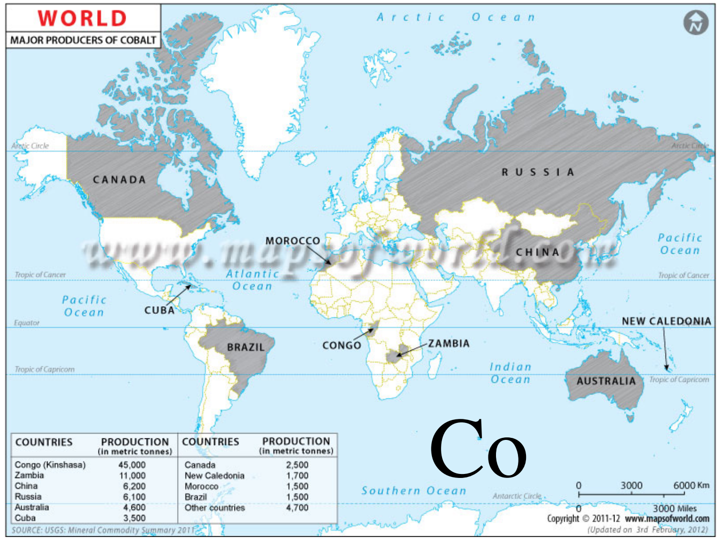
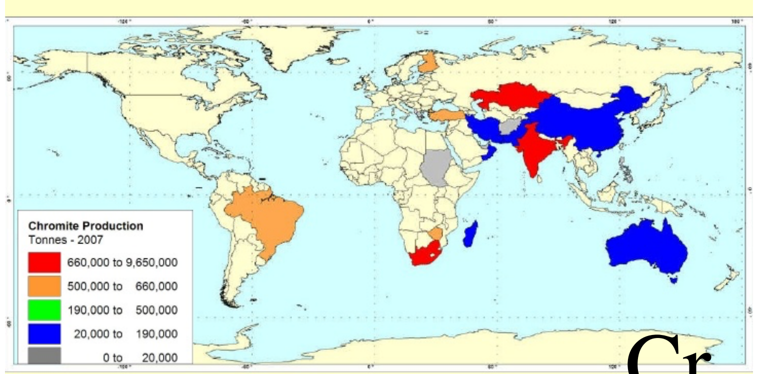
STRATEGIC MATERIALS

Co, Cr, Ta and Nb has been designated a "**strategic aerospace element**," because the United States is almost entirely dependent on imports for the consumption of these elements ***Three nations, South Africa, Zaire, and the U. S. S. R., account for over half of the world's production of Cr, Co, Mn, and Pt group metals***.

Disruptions of supply, such as the Canadian nickel strike in 1968 and the rebel interruptions of cobalt production in Zaire in 1978, had a major impact on U.S. industries.



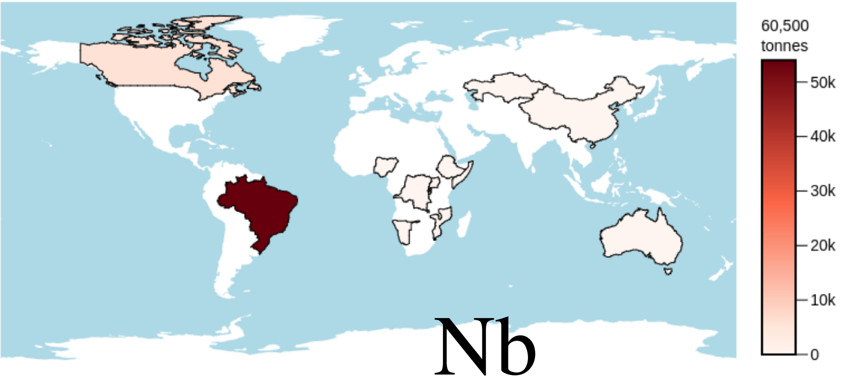


World chromite production

- South Africa, India and Kazakhstan = 78%
- Brazil, Finland, Russia, Zimbabwe and Turkey =12%
- Canada poised to be the next major producer

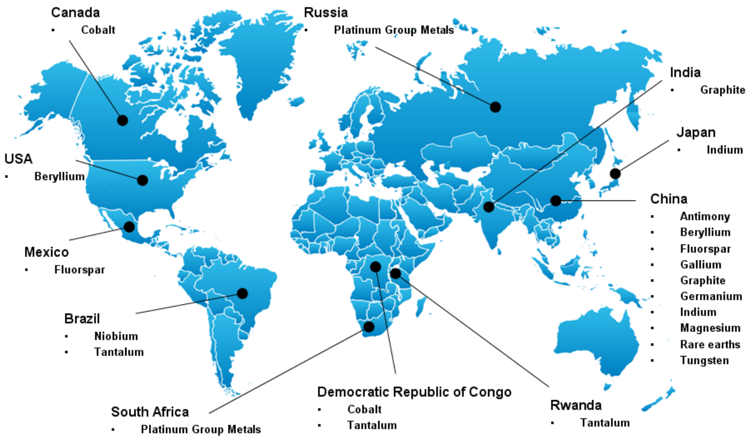
Date: 8/8/2018

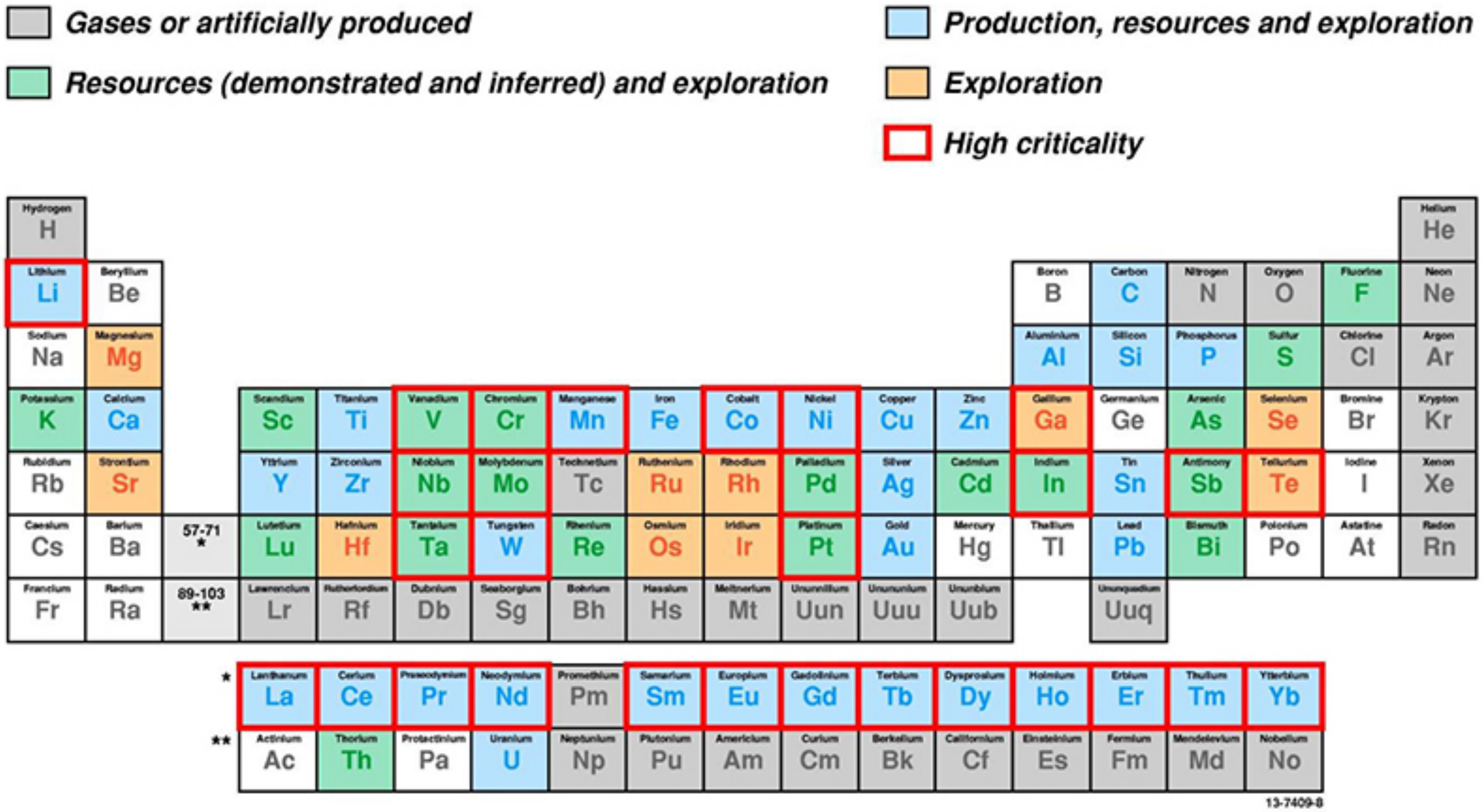
Niobium Production 2015



Source: U.S. Geological Survey (USGS)

