

# **International Perspective on Energy Materials Criticality**

## **ISTC SAC Seminar on Energy Security**

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**Presented by  
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U.S. Civilian Research & Development Foundation – Global  
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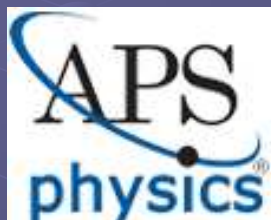
**October 22-23, 2013, Almaty Republic of Kazakhstan**

# 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 of Energy, South Korea, Japan, and others.

# Energy Critical Elements

## Securing Materials for Emerging Technologies



Energy Critical Elements:

5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.0064	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
13 Al Aluminum 26.9815386	14 Si Silicon 28.0855	15 P Phosphorus 30.973762	16 S Sulfur 32.06		
28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.61	33 As Arsenic 74.92160
46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760
78 Pt Platinum 195.078	79 Au Gold 196.966569	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98039
89 Tb Terbium 158.92534	90 Dy Dysprosium 162.5	91 Ho Holmium 164.93032	92 Er Erbium 167.254	93 Tm Thulium 168.93401	94 Yb Ytterbium 173.04
					95 Lu Lutetium 174.967

Securing Materials for Emerging Technologies  
A REPORT BY THE APS PANEL ON PUBLIC AFFAIRS & THE MATERIALS RESEARCH SOCIETY

MRS APS physics



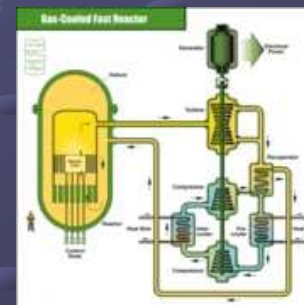
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## The Twin Pressures

