

# Strategic & Critical Minerals – A Global Perspective

## Energy Critical Elements – Securing Materials for Emerging Technologies

Jon Price

Nevada Bureau of Mines and Geology



\* with help from Murray Hitzman, Colorado School of Mines

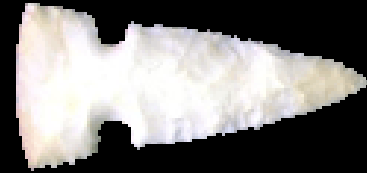
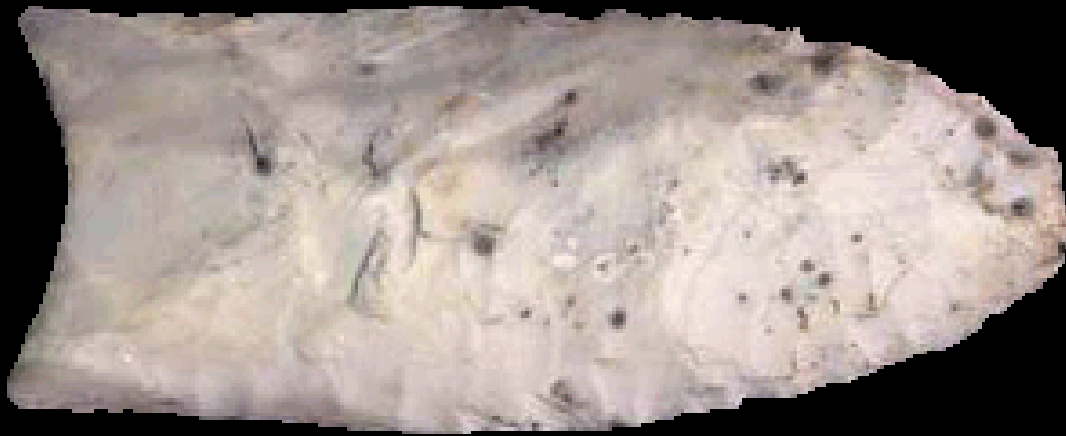
# **Strategic & Critical Minerals – A Global Perspective**

## **Energy Critical Elements – Securing Materials for Emerging Technologies**

**Jon Price**

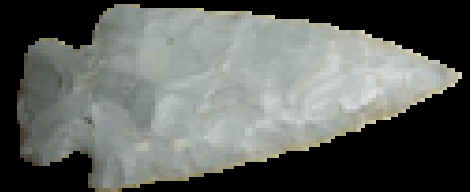
**Nevada Bureau of Mines and Geology**

- 1. Critical and strategic minerals will change with time.**
- 2. Demand is high.**
- 3. China will be a major force in the world of strategic and critical minerals.**
- 4. The U.S.A. has the right geology to be a major force as well for many, but not all, minerals.**



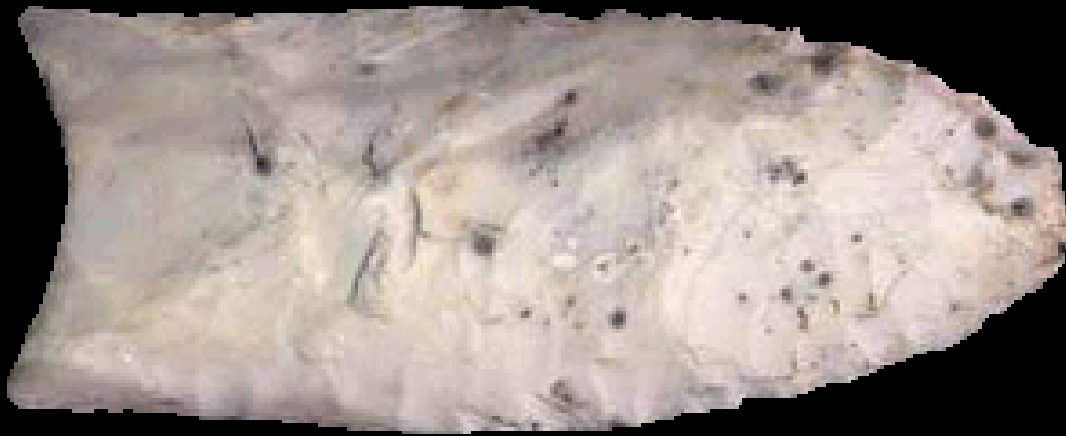
Arrowhead clipart from [www.firstpeople.us](http://www.firstpeople.us)

**Critical and strategic minerals will change with time.**



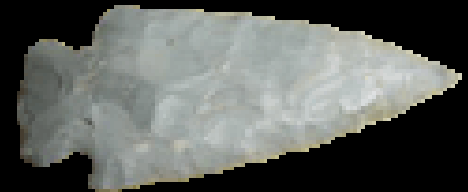
Avatar





Arrowhead clipart from [www.firstpeople.us](http://www.firstpeople.us)

**Critical and strategic minerals will change with time.**




**$\text{CuIn}_x\text{Ga}_{(1-x)}\text{Se}_2$  or CIGS, for solar panels?**

**$\text{CdTe}$ ,  $\text{GaAs}$ , and  $\text{Ge}$  for solar panels?**

**$\text{Nd}$ ,  $\text{Dy}$  for magnets for wind and other electrical turbines?**

**$\text{Li}$  and  $\text{V}$  for different types of batteries?**

## Energy Critical Elements:

						2 <b>He</b> Helium 4.003		
		5 <b>B</b> Boron 10.811	6 <b>C</b> Carbon 12.0107	7 <b>N</b> Nitrogen 14.00674	8 <b>O</b> Oxygen 15.9994	9 <b>F</b> Fluorine 18.9984032	10 <b>Ne</b> Neon 20.1797	
		13 <b>Al</b> Aluminum 26.981538	14 <b>Si</b> Silicon 28.0855	15 <b>P</b> Phosphorus 30.973761	16 <b>S</b> Sulfur 32.066			
28 <b>Ni</b> Nickel 58.6934	29 <b>Cu</b> Copper 63.546	30 <b>Zn</b> Zinc 65.39	31 <b>Ga</b> Gallium 69.723	32 <b>Ge</b> Germanium 72.61	33 <b>As</b> Arsenic 74.92160			34 <b>Se</b> Selenium 78.96
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65 <b>Tb</b> Terbium 158.92534	66 <b>Dy</b> Dysprosium 162.50	67 <b>Ho</b> Holmium 164.93032	68 <b>Er</b> Erbium 167.26	69 <b>Tm</b> Thulium 168.93421	70 <b>Yb</b> Ytterbium 173.04	71 <b>Lu</b> Lutetium 174.967		

**A 2011 policy-oriented study by the American Physical Society and the Materials Research Society – concerning the availability of minerals needed for new energy technologies.**

