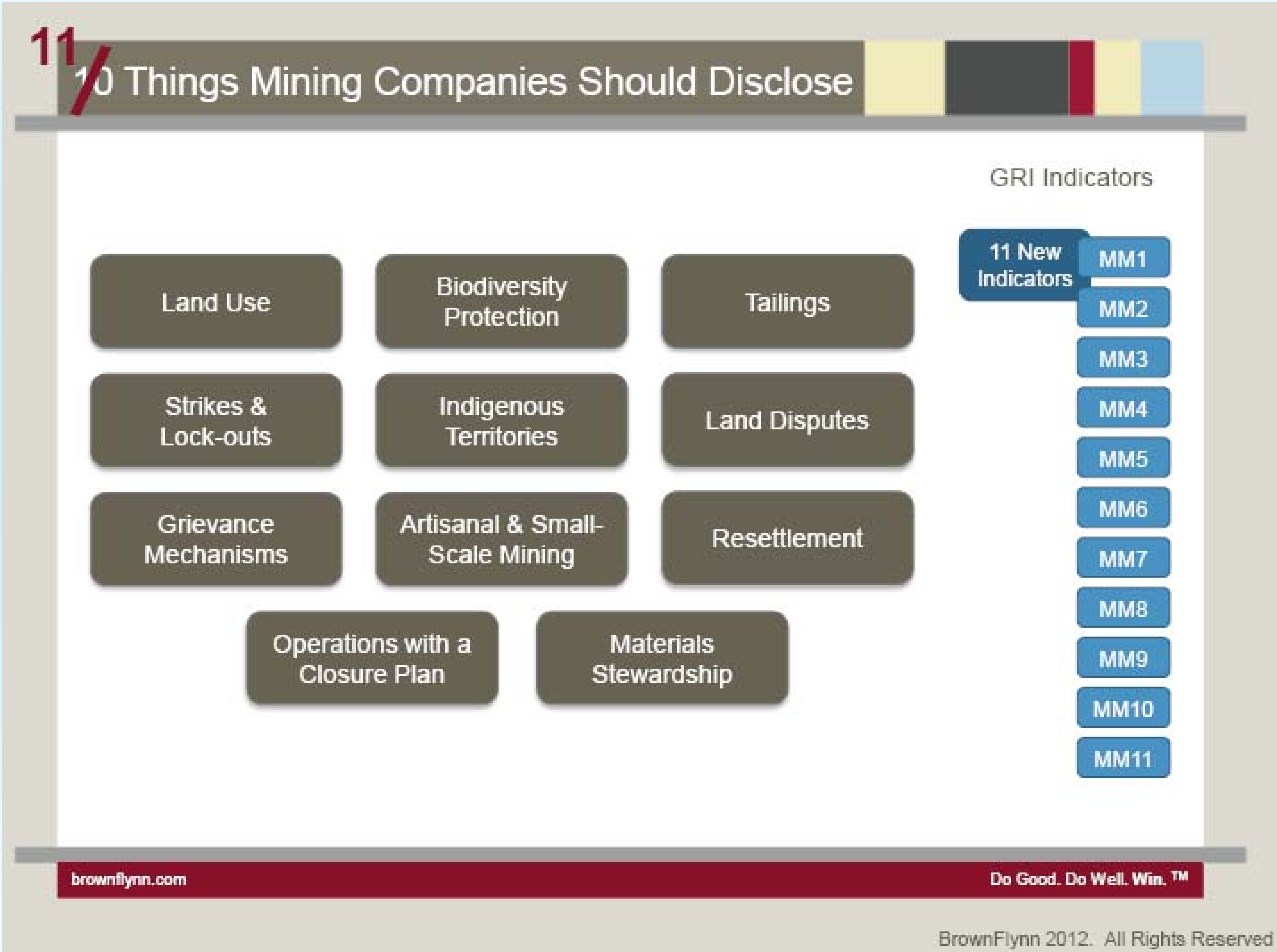
Bottlenecks

- Risk and timing of investment
  - Unpredictable
  - Rapid change in demand
  - Engineering/design/production of these products is faster then the exploration/mining/processing
- Extraction
  - Supplies
  - Economically feasible in a timely manner
- Refining
  - Technically feasible
  - Economical

FUTURE GEOLOGICAL RESEARCH

- Need for understanding the mineralogy and distribution of these minerals in known ore deposits
  - Geologic mapping (lithology, structure, alteration)
  - Geologic deposit models
  - Mineralogy/chemistry
- Are there additional geologic sources for some of these minerals?
- What are the potential environmental consequences of mining these minerals and how do we mitigate them?

SUTAINABLE DEVELOPMENT



In the past, many companies increased spending on poorly considered “feel-good” projects when prices were high, and then cut them when prices dropped. So it is no surprise that global best practice – including recent revisions to the IFC standards – puts more emphasis on social management.

Growing global understanding of social-management systems – made up of assessments, policies, management oversight and deployment of teams with appropriate budgets and training – reflects a deeper understanding of CSR as a basic operating obligation for all extractive companies, regardless of size or global location. **CSR is scalable, just as other risk-management systems are.**