Production concentration of critical raw mineral materials




Gases or artificially produced
Resources (demonstrated and inferred) and exploration
Production, resources and exploration
Exploration
High criticality
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 57-71 * Lu Hf Ta W Re Os Ir Pt Au Hg Tl Pb Bi Po At Rn
Fr Ra 89-103 ** Lr Rf Db Sg Bh Hs Mt Uun Uuu Uub Uuq
* La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb
** Ac Th Pa U Np Pu Am Cm Bk Cf Es Fm Md No
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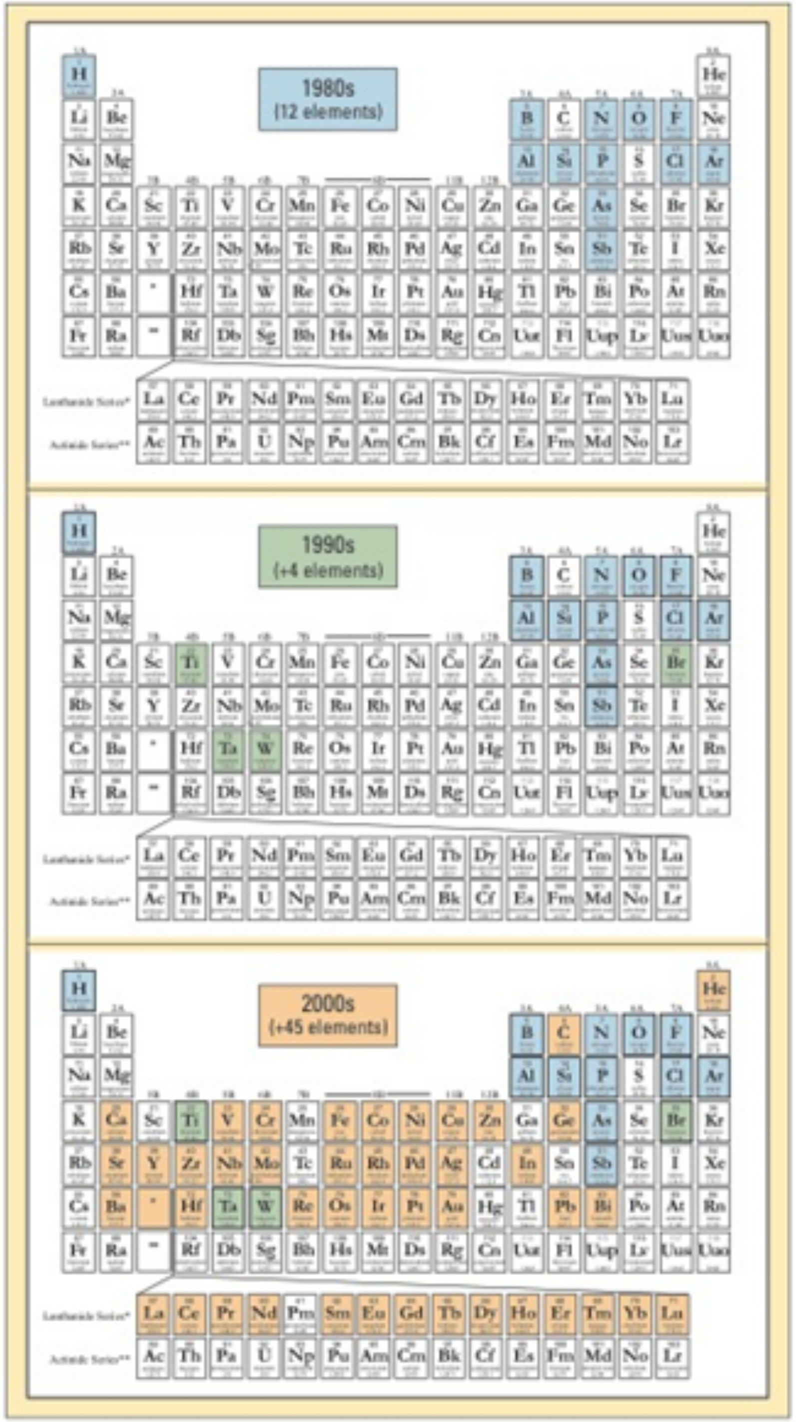
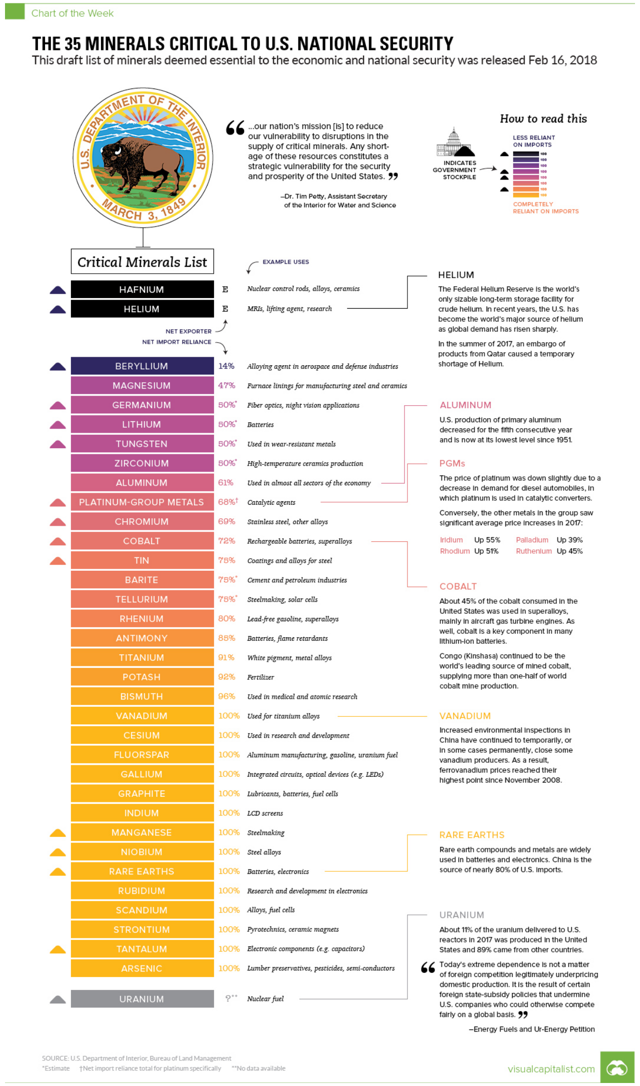


