International Perspective on Energy Materials Criticality

ISTC SAC Seminar on Energy Security

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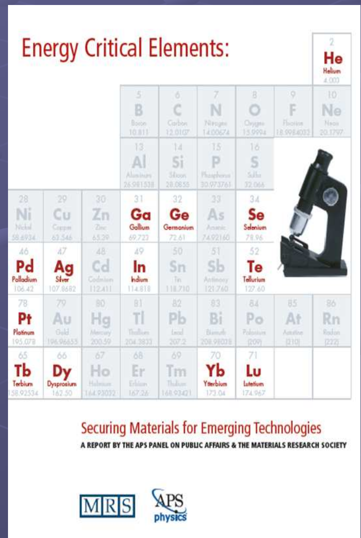
October 22-23, 2013, Almaty Republic of Kazakhstan

Abstract

- The full development of emerging energy technologies, upon which the sustainable equilibrium of our environment may depend, relies on access to chemical and isotopic elements that have unique attributes. A famous example is that of the rare earth elements, which are used to make high strength magnets in electric vehicles and wind-generated power. However, the supply of such energy critical materials may be at risk in some cases, including the rare earths. Quantitative assessment of materials' importance and supply risk is known as "criticality" not to be confused with nuclear criticality.
- Along the lines of a landmark report "Energy Critical Materials" by the American Physical Society and the Materials Research Society published in 2011, various countries and companies have developed criticality criteria to match their specific needs. This presentation provides an overview of the methodology and compares studies by APS-MRS, European Union, US Department if Energy, South Korea, Japan, and others.

Energy Critical Elements

Securing Materials for Emerging Technologies



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The Twin Pressures

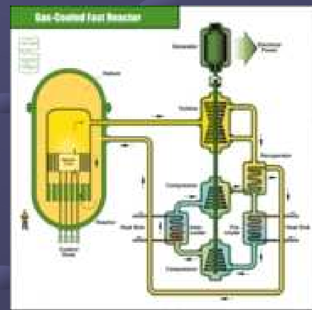
Increasing Energy Demand

Concern About Climate Change

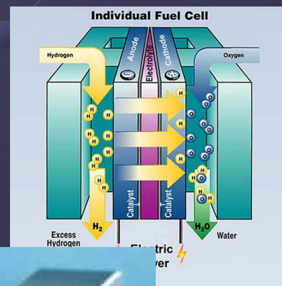
Stimulated Development of New Sources of Energy