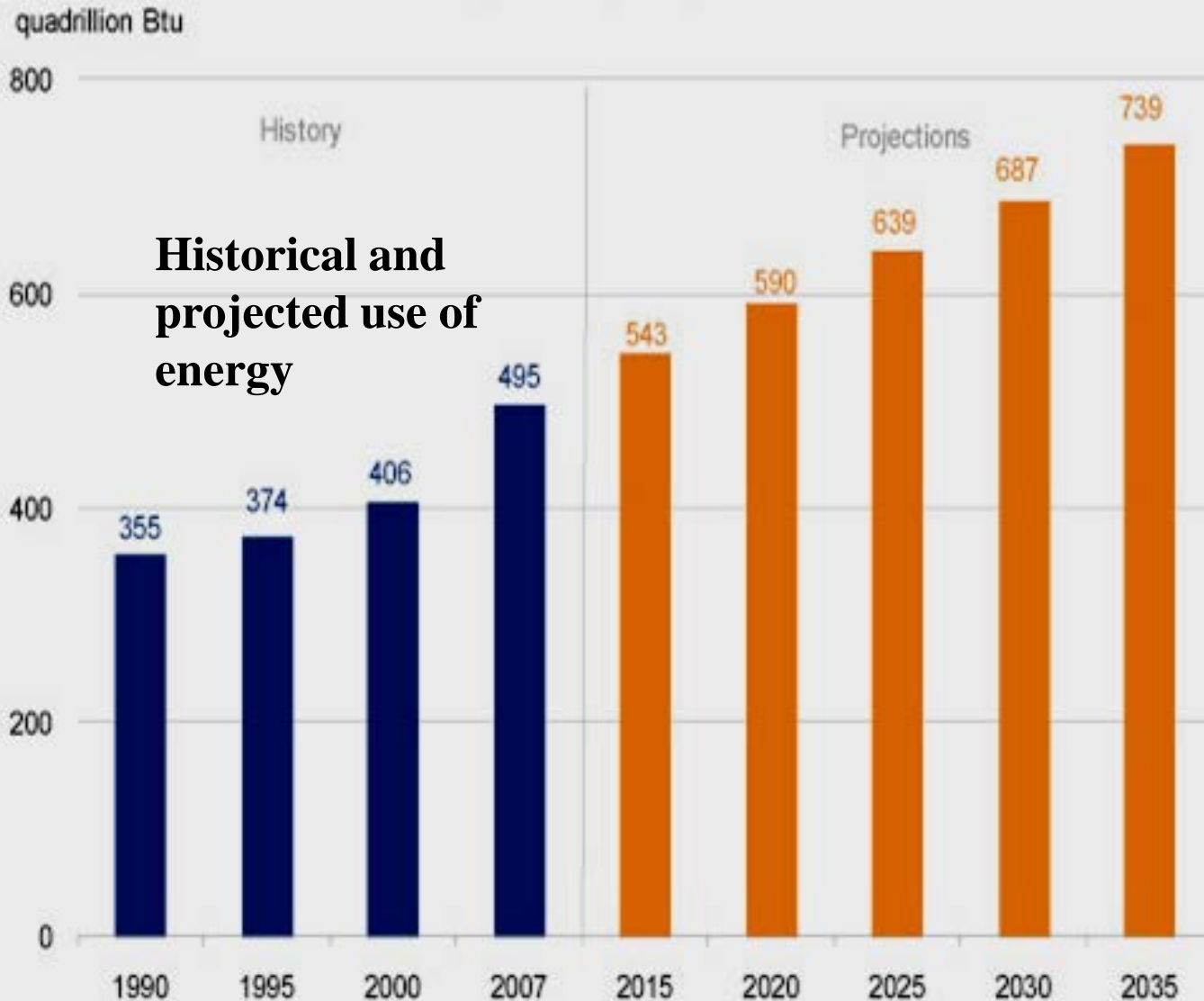
### Securing Materials for Emerging Technologies

A REPORT BY THE APS PANEL ON PUBLIC AFFAIRS & THE MATERIALS RESEARCH SOCIETY

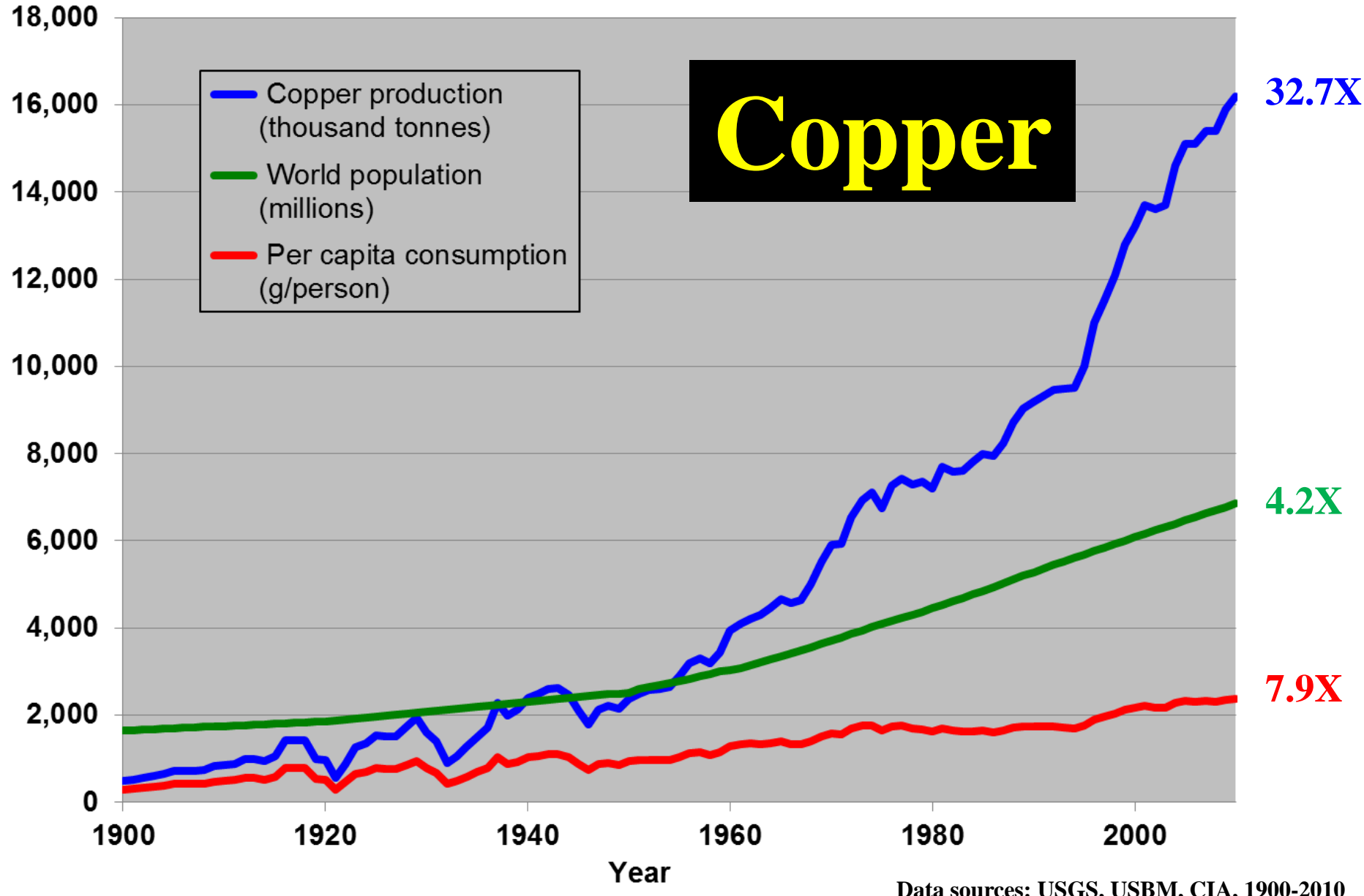


**Robert Jaffe, MIT, Chair**  
**Jon Price, NBMG, Co-Chair**

# The underlying issue: Increasing worldwide demand for energy, mineral resources, food, etc.



*EIA, 2010*



**Both world population and average standard of living keep rising.**



Photo copyrighted by Michael Collier, from the AGI website, Rio Tinto/Kennecott Utah Copper mine; the remaining resource as of 16 May 2008 = 3.06 million metric tons of Cu

**Global copper production in 2010 (16.2 million metric tons) nearly equaled over 100 years of production from the Bingham Canyon mine (17.0 million metric tons).**




## Definition:


**Energy-critical elements (ECEs)** are a class of chemical elements that currently appear **critical to one or more new energy-related technologies**. A shortage of these elements would significantly inhibit large-scale deployment, which could otherwise be **capable of transforming the way we produce, transmit, store, or conserve energy**. We reserve the term **ECE** for chemical elements that **have not been widely extracted, traded, or utilized in the past, and are therefore not the focus of well-established and relatively stable markets**.