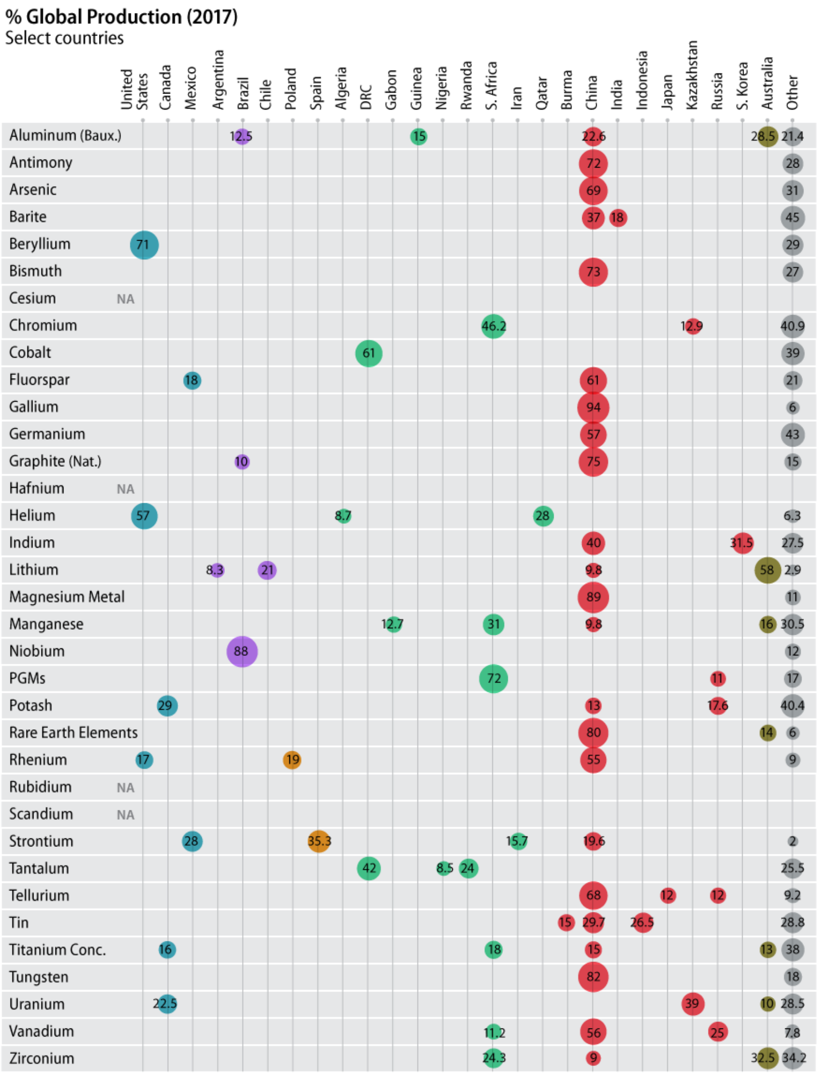
It would be no exaggeration to say that without minerals, no aspect of our daily lives would be possible.



Under the Executive Order, a critical mineral is defined as:

A non-fuel mineral or mineral material essential to the economic and national security of the United States, the supply chain of which is vulnerable to disruption…

Energy	*Technology*	*Industrial*	*Steel*	*Batteries*	*Research*
HAFNIUM	GERMANIUM	BERYLLIUM	MAGNESIUM	LITHIUM	HELIUM
RHENIUM	INDIUM	ZIRCONIUM	CHROMIUM	COBALT	RUBIDIUM
TANTALUM	GALLIUM	TUNGSTEN	TIN	ANTIMONY	CESIUM
URANIUM	RARE EARTHS	ALUMINUM	TELLURIUM	GRAPHITE	BISMUTH
		PGMs	MANGANESE		
		BARITE	VANADIUM		
		FLUORSPAR	NIOBIUM		
		ARSENIC			
		SCANDIUM			
		STRONTIUM			
		TITANIUM			
		POTASH			



The United States is 100% import reliant on 14 minerals on the critical minerals list. These minerals are difficult to substitute inputs into the U.S. economy and national security applications; **they include graphite, Mn, Nb, rare earths, and Ta**, among others. The United States is more than 75% import reliant on an additional 10 critical minerals: **Sn, barite, bauxite, Bi, K, Re, Te, Ti, and U**.

in 2010 Chinese export of rare earth (REEs) to Japan closed down overnight over a maritime dispute

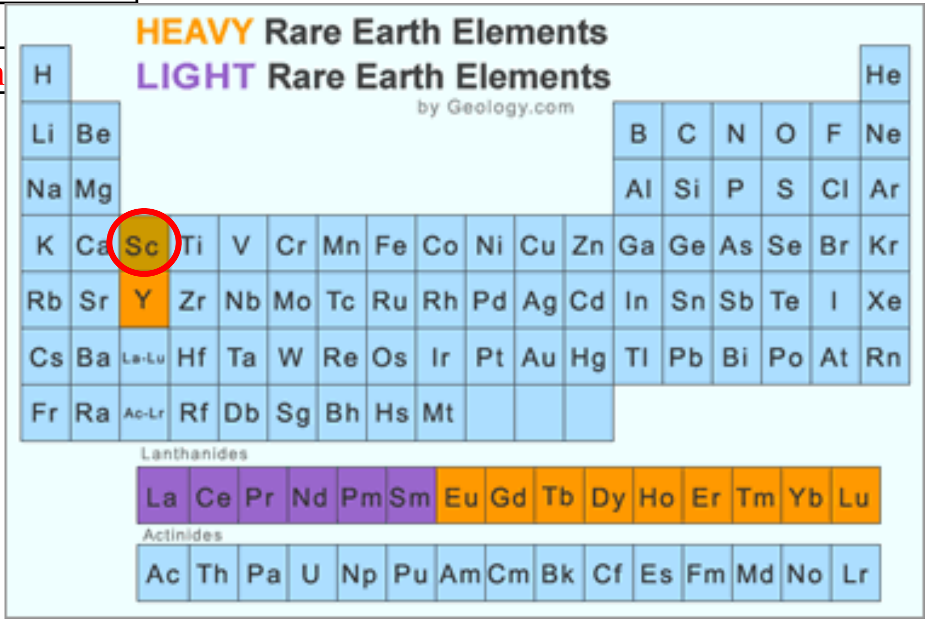
The 2020 EU list contains 30 materials as compared to 14 materials in 2011, 20 materials in 2014 and 27 materials in 2017.

Bauxite, Li, Ti and Sr are added to the list for the first time.

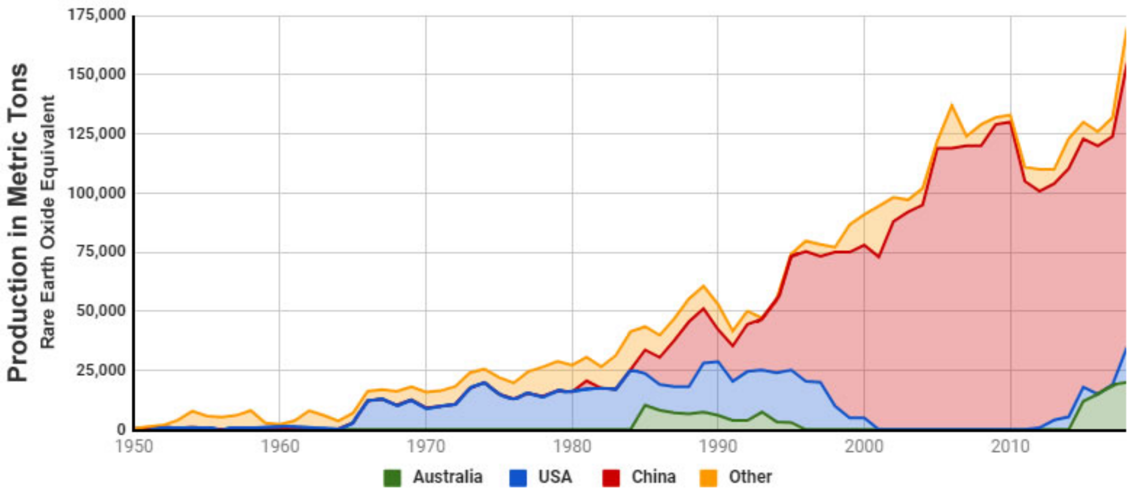
Helium remains a concern as far as supply concentration is concerned, but is removed from the 2020 critical list due to a decline in its economic importance.