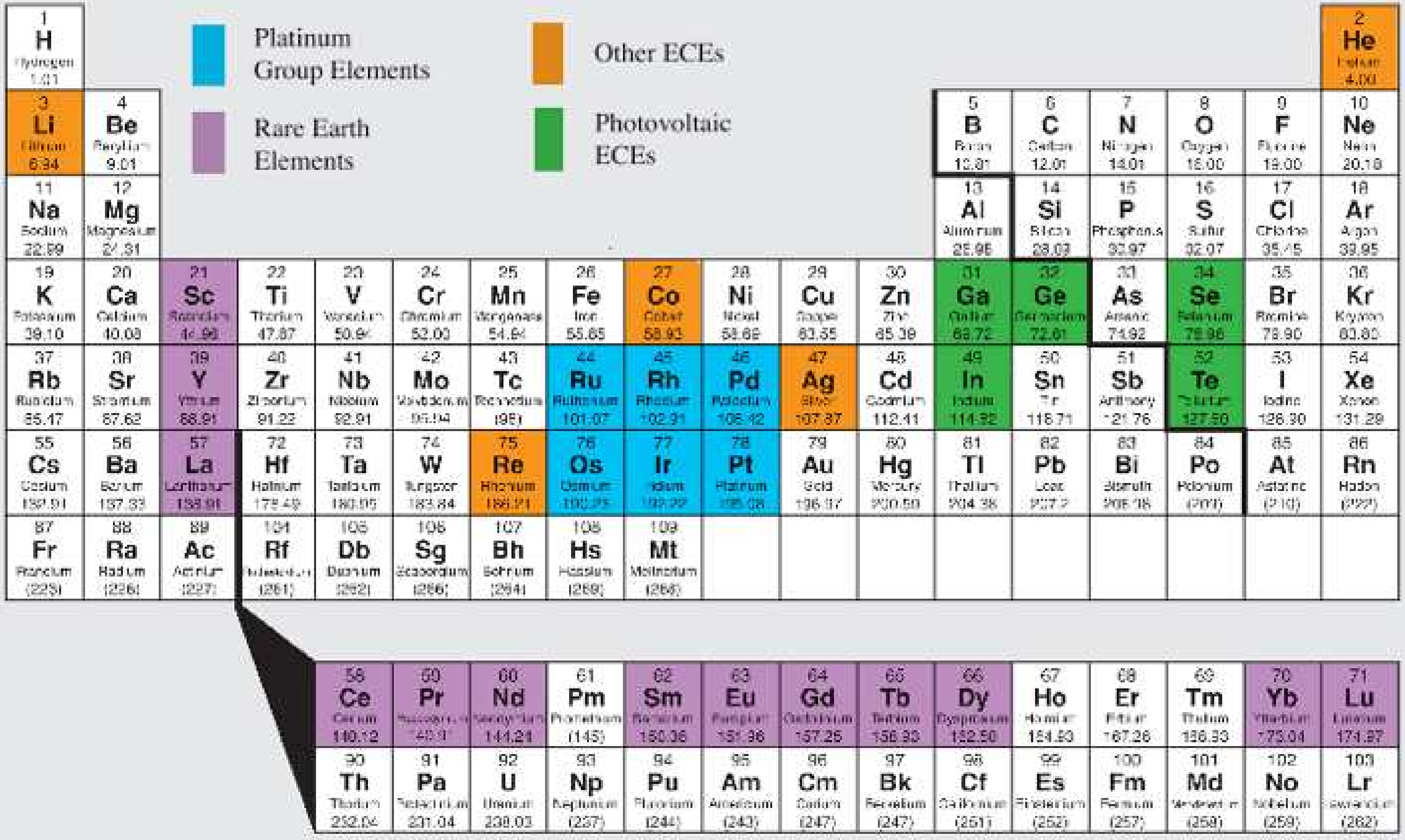
- Photovoltaic solar cells Ga, Ge, In, Se, Ag, Te
- Magnets for wind turbines and hybrid cars Dy, Nd, Pr, Sm, Co
- High performance batteries Li, La
- Cryogenics and advanced nuclear reactors He
- Alloys for high performance turbines Re
- Fuel cells catalysts Pt, Pd
- Solid state and fluorescent lighting Y, Gd, Eu, Tb



Energy Critical Elements

Definition:

- Elements necessary for current and emerging energy technologies
- Demand could exceed supply
- Not widely extracted, traded, or utilized
- Are not the focus of a relatively stable markets



The United States relies on imports for more than 90% of its supply of the majority of ECEs identified

Rare Earth Elements

Unique Magnetic and Optical Properties

La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Tb, Lu – Sc, Y

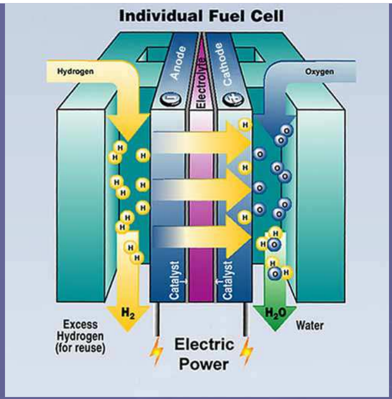
“Rare Earth Crisis” received media attention

Dramatic price escalation and shortages

Example of government policy

Abandonment of technology could occur

Nearly all current global production occurs in China, by mining of unusual lateritic clay type



Platinum and Palladium
Geopolitical Consideration

Platinum 0.0000005% and palladium 0.0000015% of Earth's crust

Examples of elements whose supply could be at risk, because they occur in economic concentrations in few geological environments and in geographic locations where political stability might be a concern.

Pt and Pd are used as catalysts in fuel cells that have many potential applications, including hydrogen fuel and hybrid cars. In 2009, global production of platinum (178 MT) was dominated by South Africa (79%) and Russia (11%), as was production of palladium (195 MT) with each country producing about 41%.

Rhenium

0.00000007% of Earth's crust

Rhenium is a critical material in turbine engines

Worldwide demand predicted to exceed worldwide supply, potentially resulting in a Re shortage that would cripple GE's turbine engine market. GE made a decision to reduce the company's reliance on Re with a strategy, including both the recycling and R&D of substitute materials.