# Some ECEs today

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)	101 <b>Rf</b> Rutherfordium (261)	102 <b>Db</b> Dubnium (262)	103 <b>Sg</b> Seaborgium (266)	104 <b>Bh</b> Bohrium (264)	105 <b>Hs</b> Hassium (265)	106 <b>Mt</b> Meitnerium (268)															

 Platinum Group Elements

 Other ECEs

 Rare Earth Elements

 Photovoltaic ECEs

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)

# New Energy Technologies

- Renewable
- CO<sub>2</sub> neutral

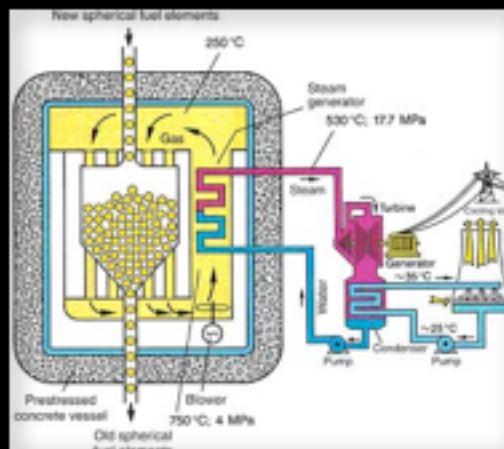


Tellurium Gallium  
Indium Germanium



Neodymium  
Dysprosium  
Praseodymium  
Samarium

Terbium  
Europium



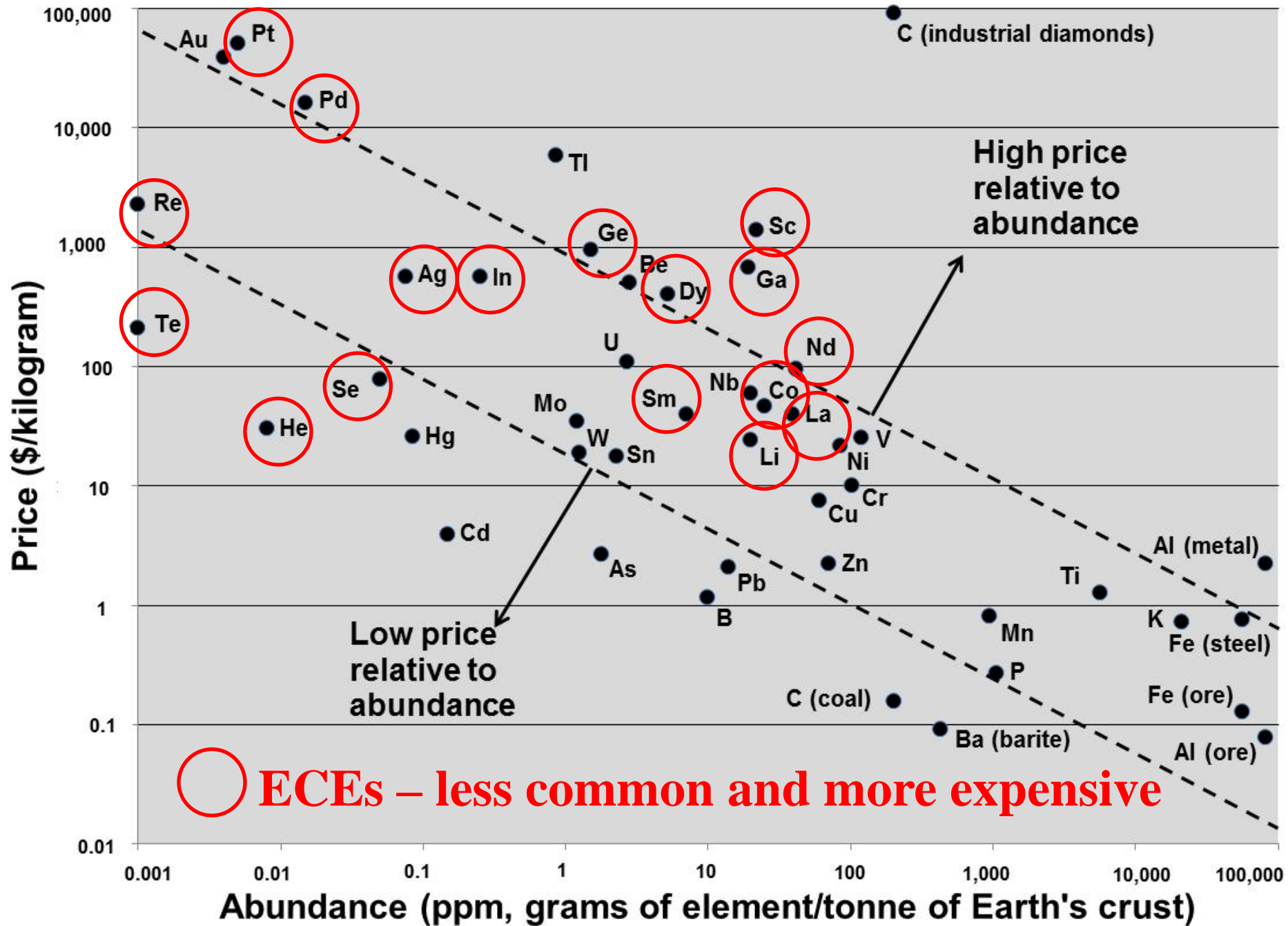
Helium



Lithium  
Lanthanum

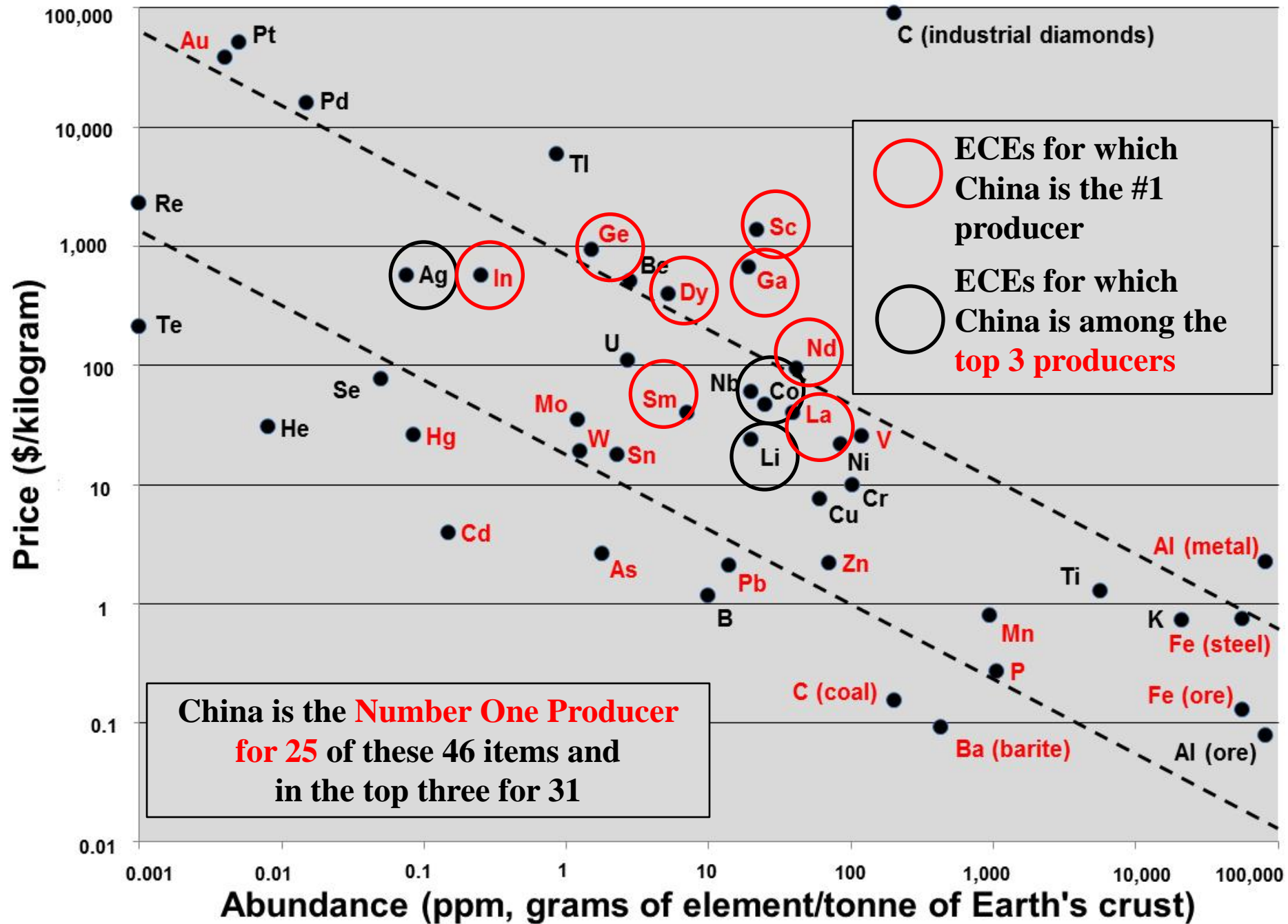
# **Constraints on availability of ECEs**

- A. Crustal abundance, concentration, and distribution**
- B. Geopolitical risk**
- C. Risks of joint production**
- D. Environmental and social concerns**
- E. Response times in production and utilization**