The Commission will monitor Ni closely, in view of developments relating to growth in demand for battery raw materials.

2020 Critical Raw Materials		
Antimony	**Hafnium**	Phosphorus
Baryte	**Heavy Rare Earth Elements**	**Scandium**
Beryllium	**Light Rare Earth Elements**	Silicon metal
Bismuth	**Indium**	**Tantalum**
Borate	**Magnesium**	**Tungsten**
Cobalt	Natural Graphite	**Vanadium**
Coking Coal	Natural Rubber	Bauxite
Fluorspar	**Niobium**	**Lithium**
Gallium	**Platinum Group Metals**	**Titanium**
Germanium	Phosphate rock	**Strontium**



Defense Uses of Rare Earth Elements	
Lanthanum	night-vision goggles
Neodymium	laser range-finders, guidance systems, communications
Europium	fluorescents and phosphors in lamps and monitors
Erbium	amplifiers in fiber-optic data transmission
Samarium	permanent magnets that are stable at high temperatures
Samarium	precision-guided weapons
Samarium	"white noise" production in stealth technology



Did You Know? Rare earth magnets are used in wind turbines. ***Some large turbines require two TONS of rare earth magnets.*** These magnets are very strong and make the turbines highly efficient. Rare earth magnets are used in turbines and generators in many alternative energy applications.

Rare Earth Element Production: This chart shows a history of rare earth element production, in metric tons of rare earth oxide equivalent, between 1950 and 2018. It clearly shows the United States' entry into the market in the mid-1960s when color television exploded demand. When China began selling rare earths at very low prices in the late 1980s and early 1990s, mines in the United States were forced to close because they could no longer make a profit. When China cut exports in 2010, rare earth prices skyrocketed. That motivated new production in the United States, Australia, Russia, Thailand, Malaysia, and other countries.

History of Rare Earth Production and Trade

Pre-1965

Before 1965 there was relatively little demand for rare earth elements. At that time, most of the world's supply was being produced from deposits in **India** and **Brazil**. In the 1950s, **South Africa** became the leading producer from rare earth bearing **monazite** (Ce,La,Nd,Th)(PO_4 SiO_4).deposits. **At that time, the Mountain Pass Mine in California was producing minor amounts of rare earth oxides.**

Color Television Ignites Demand

The demand for rare earth elements saw its first explosion in the mid-1960s, as the first color television sets were entering the market. **Europium was the essential material for producing the color images.** The Mountain Pass Mine began producing europium from bastnasite, which contained about 0.1% europium. **This effort made the Mountain Pass Mine the largest rare earth producer in the world and placed the United States as the leading producer.**

Mountain Pass rare earth mine

The **Mountain Pass Mine** (California) was discovered in 1949. The mine once supplied most of the world's rare-earth elements. It was the only rare earth mining and processing facility in the United States. It is a world-class rare-earth mineral deposit. The metals that can be extracted from it include: Ce, La, Nd,and Eu.

The mine closed in 2002 in response to both environmental restrictions and competition from Chinese suppliers

*In the 1980s, the company began piping wastewater up to 14 miles to evaporation ponds. This pipeline repeatedly ruptured during cleaning operations to remove mineral deposits called **scale**. The scale is radioactive because of the presence of **Th** and **Ra**. A federal investigation later found that some 60 spills—some unreported—occurred between 1984 and 1998. **In all, about 600,000 gallons of radioactive and other hazardous waste flowed onto the desert floor***

China Enters the Market

China began producing notable amounts of rare earth oxides in the **early 1980s** and became the world's leading producer in the early 1990s. Through the 1990s and early 2000s, China steadily strengthened its hold on the world's rare earth oxide market. ***They were selling rare earths at such low prices that the Mountain Pass Mine and many others throughout the world were unable to compete and stopped operation.***

Defense and Consumer Electronics Demand

At the same time, world demand was skyrocketing as rare earth metals were designed into a wide variety of defense, aviation, industrial, and consumer electronics products. **China capitalized on its dominant position and began restricting exports and allowing rare earth oxide prices to rise to historic levels.**

China as the Largest Rare Earth Consumer

In addition to being the world's largest producer of rare earth materials, China is also the dominant consumer. They use rare earths mainly in manufacturing electronics products for domestic and export markets.

China's Apex of Production Dominance?

The Chinese dominance may have peaked in 2010 when they controlled about 95% of the world's rare earth production, and prices for many rare earth oxides had risen over 500% in just a few years. That was an awakening for rare earth consumers and miners throughout the world. Mining companies in the United States, Australia, Canada, and other countries began to reevaluate old rare earth prospects and explore for new ones.

High prices also caused manufacturers to do three things: 1) seek ways to reduce the amount of rare earth elements needed to produce each of their products; 2) seek alternative materials to use in place of rare earth elements; and, 3) develop alternative products that do not require rare earth elements.

China Buying Resources Outside of China

Chinese companies have been purchasing rare earth resources in other countries.

Rare Earth Production Outside of China

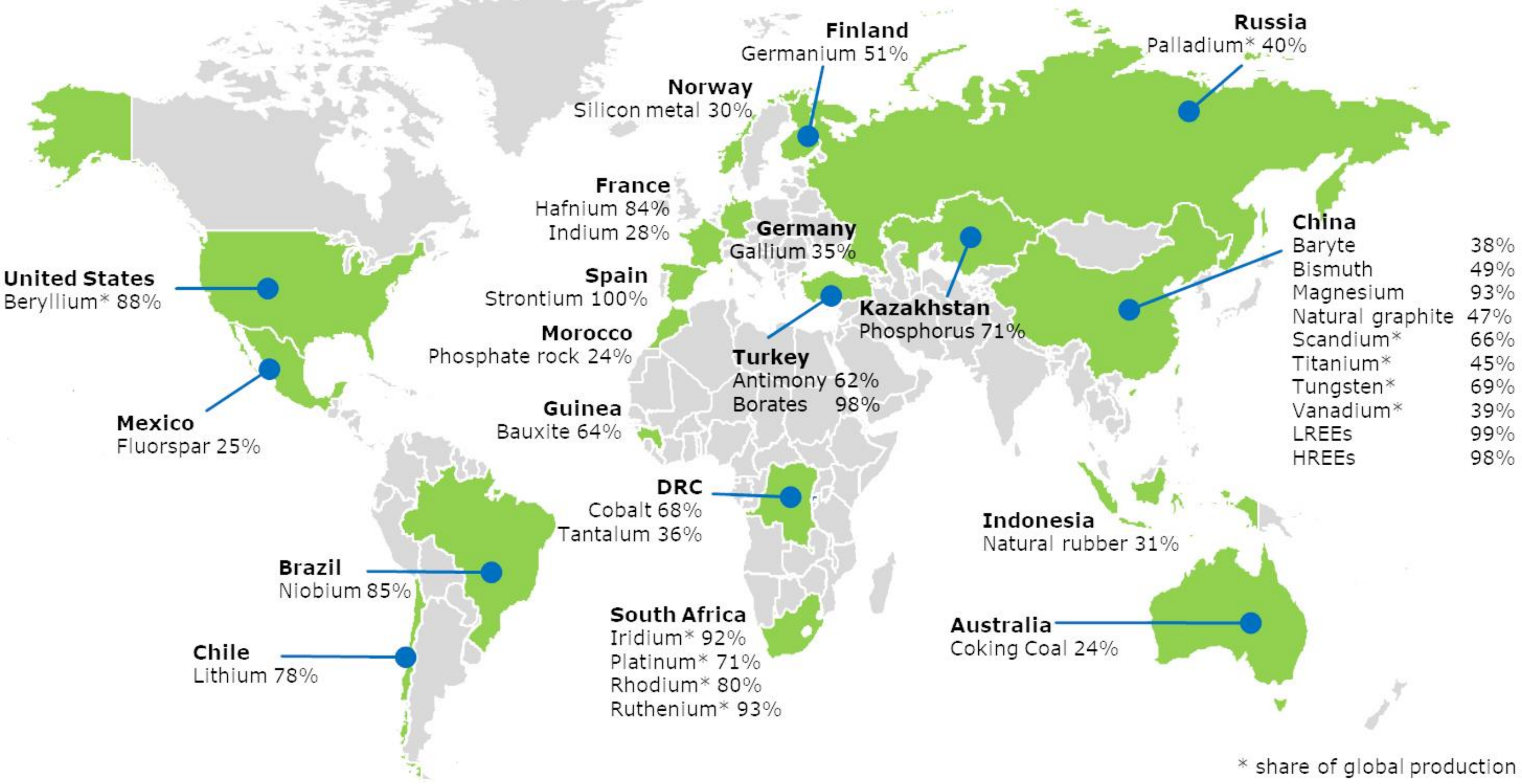
Mines in Australia began producing rare earth oxides in 2011. In 2012 and 2013 they were supplying about 2% to 3% of world production.