Lithium

0.002% of Earth's crust

Principal component in one of the most promising forms of high energy-density batteries.

Exploration for and development of new Li supplies remains in limbo because of ill defined future for Li batteries suitable for all-electric vehicles and the lack of a clear decision on the fundamental battery design

The choice of which battery technology to develop depends largely on the availability and price of the component materials

Supply in the marketplace is experiencing significant uncertainty associated with time delays in production and utilization

Tellurium

0.0000001% of Earth's crust

Because Te production is so small (on the order of 200 MT in 2009) compared to that of Cu (15,800,000 MT in 2009), there is little incentive to maximize Te recovery from Cu processing, even though Te costs considerably more than Cu ($145/kg vs. $5.22/kg)

Te is used in photovoltaic panels, where it is employed in films a few microns thick. For a thickness of 3 microns and a photovoltaic efficiency of 10%, the Te content would be 0.1 gram per watt of installed electric generating capacity or 100 MT of Te per gigawatt of installed capacity.

There are many unknowns that make predicting the capacity of supply to expand to meet a significantly increased demand for Te difficult.

Helium

0.0000008 % of Earth's crust

Indispensible for *cryogenic applications.* Helium liquefies at the lowest temperature of all elements and does not solidify, even at absolute zero temperature.

Helium is the only element that cannot be rendered radioactive by exposure to radiation.

Helium has the highest specific heat capacity of any gaseous element, except hydrogen. Its excellent thermal properties, combined with its chemical and nuclear inertness, make it the fluid of choice for advanced nuclear reactor design

The helium supply is at risk because it is not gravitationally bound to the Earth

Abundance Versus concentration: The Germanium Example

0.00015% of Earth's crust by weight

Germanium is not particularly scarce; it is twenty times more abundant than silver, for example. However, germanium substitutes for other elements in minerals and rarely forms minerals in which it is a principal component.

Global production in 2009 from zinc refining to be 140 MT, of which 71% came from China.

Germanium is used in fiber optics, infrared optics, and as an ECE in solar photovoltaic cells

Co-Production

Many energy-critical elements are produced jointly with other elements

Gallium is obtained as a by-product of aluminum and zinc processing

Germanium is typically derived as a by-product of zinc, lead, or copper refining

Selenium and tellurium are most often by-products of copper refining

Helium is a by-product of natural gas production

Rare earth elements as well as platinum group elements are regarded as co-products with one another