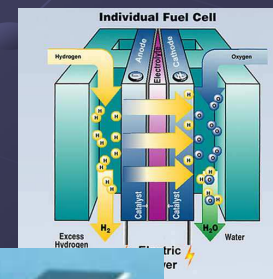
Increasing Energy  
Demand

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



1 <b>H</b> Hydrogen 1.01																	2 <b>He</b> Helium 4.00														
3 <b>Li</b> Lithium 6.94	4 <b>Be</b> Beryllium 9.01																	5 <b>B</b> Boron 10.81	6 <b>C</b> Carbon 12.01	7 <b>N</b> Nitrogen 14.01	8 <b>O</b> Oxygen 16.00	9 <b>F</b> Fluorine 19.00	10 <b>Ne</b> Neon 20.18								
11 <b>Na</b> Sodium 22.99	12 <b>Mg</b> Magnesium 24.31																	13 <b>Al</b> Aluminum 26.98	14 <b>Si</b> Silicon 28.09	15 <b>P</b> Phosphorus 30.97	16 <b>S</b> Sulfur 32.07	17 <b>Cl</b> Chlorine 35.45	18 <b>Ar</b> Argon 39.95								
19 <b>K</b> Potassium 39.10	20 <b>Ca</b> Calcium 40.08	21 <b>Sc</b> Scandium 44.96	22 <b>Ti</b> Titanium 47.87	23 <b>V</b> Vanadium 50.94	24 <b>Cr</b> Chromium 52.00	25 <b>Mn</b> Manganese 54.94	26 <b>Fe</b> Iron 55.85	27 <b>Co</b> Cobalt 58.93	28 <b>Ni</b> Nickel 58.69	29 <b>Cu</b> Copper 63.55	30 <b>Zn</b> Zinc 65.39	31 <b>Ga</b> Gallium 69.72	32 <b>Ge</b> Germanium 72.61	33 <b>As</b> Arsenic 74.92	34 <b>Se</b> Selenium 78.96	35 <b>Br</b> Bromine 79.90	36 <b>Kr</b> Krypton 83.80														
37 <b>Rb</b> Rubidium 85.47	38 <b>Sr</b> Strontium 87.62	39 <b>Y</b> Yttrium 88.91	40 <b>Zr</b> Zirconium 91.22	41 <b>Nb</b> Niobium 92.91	42 <b>Mo</b> Molybdenum 95.94	43 <b>Tc</b> Technetium (98)	44 <b>Ru</b> Ruthenium 101.07	45 <b>Rh</b> Rhodium 102.91	46 <b>Pd</b> Palladium 106.42	47 <b>Ag</b> Silver 107.87	48 <b>Cd</b> Cadmium 112.41	49 <b>In</b> Indium 114.82	50 <b>Sn</b> Tin 118.71	51 <b>Sb</b> Antimony 121.76	52 <b>Te</b> Tellurium 127.60	53 <b>I</b> Iodine 126.90	54 <b>Xe</b> Xenon 131.29														
55 <b>Cs</b> Cesium 132.91	56 <b>Ba</b> Barium 137.33	57 <b>La</b> Lanthanum 138.91	72 <b>Hf</b> Hafnium 178.49	73 <b>Ta</b> Tantalum 180.95	74 <b>W</b> Tungsten 183.84	75 <b>Re</b> Rhenium 186.21	76 <b>Os</b> Osmium 190.23	77 <b>Ir</b> Iridium 192.22	78 <b>Pt</b> Platinum 195.08	79 <b>Au</b> Gold 196.97	80 <b>Hg</b> Mercury 200.59	81 <b>Tl</b> Thallium 204.38	82 <b>Pb</b> Lead 207.2	83 <b>Bi</b> Bismuth 208.98	84 <b>Po</b> Polonium (209)	85 <b>At</b> Astatine (210)	86 <b>Rn</b> Radon (222)														
87 <b>Fr</b> Francium (223)	88 <b>Ra</b> Radium (226)	89 <b>Ac</b> Actinium (227)	104 <b>Rf</b> Rutherfordium (261)	105 <b>Db</b> Dubnium (262)	106 <b>Sg</b> Seaborgium (266)	107 <b>Bh</b> Bohrium (264)	108 <b>Hs</b> Hassium (269)	109 <b>Mt</b> Meitnerium (268)																							
																		58 <b>Ce</b> Cerium 140.12	59 <b>Pr</b> Praseodymium 140.91	60 <b>Nd</b> Neodymium 144.24	61 <b>Pm</b> Promethium (145)	62 <b>Sm</b> Samarium 150.36	63 <b>Eu</b> Europium 151.96	64 <b>Gd</b> Gadolinium 157.25	65 <b>Tb</b> Terbium 158.93	66 <b>Dy</b> Dysprosium 162.50	67 <b>Ho</b> Holmium 164.93	68 <b>Er</b> Erbium 167.26	69 <b>Tm</b> Thulium 168.93	70 <b>Yb</b> Ytterbium 173.04	71 <b>Lu</b> Lutetium 174.97
																		90 <b>Th</b> Thorium 232.04	91 <b>Pa</b> Protactinium 231.04	92 <b>U</b> Uranium 238.03	93 <b>Np</b> Neptunium (237)	94 <b>Pu</b> Plutonium (244)	95 <b>Am</b> Americium (243)	96 <b>Cm</b> Curium (247)	97 <b>Bk</b> Berkelium (247)	98 <b>Cf</b> Californium (251)	99 <b>Es</b> Einsteinium (252)	100 <b>Fm</b> Fermium (257)	101 <b>Md</b> Mendelevium (258)	102 <b>No</b> Nobelium (259)	103 <b>Lr</b> Lawrencium (262)

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, Yb, Lu – Sc, Y

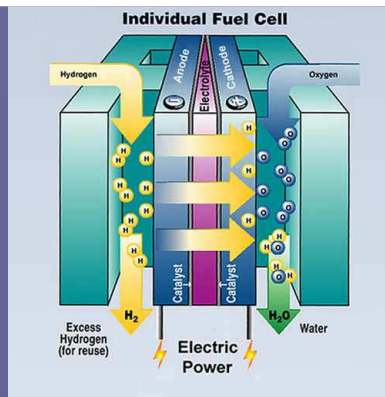
“Rare Earth Crisis” received media attention