In 2012 the Mountain Pass Mine came back into production, and USA produced about 4% of the world's rare earth elements in 2013.

Production in Brazil, Malaysia, Russia, Thailand, Vietnam, continued or increased.

China is still the world leader in rare earth production, they control about 36% of the world's reserves

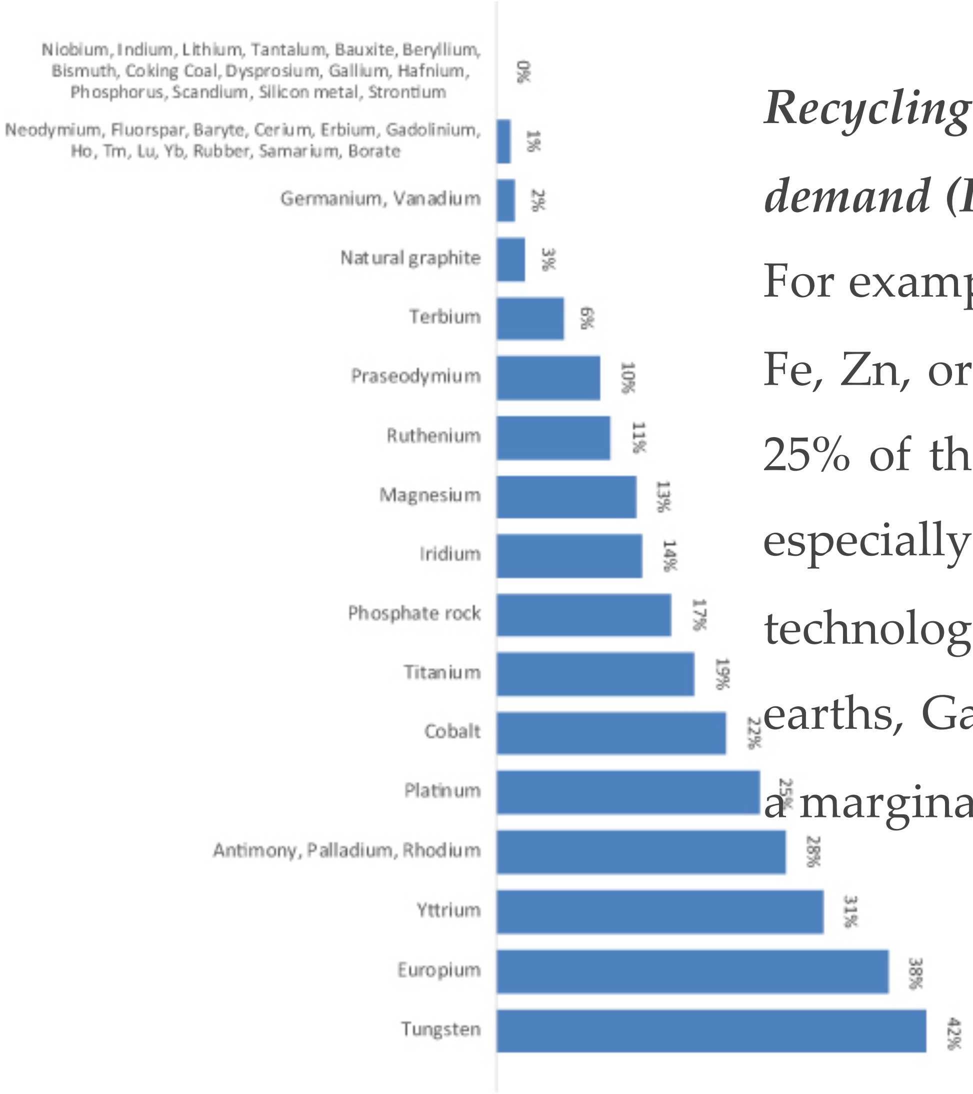
World Mine Production and Reserves (2017 Estimates)	
Country	Reserves (Metric Tons)
United States	1,400,000
Australia	3,400,000
Brazil	22,000,000
Canada	830,000
China	44,000,000
Greenland	1,500,000
India	6,900,000
Malawi	140,000
Malaysia	30,000
Russia	18,000,000
South Africa	860,000
Thailand	not available
Vietnam	22,000,000
World total (rounded)	120,000,000



The supply of many critical raw materials is highly concentrated. For example, China provides 98 % of the EU's supply of rare earth elements (REE), Turkey provides 98% of the EU's supply of borate, and South Africa provides 71% of the EU's needs for Pt and an even higher share of the platinum group metals iridium, rhodium, and ruthenium.

For electric vehicle batteries and energy storage, the **EU** would need up to 18 times more Li and 5 times more Co in 2030, and almost 60 times more Li and 15 times more Co in 2050, compared to the current supply to the whole EU economy.

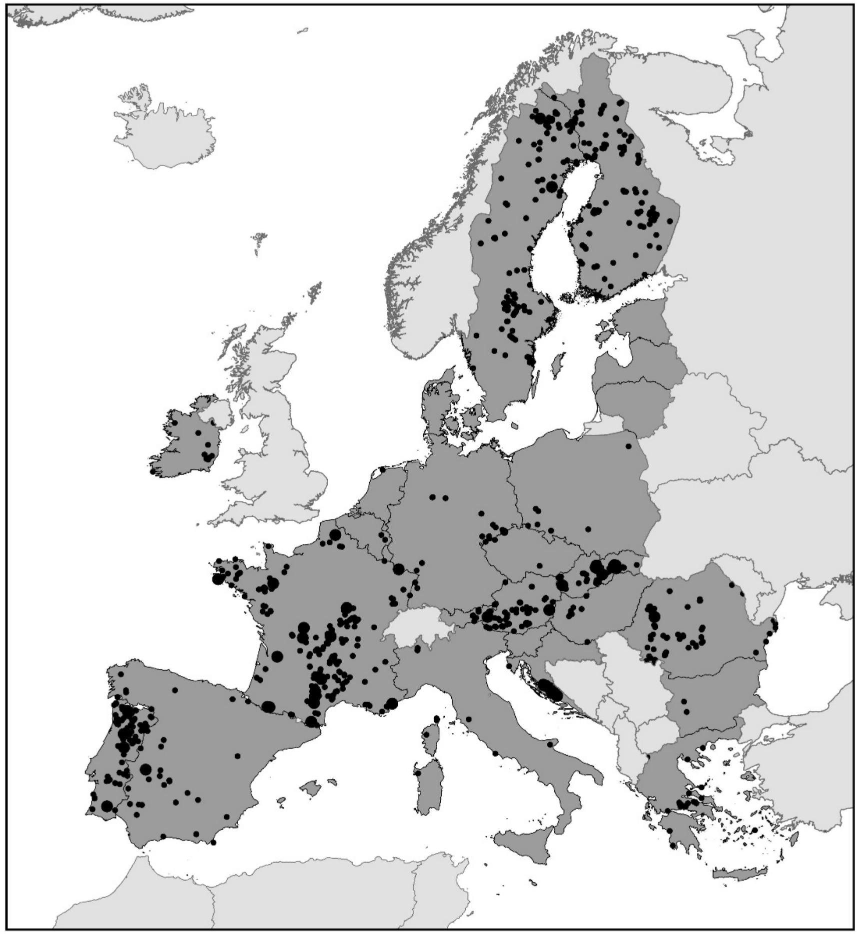
The World Bank projects that demand for metals and minerals increases rapidly with climate ambition. The most significant example of this is electric storage batteries, where the rise in demand for relevant metals, Al, Co, Fe, Pb, Li, Mn and Ni would grow by more than 1000 per cent by 2050.