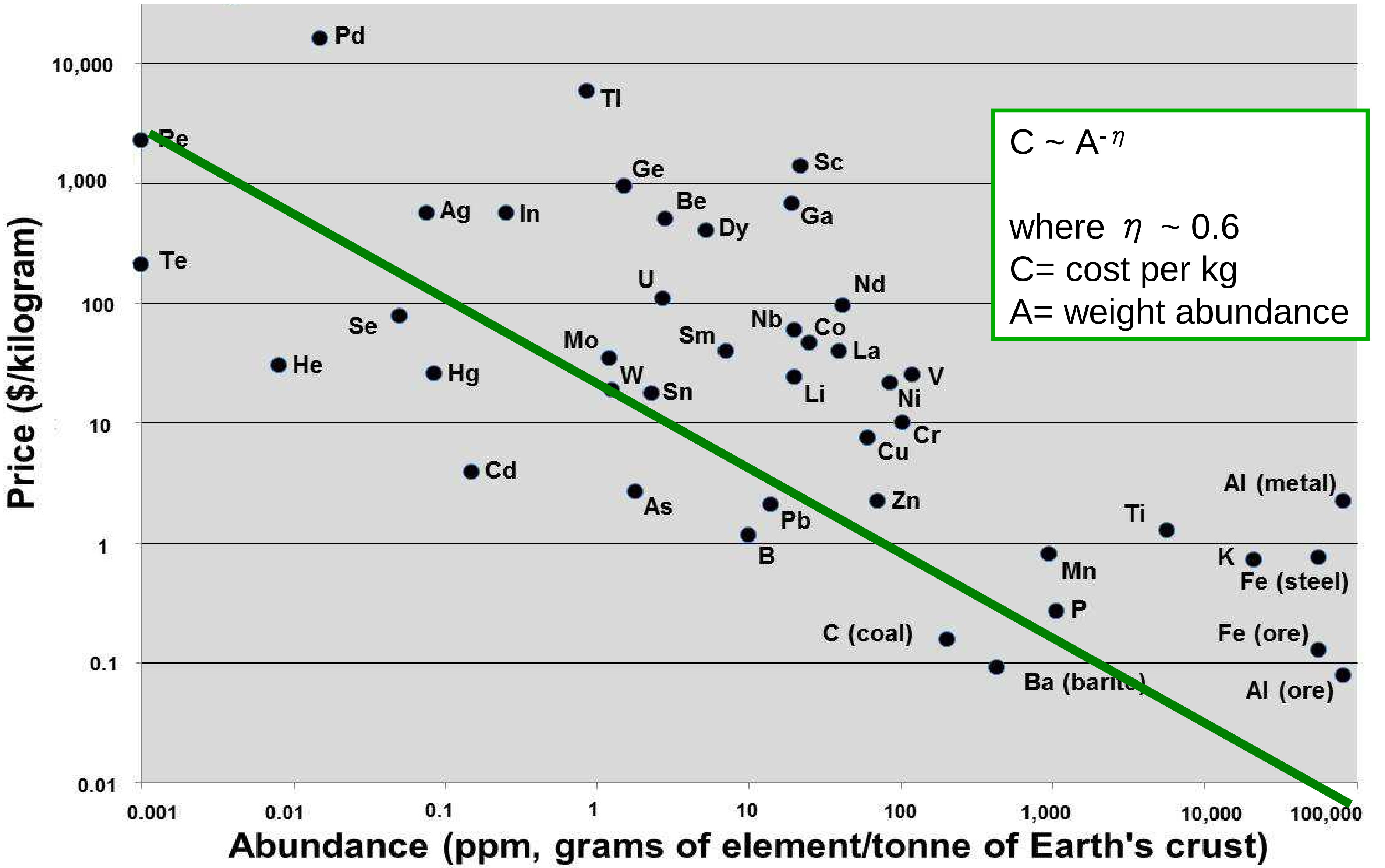
Nearly all Te is obtained as a by-product of the electrolytic refining of copper (Cu). Unfortunately, however, acid leaching followed by solvent extraction-electrowinning is replacing electrolytic refining of Cu and does not recover Te.

Geopolitical Supply Risks

Among the energy-critical elements, the rare earths, platinum group elements, and lithium are perhaps most vulnerable to geopolitical risks. The present "rare earth crisis" appears to be an example of government policy.

Platinum production is concentrated in the hands of a small number of companies in South Africa, which produced 79% of the world's supply in 2009.

The history of cobalt, copper, and tantalum production in the Democratic Republic of the Congo is one of numerous examples



Price ($/kilogram)
10,000
1,000
100
10
1
0.1
0.01
Abundance (ppm, grams of element/tonne of Earth's crust)
0.001
0.01
0.1
1
10
100
1,000
10,000
100,000
Pd
Tl
Re
Te
Ge
Sc
Ag
In
Be
Ga
Dy
U
Nd
Se
Nb
Co
Mo
Sm
La
He
Hg
W
Sn
V
Li
Ni
Cr
Cu
Cd
Al (metal)
As
Zn
Pb
Ti
B
K
Mn
Fe (steel)
P
C (coal)
Fe (ore)
Ba (barite)
Al (ore)
C ~ A-η
where η ~ 0.6
C= cost per kg
A= weight abundance

Report Recommendations

Coordination

International relations, Trade policy, Energy independence, Environmental standards, production and use

Information

Analyze and disseminate information across the life-cycle supply chain

Research and Development

Expand availability and reduce dependence, Focused on substitutes, extraction, utilization, manufacturing, and recycling

Materials Efficiency

Enhance vital aspects of the supply chain, recycling preconsumer, and functional recycling