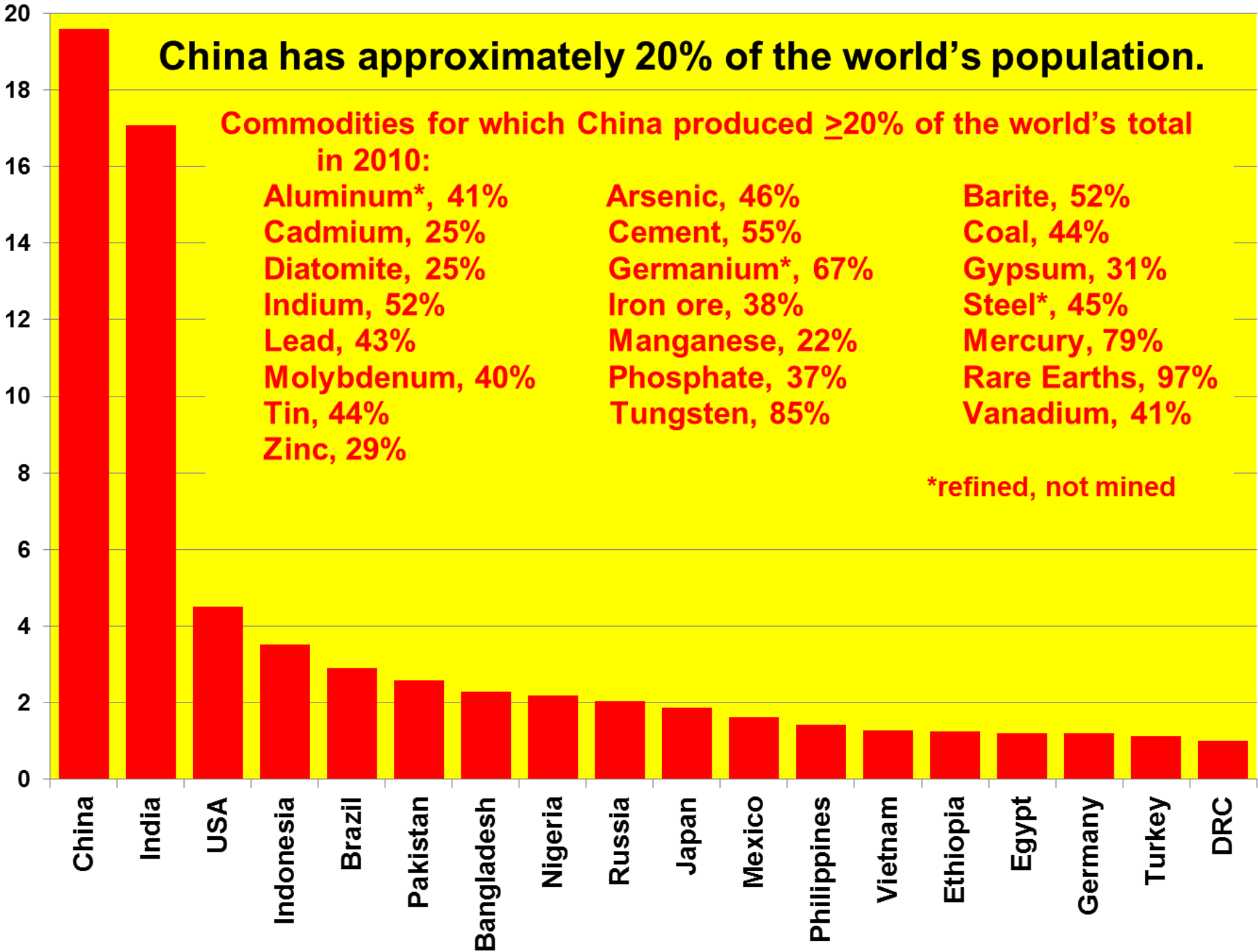
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# China has approximately 20% of the world's population.

Percentage of global population



Commodities for which China produced  $\geq 20\%$  of the world's total in 2010:

Aluminum\*, 41%

Cadmium, 25%

Diatomite, 25%

Indium, 52%

Lead, 43%

Molybdenum, 40%

Tin, 44%

Zinc, 29%

Arsenic, 46%

Cement, 55%

Germanium\*, 67%

Iron ore, 38%

Manganese, 22%

Phosphate, 37%

Tungsten, 85%

Barite, 52%

Coal, 44%

Gypsum, 31%

Steel\*, 45%

Mercury, 79%

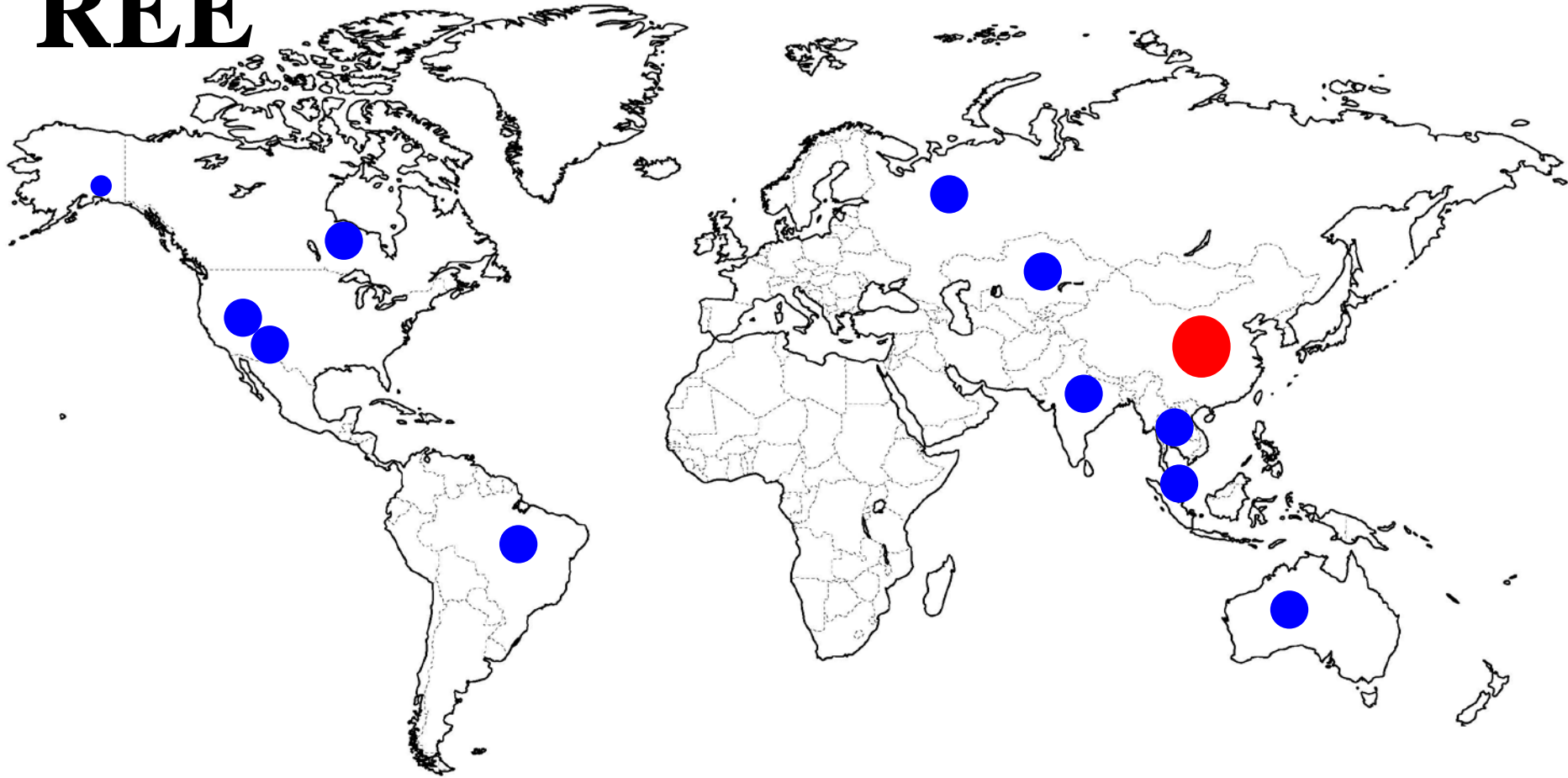
Rare Earths, 97%

Vanadium, 41%

\*refined, not mined



# REE



World's leading rare earth producer (China, 97%)



Countries with 4% or more of global production - none



Other countries with production or major reserves

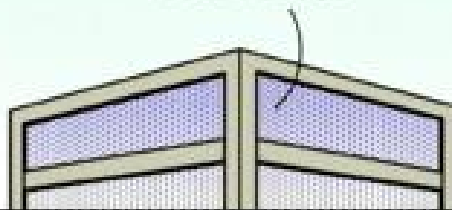
**Rare earth elements – significant current supply risk**

OUR CONSULTANT WILL TELL US HOW WE CAN SECURE A LONG-TERM SUPPLY OF RARE EARTH METALS FOR OUR PRODUCTS.