Recycling's contribution to meeting materials demand (Recycling Input Rate)

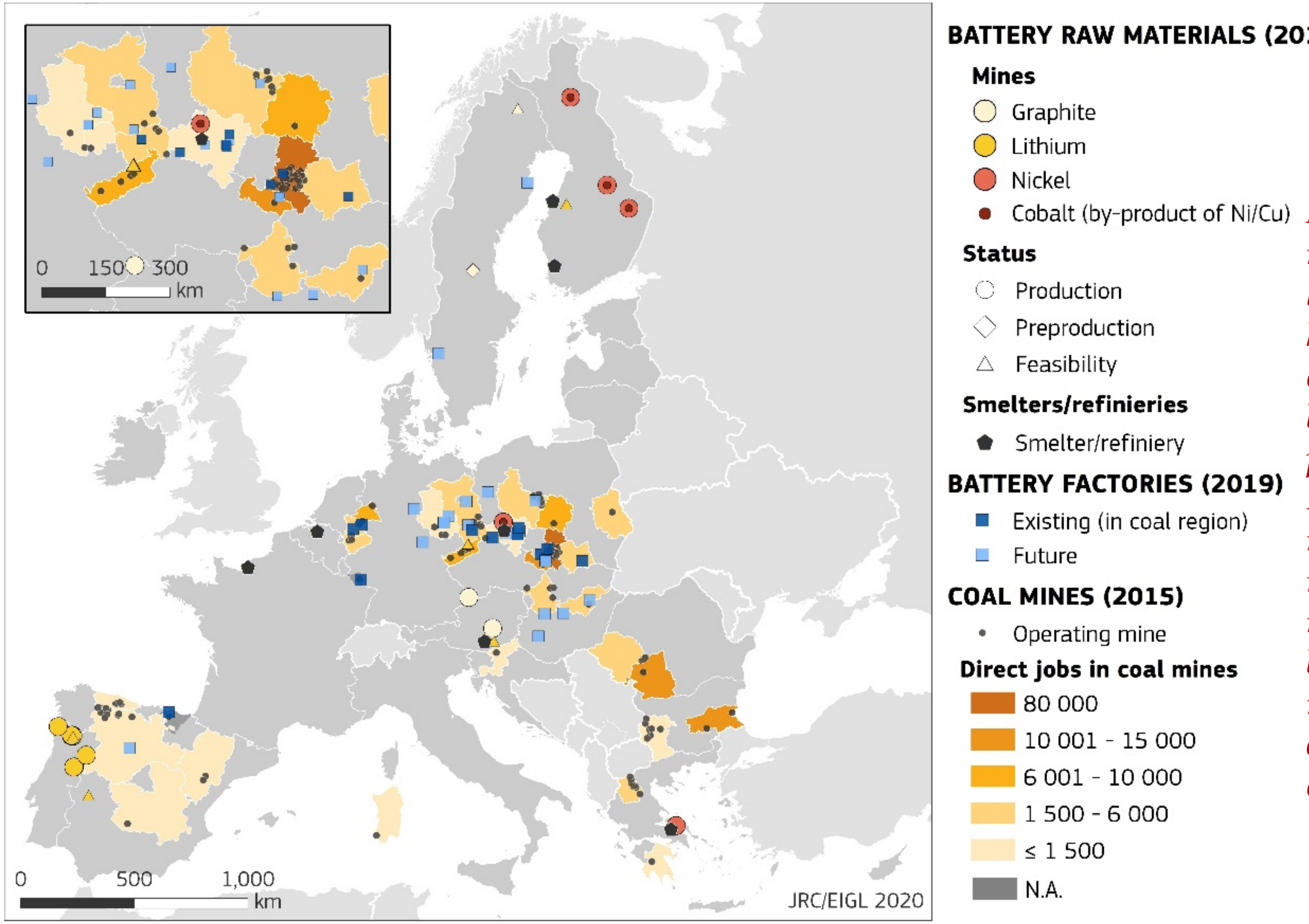
For example, more than 50% of some metals such as Fe, Zn, or Pt are recycled and they cover more than 25% of the EU's consumption. For others, however, especially those needed in renewable energy technologies or high-tech applications such as rare earths, Ga, or In, secondary production makes only a marginal contribution.

CRITICAL RAW MATERIALS RESOURCES POTENTIAL IN THE EU



Data provided by EuroGeoSurveys combined with other EU data sources

Looking at the geographical distribution of critical raw materials in Europe, the development of battery raw materials such as **lithium, nickel, cobalt, graphite and manganese** provides interesting opportunities.



Many battery raw material resources lie in regions that are heavily dependent on coal and where battery factories are planned. Furthermore, many mining wastes are rich in critical raw materials and could be revisited to create new economic activity on existing or former coal-mining sites.

Tantalum

Tantalum is a metallic element contained in the mineral tantalite and is extracted from primary and placer mineral deposits. It often occurs with niobium but is also present with other minerals such as rare earths, uranium, and cassiterite (tin ore).

Tantalum's high melting point (3000 C) and corrosion resistance makes it super-capacitive, (i.e., characterized by a high capacity to store and release electrical charges). This metal, which is used in numerous high-tech electronic devices, is produced and traded in conflict areas in Central Africa; thus, in certain instances, tantalum is classified as a conflict mineral and subject to disclosure rules *(conflict minerals in the Democratic Republic of the Congo or adjoining countries like Rwanda are financing extreme levels of violence in the DRC). Africa provides 80% of the primary Ta production (60% from the DRC and Rwanda) as China dominates processing and manufacturing capacity.*

Congressional Interest

Proposed Congressional findings mentioned in a number of bills introduced since the 111th Congress on critical minerals include:

- Emerging economies are increasing their demand for REEs as they industrialize and modernize;
- A variety of minerals are essential for economic growth and for infrastructure;
- The United States has vast mineral resources but at the same time is becoming more dependent on imports;
- Mineral exploration dollars in the United States are approximately 7% of the world total (compared to 19% in the early 90s);
- Heavy rare earth elements are critical to national defense;
- China has near-monopoly control over the rare earth value chain, and there has been a transfer of technology from U.S. firms and others to China in order to gain access to rare earths and downstream materials;
- Thorium regulations are a barrier to rare earth development in the United States;
- A sense of Congress that China could disrupt REE and other critical mineral supplies to the United States;
- It is important to develop the domestic industrial base for the production of strategic and critical minerals; and
- The United States must accept some risk in the form of aiding domestic investment opportunities.