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



Indispensable 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

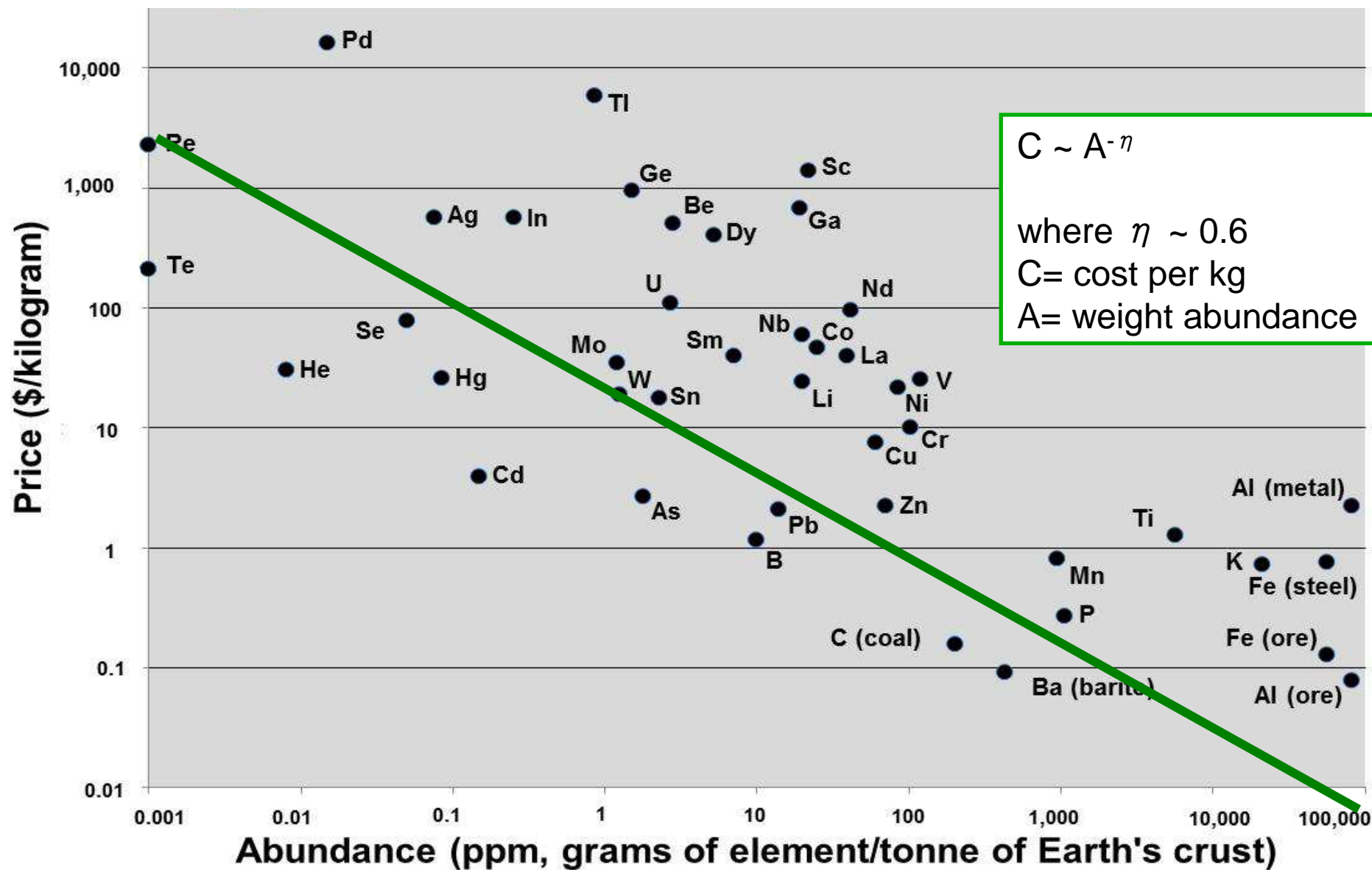
Nearly all Te is obtained as a by-product of the electrolytic refining of copper (Cu). Unfortunately, however, acid leaching followed by solvent extraction-electrowinning is replacing electrolytic refining of Cu and does not recover Te.

# 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



# 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 exception

# **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

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Securing Materials for Emerging Tech  
A REPORT BY THE APS PANEL ON PUBLIC AFFAIRS & THE MRS



American Physical Society and the  
Materials Research Society  
February 2011

## Critical raw materials for the EU

Report of the Ad-hoc Working Group on  
defining critical raw materials

The ad-hoc Working Group is a sub-group of  
the Raw Materials Supply Group and is  
chaired by the European Commission

Version of 30 July 2010

Note: The full report will be available on the  
Enterprise and Industry Directorate General website  
[http://ec.europa.eu/enterprise/policies/raw-materials/documents/index\\_en.htm](http://ec.europa.eu/enterprise/policies/raw-materials/documents/index_en.htm)



European Commission  
June 2010

DEPARTMENT OF ENERGY

## Critical Materials Strategy

December 2011



We Mean Business

U.S. DEPARTMENT OF  
**ENERGY**

US Department of Energy  
December 2011