Dilbert.com DilbertCartoonist@gmail.com

CHINA HAS MOST OF THE RARE EARTH METALS. TRY DYING. AND REINCARNATING. THERE'S A 20% CHANCE THAT YOU'LL BE BORN CHINESE.

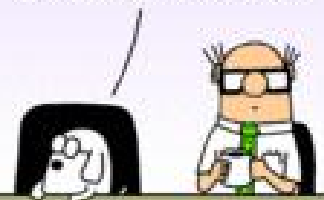


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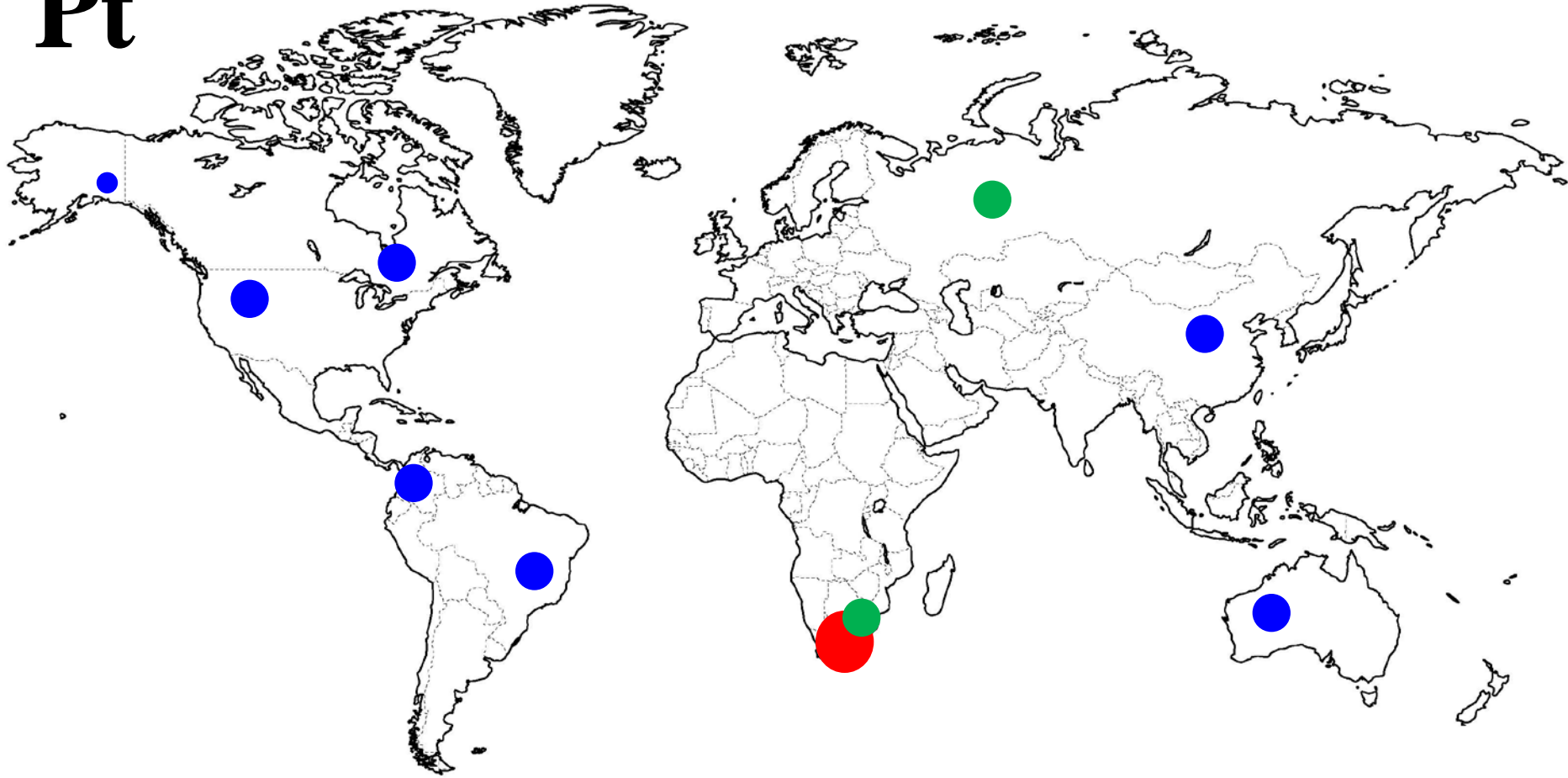
WHAT'S PLAN B?



IF THE ONLY PART THAT GOES WRONG IS THE CHINESE PART, YOU CAN TRY DYING AGAIN.



Pt



World's leading platinum producer (South Africa, 75%)



Countries with 4% or more of global production



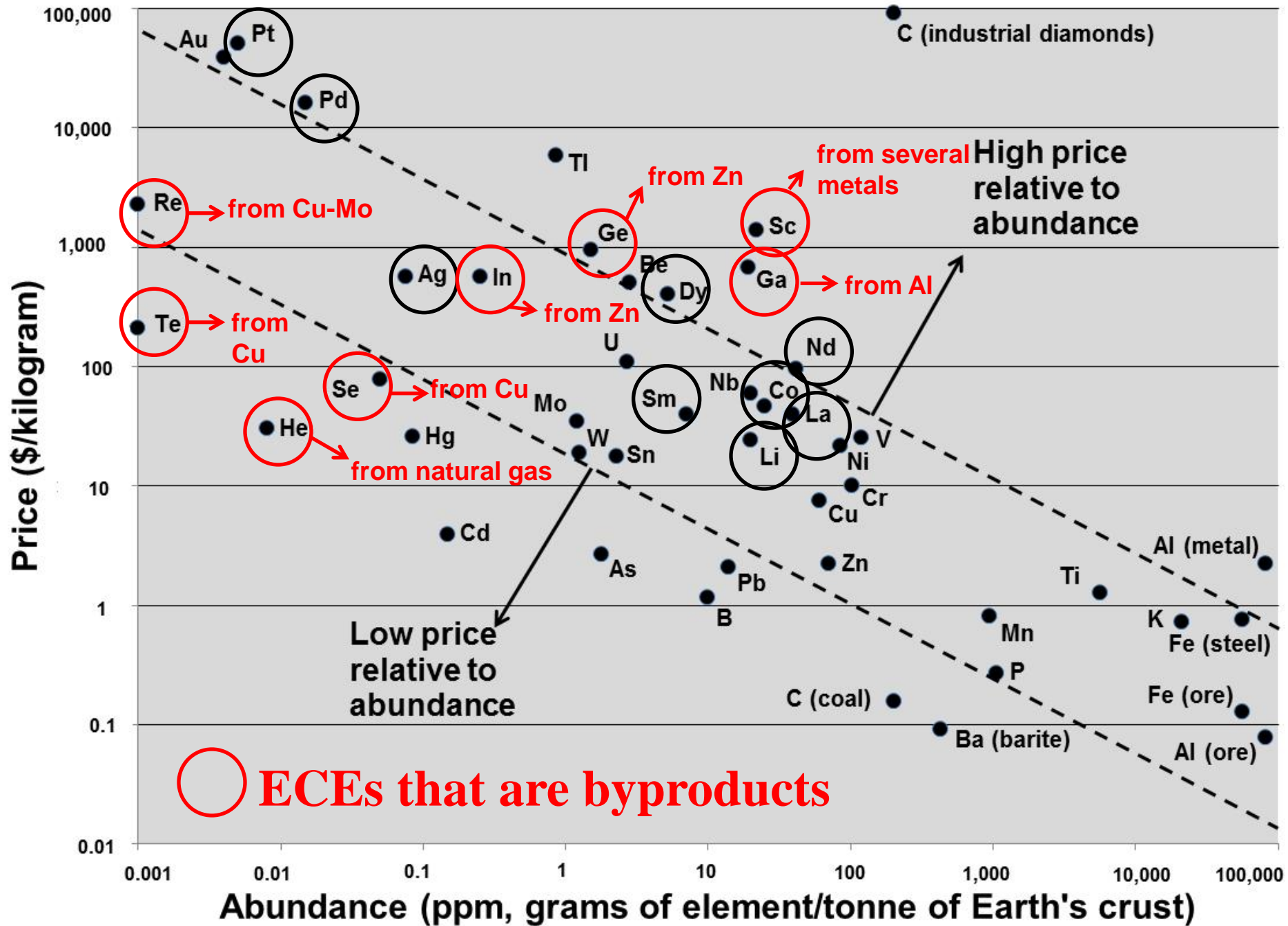
Other countries with production or major reserves