A List of All Rare Earth Elements

Z	ELEMENT	SYMBOL	USE
21	Scandium	Sc	Aerospace framework, high-intensity street lamps, high performance equipment
39	Yttrium	Y	TV sets, cancer treatment drugs, enhances strength of alloys
57	Lanthanum	La	Camera lenses, battery-electrodes, hydrogen storage
58	Cerium	Ce	Catalytic converters, colored glass, steel production
59	Praseodymium	Pr	Super-strong magnets, welding goggles, lasers
60	Neodymium	Nd	Extremely strong permanent magnets, microphones, electric motors of hybrid automobiles, laser
61	Promethium	Pm	Not usually found in Nature
62	Samarium	Sm	Cancer treatment, nuclear reactor control rods, X-ray lasers
63	Europium	Eu	Color TV screens, fluorescent glass, genetic screening tests
64	Gadolinium	Gd	Shielding in nuclear reactors, nuclear marine propulsion, increases durability of alloys
65	Terbium	Tb	TV sets, fuel cells, sonar systems
66	Dysprosium	Dy	Commercial lighting, hard disk devices, transducers
67	Holmium	Ho	Lasers, glass coloring, High-strength magnets
68	Erbium	Er	Glass colorant, signal amplification for fiber optic cables, metallurgical uses
69	Thulium	Tm	High efficiency lasers, portable x-ray machines, high temperature superconductor
70	Ytterbium	Yb	Improves stainless steel, lasers, ground monitoring devices
71	Lutetium	Lu	Refining petroleum, LED light bulbs, integrated circuit manufacturing

(Z = Atomic Number)

Elements 29, 61 = Rare Earths
Elements 57 – 60, 62 = Light Rare Earth Elements
Elements 39, 63 – 71 = Heavy Rare Earth Elements

China produces the vast majority of heavy rare earths, **W (85%), In, Sn e terre rare**

W (60% per fare carburi) praticamente solo in Cina (85%) e attualmente nessuna produzione in USA

In (raro quanto l' Ag la Cina ne produce il 50%) attualmente niente in USA. Produzione di Indium Tin Oxide (ITO) x touch screen, flat screen, pannelli solari.

Sn (Cina produce 88% niente in USA), ritardante di fiamma e semiconduttori

China had gains in production that far outpaced the rest of the world. By 2003, **China had already dominated in the production of graphite, indium, magnesium compounds, magnesium metal, REEs, tungsten, vanadium, and yttrium**. Chinese producers are seeking not only to expand their production capacity at home but to continue to negotiate long-term supply agreements, particularly **in Africa (cobalt and tantalum)**, Australia (lithium), and South America (lithium)

The dominant producing region for Cr, Mn, Pt group metals, Ta, and Co is southern Africa

Brazil produces 88% of the world's Nb

Australia accounts for 58% of the world's Li production

Lithium-Ion Batteries

Co, Li, NI, and other materials are needed for these batteries

There is a Li-Co oxide battery which has a high energy density but also a high Co content and price. The steep country risk associated with cobalt production in the Democratic Republic of the Congo (DRC) led researchers to look for alternative suppliers. One example would be to use a Mn-oxide battery, wherein cobalt is partially replaced by nickel and manganese. The researchers identified lithium as needed for all battery types. ***By 2035 an annual growth rate of 7.5% is needed for Li supply and 3% growth rate in Co supply to meet electric vehicle demand***

Solar Energy and Wind Technologies

In **solar energy systems**: Ag, Cd, Te, In, Ga, Se, Ge are contained , and four of the REEs are used in **wind technologies** (dysprosium (Dy), neodymium (Nd), terbium (Te), and praseodymium (Pr)).

Crystalline silicon photovoltaics: cells are connected electrically to each other with metal strips consisting of an alloy rich in Ag. Silver is the metal of choice because of its' superior electrical conductivity. The current Ag content is in the range of 8 g/m^2 decreases are sought by substituting Ag to a large degree of Cu.

Dye sensitized solar cells, DSSC: organic solar cells, they belong to the third generation of photovoltaics. A complex based on Ru and Os gives the best cell performance. The metallization of the cell is based on a Ag ink. Pt acts as a catalyst

Material consumption of some selected raw materials in dye-sensitized solar cells [2].

Material	Needed mass/area [g/m^2]
Ruthenium	0.07
Platinum	0.03
Silver	1

Thin film photovoltaic panels

CdTe-panels are cost efficient to produce and thus are regarded as the most promising thin film technology. The confirmed measured electricity generation efficiency is as high as 17.5%, however in commercial applications somewhat lower, 10-11%. Tellurium is a critical metal. The need of Te has been estimated to be 6.5 g/m^2

CIS or CIGS (Cu-In-selenide or Cu-In-Ga- selenide) yields an efficiency of 15% whereas commercial applications show an efficiency range of 7-12%. Indium and gallium are critical metals. The need of these metals is estimated to be 2.9 g/m^2 (In) and 0.53 gm^2 (Ga)

Concentrated solar power e CSP: The heat is transformed to electricity by conventional turbine technology. Ag has highest optical reflectivity of all elements and is thus used on the surface of the mirrors to obtain high reflectance. The Ag content per mirror area is constant for all technologies (1 g/m^2),

Wind Technologies

Permanent magnets based on rare earth elements produce very high magnetic fields, thus even compact and light generators generate high torque. Therefore wind generators can operate with low rotational speeds. REEs used in permanent magnets (currently used in some of the new wind turbines) will not keep pace with demand from multiple end uses as well as the increased use of the magnets in electric vehicles. Turbine manufacturing, is 100% dependent on permanent magnet imports, primarily from China, as that country produces 75% of the world's permanent magnets which contain REEs

Permanent Magnets

Dy, Nd, Te, and Pr go into a neodymium-iron-boron (NdFeB) permanent magnet. Nd in the magnet varies between 28-31%. Dy (2-3%) and in small quantities Pr and Te. The need for REE is 160-200 kg/MW in gearless applications and 30 kg/MW for generator with gears

Rare Earth Elements

Rare earth elements often occur with other elements, such as Cu, Au, U, phosphates, and Fe, and have often been produced as a byproduct. The lighter elements, such as lanthanum, cerium, praseodymium, and neodymium, are more abundant and concentrated and usually make up about 80%-99% of a total deposit. The heavier elements—gadolinium through lutetium and yttrium—are scarcer but very "desirable"

Most REEs throughout the world are located in deposits of the minerals bastnaesite and monazite. Bastnaesite deposits in the United States and China account for the largest concentrations of REEs, while monazite deposits in Australia, South Africa, China, Brazil, Malaysia, and India account for the second-largest concentrations of REEs. Bastnaesite occurs as a primary mineral, while monazite is found in primary deposits of other ores and typically recovered as a byproduct.

Electric cars

Electric cars can be classified into full electric vehicles and hybrid cars. A fuel cell electric vehicle (FCEV) comprises a hydrogen tank and a fuel cell as source of energy.

Motors based on permanent magnets show high power density. The permanent magnet used is based on neodymium (NdFeB). Beside neodymium, the magnet comprises small amount of dysprosium for better heat resistance and to smaller extent praseodymium, terbium and gallium

Fuel cell and hydrogen storage: Platinum serves as catalysts on both anode and cathode. In the current state the need for platinum is 0.6-0.7 g/kW

For **hybrid electric vehicle (HEV)** more important is the continuous charging/discharging cycle and ability to release power, therefore a nickel metal hydride battery (NiMH) is more suitable. The negative electrode is a metalhydrid, in automobile applications typically AB_5. A is an alloy containing rare earth metals and B can be Ni, Co, Mn or Al. The need for rare earth metals to be 1.2 kg/kWh. A typical metal A is $La_{5,7}Ce_8Pr_{0,8}Nd_{2,3}$

The power electronic system which converts DC voltage to AC voltage and vice versa as well as the electric recharging point comprise small amounts of critical metals like Pd, Au, Ge, In and Ag

Fuel cells and electrolysis

Electricity produced by solar and wind energy is intermittent in nature and thus a need for storage technologies is obvious. One option to store the energy produced by renewable energy sources is **hydrogen**. Hydrogen is produced through electrolysis and is burned again in fuel cells to produce electricity. Also if fuel cell electric vehicles will penetrate the market in large scale a functioning hydrogen infrastructure is needed

Alkaline water electrolysis: The need for the typical catalyst cobalt, the need for cobalt is 8.9 mg/W.

Polymer electrolyte membrane (PEM) electrolysis: The catalysts are metals: Ru and Ir on anode and Pt on cathode.