Market Intervention

Economic stockpiles of ECEs not recommended, Helium is an exeption

Join in Materials Diplomacy Issues

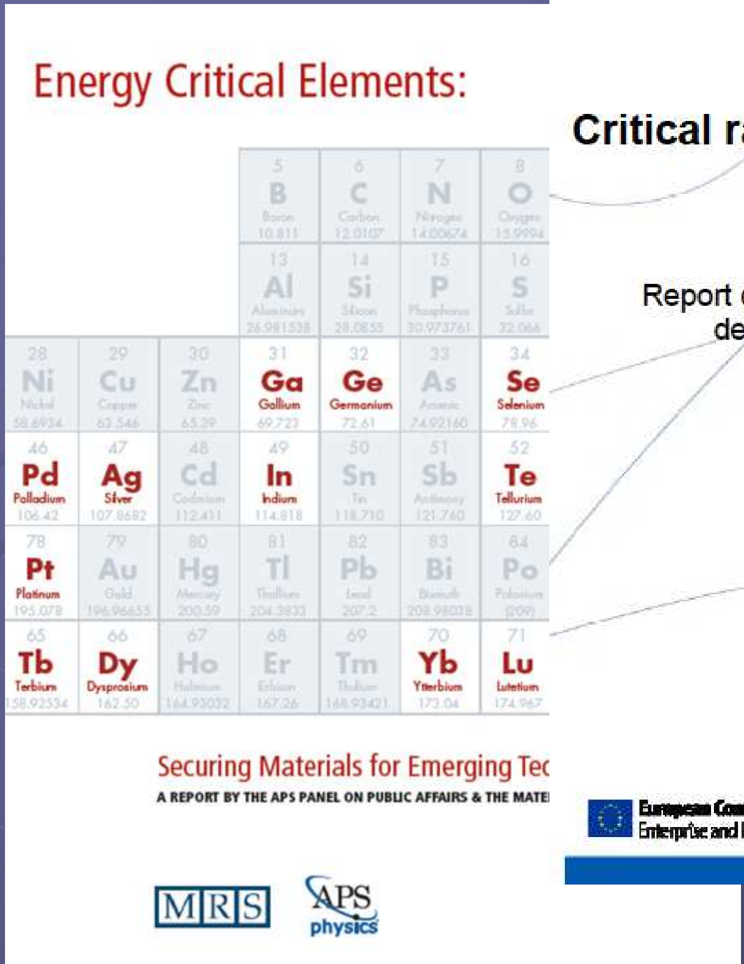
Obligation for scientists to work together in solving problems of global scope.

New and better materials to meet the challenges of sustainable development in this world, including the challenge of energy access.

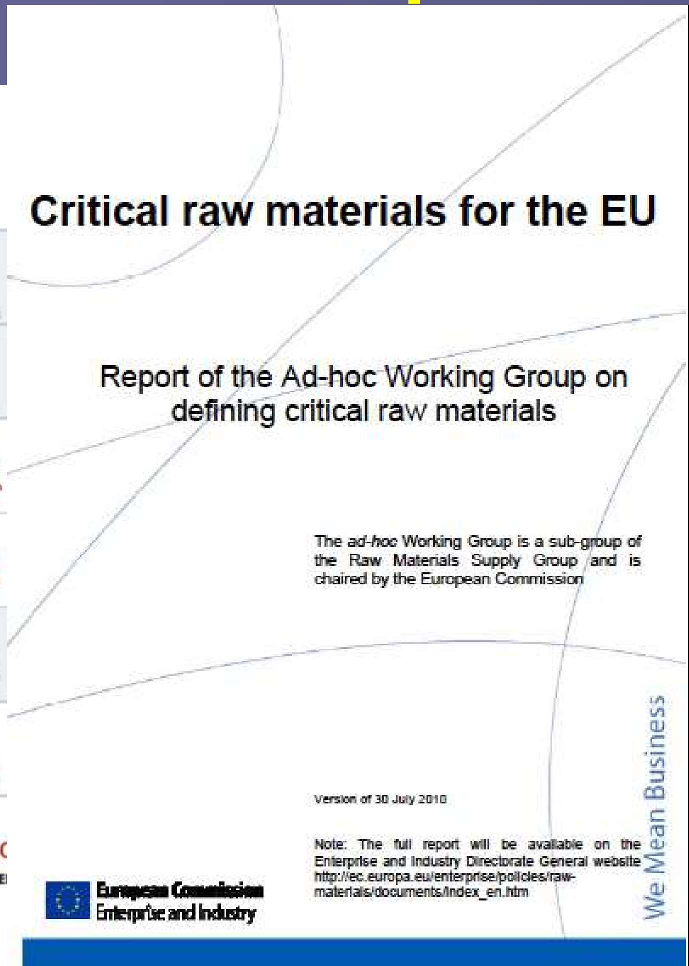
Global challenges are the lock

Materials are the key

Other Reports



American Physical Society and the Materials Research Society
February 2011



European Commission
June 2010

US Department of Energy
December 2011