## Platinum – possible supply risk

Data source: USGS

# **Constraints on availability of ECEs**

- A. Crustal abundance, concentration, and distribution**
- B. Geopolitical risk**
- C. Risks of joint production**
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	<b>Main product Cu</b>	<b>Byproduct Se</b>	<b>Byproduct Te</b>
<b>Global production (metric tons)</b>	<b>16,200,000</b>	<b>2,260</b>	<b>~500</b>
<b>Price (\$/kg)</b>	<b>\$7.54/kg</b>	<b>\$77.16/kg</b>	<b>\$210/kg</b>
<b>Value of global production (\$)</b>	<b><math>\\$122 \times 10^9</math></b>	<b><math>\\$174 \times 10^6</math></b>	<b><math>\\$105 \times 10^6</math></b>
<b>Ratio of values of global production</b>		<b>Cu:Se = 700:1</b>	<b>Cu:Te = 1200:1</b>

**Securing more mineral resources that are recovered as byproducts will require either exploration for new types of resources or research on metallurgical extraction.**

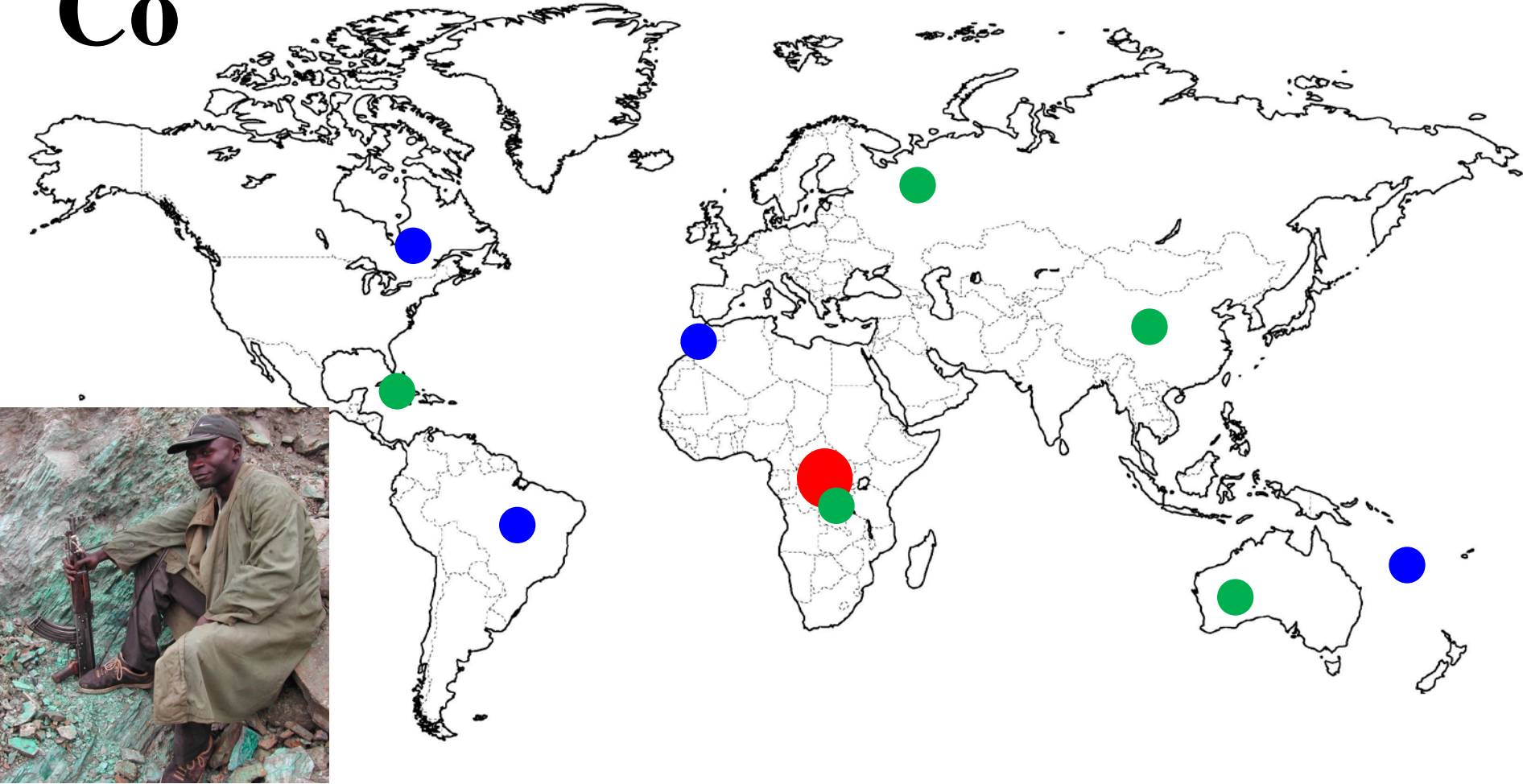
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Collapsed shaft in the street by the school in Virginia City, Nevada (circa 1995, from mining in the late 1800s) – The principal's car went into the "sinkhole."

# Co



**World's leading cobalt producer (Democratic Republic of Congo, 51%)**



**Countries with 4% or more of global production**



**Other countries with production or major reserves**

**(China = 7%)**

**Data source: USGS**



# Environmental and Social Concerns

- Decades of **increasing vigilance in mining industry** with respect to environmental and social issues
- Generally **high environmental and social standards in the developed world.**
- **Rising worldwide social and environmental sustainability standards**
  - ✓ International Council on Mining and Minerals (ICMM)
  - ✓ International Finance Corp (IFC)
  - ✓ World Bank
  - ✓ Major lending banks

**The major companies are acting responsibly.**

Galamsey (artisanal, subsistence miners) at Kyereboso, Ghana, 2008 - not a major company



# Constraints on availability of ECEs

- A. Crustal abundance, concentration, and distribution
- B. Geopolitical risk
- C. Risks of joint production
- D. Environmental and social concerns
- E. Response times in production and utilization**

Time to plan, research, develop,  
fund, permit, and deploy

**Exploration to mining:**

**5 to 15+ years**

New technology for producing,  
transmitting, storing, or  
conserving energy:

also 5 to 15+ years  
or even decades

# Findings and Recommendations

## Information

The United States government should **gather, analyze, and disseminate information on energy-critical elements across the life-cycle supply chain including discovered and potential resources, production, use, trade, disposal, and recycling.** The entity undertaking this task should be a “Principal Statistical Agency” with survey enforcement authority.

The federal government should regularly survey emerging energy technologies and the supply chain for elements throughout the periodic table, with the aim of identifying critical applications as well as potential shortfalls.

# Findings and Recommendations

## Research, development, and workforce issues

The federal government should establish a **research and development effort** focused on energy-critical elements and possible substitutes that can enhance vital aspects of the supply chain including: **geological deposit modeling, mineral extraction and processing, material characterization and substitution, utilization, manufacturing, recycling, and life-cycle analysis.**

# Findings and Recommendations

## The role of material efficiency

Steps should be taken to **improve rates of post-consumer collection of industrial and consumer products containing ECEs**, beginning with an examination of the numerous methods being explored and implemented in various states and countries.