Solid oxid fuel cell SOFC: La (20g/kW), Ce (2), Y (40) and Co (30)

LED

LED (light emitting diode) comprises a light emitting semiconductor, typically based on In and Ga (InGaN). The need for semiconducting material per LED lamp is 0.17 mg In and 0.53 g Ga. The phosphor contains Ce and Y . The need for the phosphor in a 12.5 W LED lamp is 1 g. This means 0.7 mg Ce and 450 mg Y per one lamp.

Organic LED technology, which is currently being researched, does not contain any critical metals.

In fluorescence lamps some REE metals like Dy, Ce, Eu, or Tb are suitable elements. Also La and Y are used

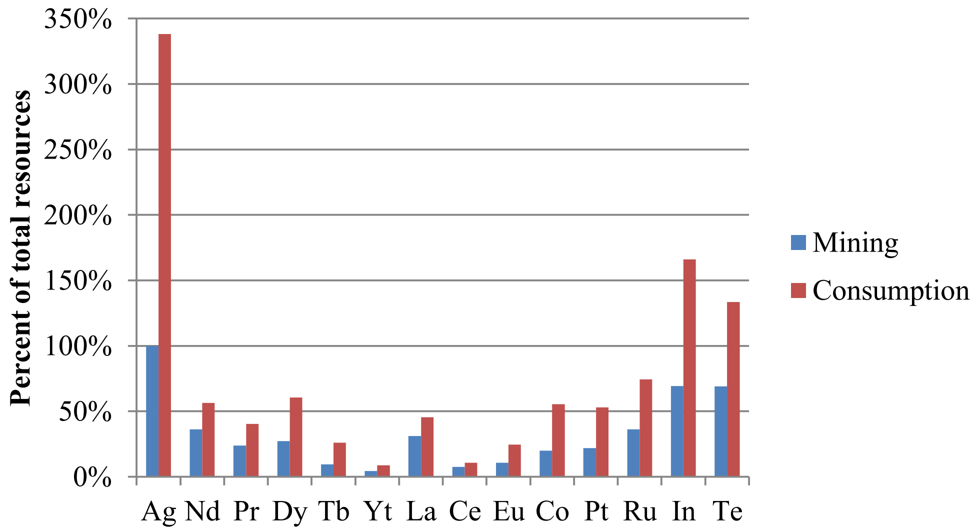
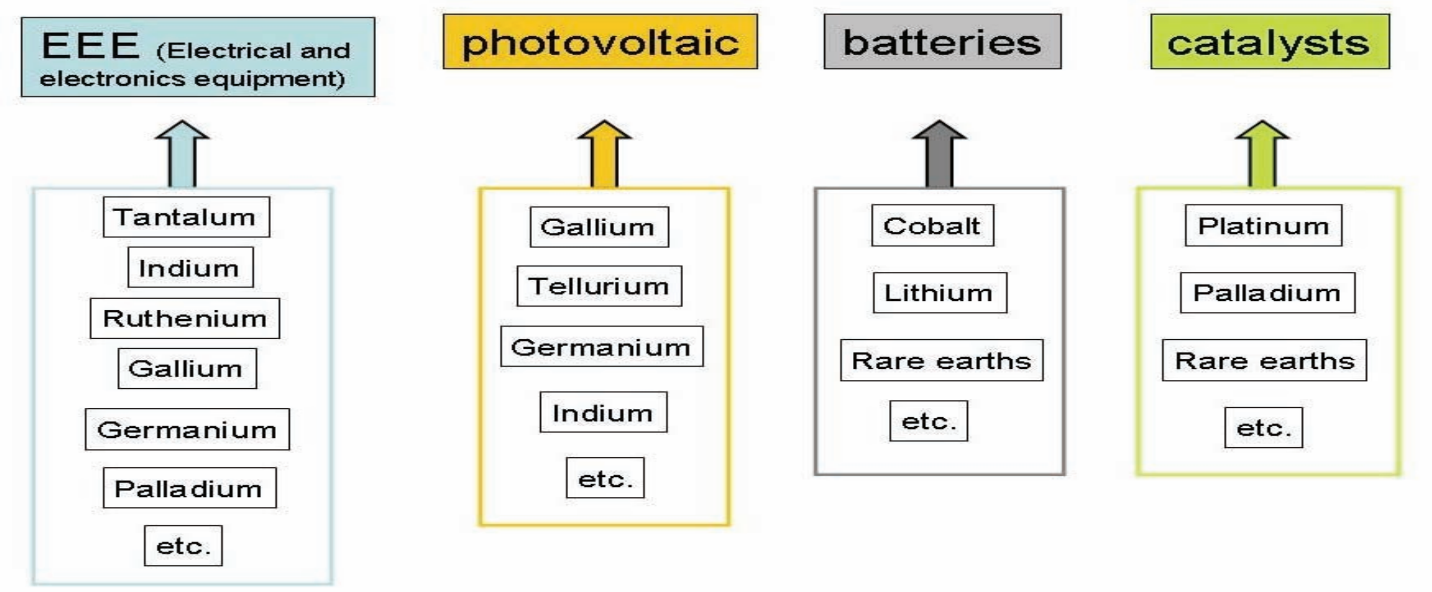


Fig. 7. Metals cumulative need for clean energy technology until 2050 in relation to global mineral resources.

The global energy sector is expected to undergo a shift towards green technologies such as solar and wind energy, electromobility and energy efficiency in the coming decades. **These technologies rely on critical metals**. According to the analysis most serious problems can arise in the solar energy sector through the availability of **silver**. Other possible material restrictions could be caused by In, Te or Ru.

Solar energy future projections do not seem to be realizable with the currently known technologies and metals resources.



timeline	Metal
short-term (within next 5 years) + **rapid** demand growth + **serious** supply risks + moderate recycling restrictions	Tellurium Indium Gallium
mid-term (till 2020) + **rapid** demand growth and + **serious** recycling restrictions	Rare earths Lithium Tantalum
or: + moderate supply risks + moderate recycling restrictions	Palladium Platinum Ruthenium
long-term (till 2050) + moderate demand growth + moderate supply risks + moderate recycling restrictions	Germanium Cobalt

Post-consumer recycling is often a much more difficult task. The main reasons are:

- Low metal concentrations in waste flows
- The critical metal is a minor composition in a complex material matrix (many other metals, plastics etc.);
- Metal concentration in a single unit is very low and the final end-use often takes place in emerging or developing countries without sufficient take-back and collection systems for secondary materials

Post-consumer automotive catalyst. Typically a range between 2g and 5g per unit is the content of ***Platinum Group Metals (PGM) like platinum, palladium and rhodium in automotive catalysts***. **This means a PGM concentration of > 1000 ppm – more than 100 times higher compared to natural ores.** Therefore automotive catalysts are interesting secondary materials for the recycling of critical metals like PGM and special refining plants are working with very high recovery rates (> 90% for the PGM)

Hoboken/Antwerp plant. This plant with a clear focus on end-of-life materials is able to recover 17 different metals. Typical input in Hoboken is e-scrap, spent industrial and automotive catalysts etc. The plant has an input capacity of about 350,000 tons

For some metals like Ta in cell phones, lithium (e.g. batteries), rare earths (broad spectrum of applications), Ga and Ge there are until today none recycling technologies in commercial scales running.

Platinum group metals from automotive catalysts

28ton platinum and 31 ton palladium were recovered from automotive catalysts **worldwide**. **In the same year the global gross-demand for the production of new automotive catalysts was 131 t platinum and 138 t palladium**. The plant at Hoboken/Antwerp has current capacities for **18t Pt and 24t Pd** – from different waste inputs. That means in about 10-15 years (average lifetimes of cars) a global capacity which is about six times higher than the total current capacity in Hoboken will be necessary for optimized global recycling capacities of platinum and palladium from spent automotive catalysts only. Furthermore optimized collection infrastructure for spent automotive catalysts will be required in the emerging economies and developing countries.

“Low–tech” gold recycling in Bangalore/India (photo by courtesy of EMPA, S