# Findings and Recommendations

## Possible market interventions

With the exception of helium, the Committee does not propose government interventions in markets beyond those contained in the other recommendations concerning research and development, information gathering and analysis, and recycling. In particular, the **Committee does not recommend nondefense-related economic stockpiles.**

**Helium is unique even among ECEs.** We concur with and reiterate the APS Helium Statement of 1995: **“Measures should be adopted that will both conserve and enhance the nation’s helium reserves.** Failure to do so would not only be wasteful, but would also be economically and technologically shortsighted.”

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## Energy Critical Elements – Securing Materials for Emerging Technologies

**Thank you!**

- 1. Critical and strategic minerals will change with time.**
- 2. Demand is high.**
- 3. China will be a major force in the world of strategic and critical minerals.**
- 4. The U.S.A. has the right geology to be a major force as well for many, but not all, minerals.**





# Conclusions from the report

- We are not facing an imminent absolute shortage of energy critical elements (Hubbard's Peak scenario).
- However, market-driven shortages are possible (happening today).
- No country can become "ECE independent."
- **Securing ECEs will require both**  
*Aggressive research (geological, metallurgical, materials science) and*  
*Free markets.*

# REEs — Chinese Export Quotas

Year	Quota
2005	65,609 t REO*
2006	61,821 t REO
2007	59,643 t REO
2008	56,643 t REO
2009	50,145 t REO
2010	30,258 t REO
(first half 2011)	14,508 t REO

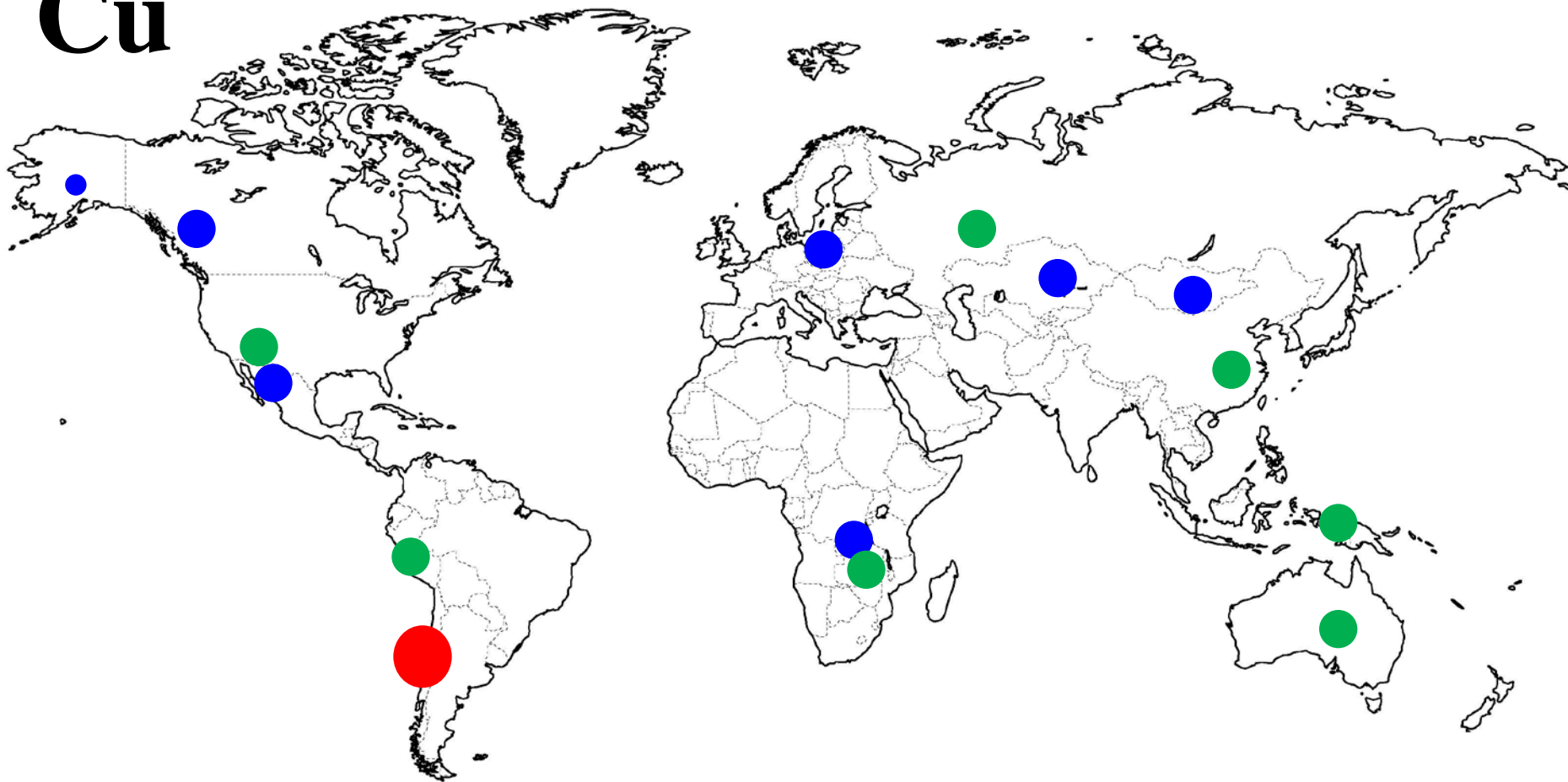
\* REO = rare earth oxides

- **Quota: Domestic + foreign companies**
- **2008: Adjusted to an equivalent 12 month quota as there was a change in the dates for which they applied**

**We exclude carbon (as coal, oil, natural gas) and uranium,** since they have been the subject of many studies and mature regulation; moreover, increased demand does not create novel issues for these elements beyond those already explored in the economic, technical, and political arenas. We exclude elements like **phosphorus and potassium,** for which we can see only peripheral relevance to energy issues.

**Many important elements are notably absent from this list. Copper, aluminum, iron, tin, and nickel are absolutely essential for energy applications. However, because they enjoy large, mature, and vigorous markets with many suppliers, a strong demand from the energy sector would most likely be met with a market-driven increase in supply.**

# Cu



**World's leading copper producer (Chile, 34%)**



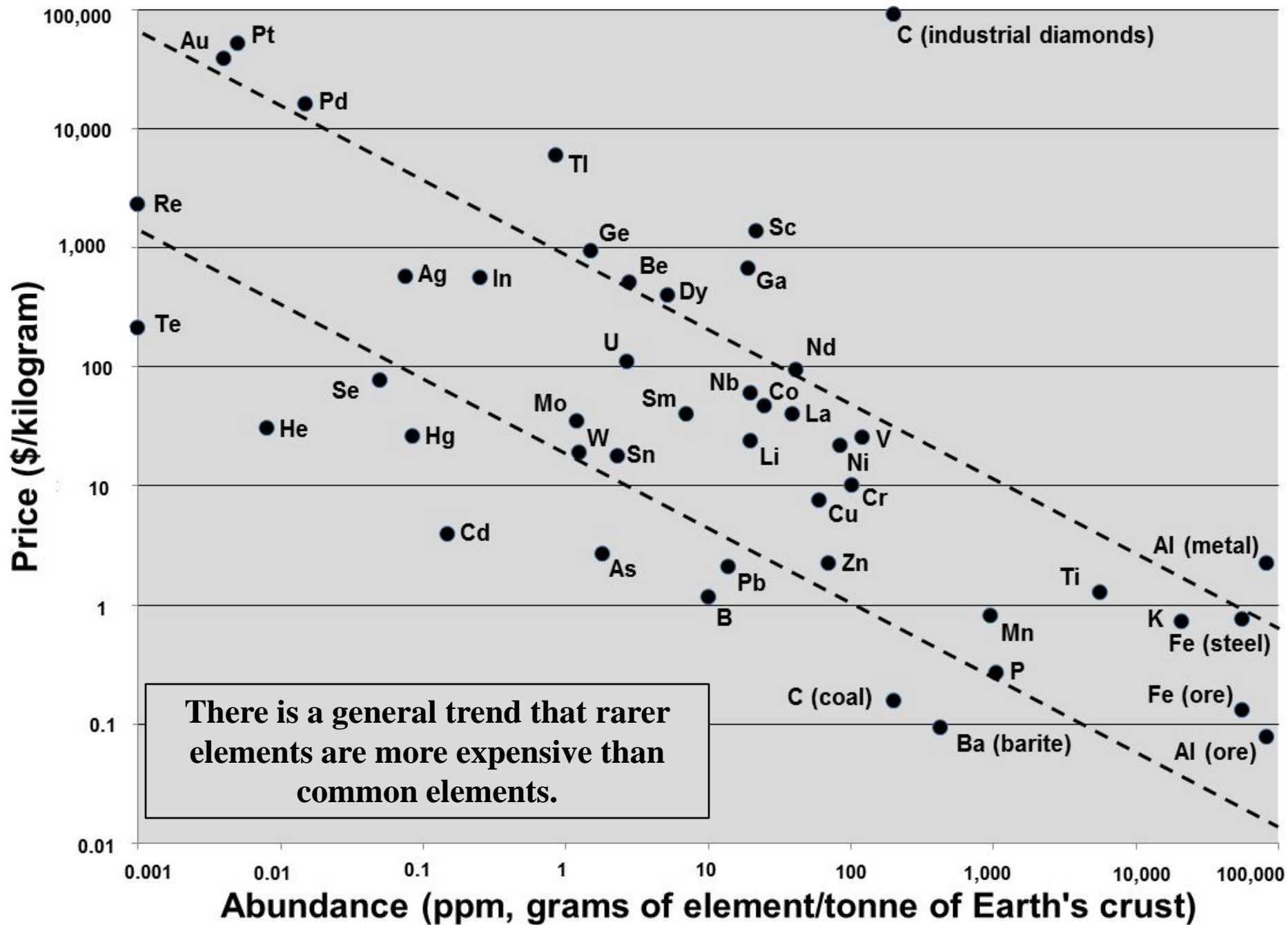
**Countries with 4% or more of global production**

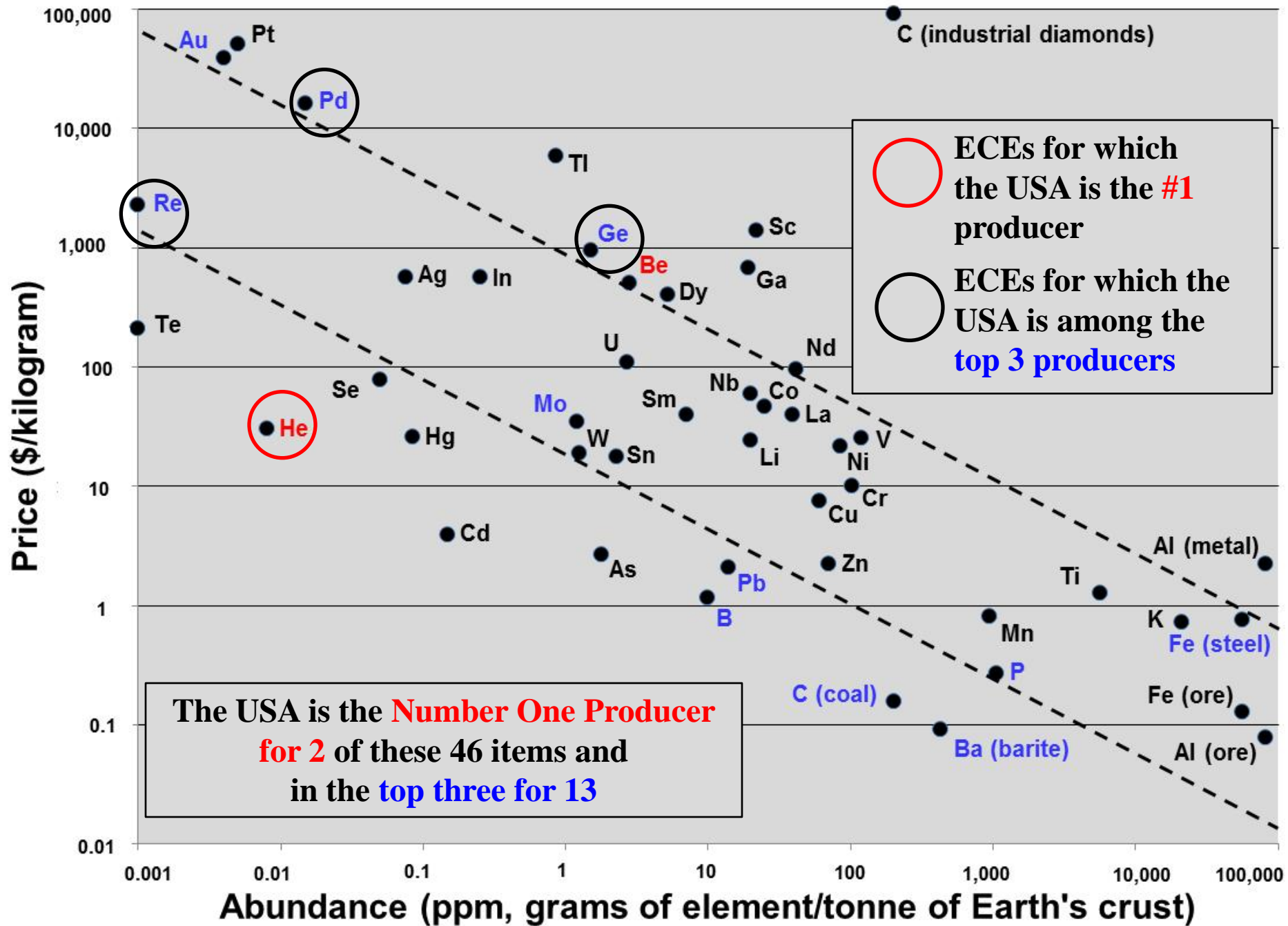


**Other countries with production or major reserves**

**Copper resources are broadly distributed.**

**Data source: USGS**












**This report surveys potential constraints on the availability of ECEs and then identifies **five specific areas of potential action** by the United States to insure their availability:**

- 1) federal agency coordination;**
- 2) information collection, analysis, and dissemination;**
- 3) research, development, and workforce enhancement;**
- 4) efficient use of materials; and,**
- 5) market interventions.**

# Thank you!

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87 <b>Fr</b> Francium (223)	88 <b>Ra</b> Radium (226)	58 <b>Ce</b> Cerium 140.116			59 <b>Pr</b> Praseodymium 140.90765	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 151.964	64 <b>Gd</b> Gadolinium 157.25	65 <b>Tb</b> Terbium 158.92534	66 <b>Dy</b> Dysprosium 162.50	67 <b>Ho</b> Holmium 164.93032	68 <b>Er</b> Erbium 167.26	69 <b>Tm</b> Thulium 168.93421	70 <b>Yb</b> Ytterbium 173.04

## Energy Critical Elements:

						2 <b>He</b> Helium 4.003
5 <b>B</b> Boron 10.811	6 <b>C</b> Carbon 12.0107	7 <b>N</b> Nitrogen 14.00674	8 <b>O</b> Oxygen 15.9994	9 <b>F</b> Fluorine 18.9984032	10 <b>Ne</b> Neon 20.1797	
13 <b>Al</b> Aluminum 26.981538	14 <b>Si</b> Silicon 28.0855	15 <b>P</b> Phosphorus 30.973761	16 <b>S</b> Sulfur 32.066			
28 <b>Ni</b> Nickel 58.6934	29 <b>Cu</b> Copper 63.546	30 <b>Zn</b> Zinc 65.39	31 <b>Ga</b> Gallium 69.723	32 <b>Ge</b> Germanium 72.61	33 <b>As</b> Arsenic 74.92160	
46 <b>Pd</b> Palladium 106.42	47 <b>Ag</b> Silver 107.8682	48 <b>Cd</b> Cadmium 112.411	49 <b>In</b> Indium 114.818	50 <b>Sn</b> Tin 118.710	51 <b>Sb</b> Antimony 121.760	
78 <b>Pt</b> Platinum 195.078	79 <b>Au</b> Gold 196.96655	80 <b>Hg</b> Mercury 200.59	81 <b>Tl</b> Thallium 204.3833	82 <b>Pb</b> Lead 207.2	83 <b>Bi</b> Bismuth 208.98038	
65 <b>Tb</b> Terbium 158.92534	66 <b>Dy</b> Dysprosium 162.50	67 <b>Ho</b> Holmium 164.93032	68 <b>Er</b> Erbium 167.26	69 <b>Tm</b> Thulium 168.93421	70 <b>Yb</b> Ytterbium 173.04	71 <b>Lu</b> Lutetium 174.967



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